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May 7, 2014

By ECFS

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Re: *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269

Dear Ms. Dortch:

Attached to this letter are the following materials previously filed in GN Docket No. 12-268.

Attachment	Date	Description
1	January 25, 2013	Comments of AT&T Inc.
		Exhibit A – Jeffrey H. Reed and Nishith Tripathi, *The 600 MHz Spectrum Auction: An Analysis of the Band Plan Framework*
		Exhibit B – Yeon-Koo Che, Phil Haile and Michael Kearns, *Design of the FCC Incentive Auctions*
2	March 12, 2013	Reply Comments of AT&T Inc.
		Jeffrey Reed and Nishith Tripathi, *The 600 MHz Auction: An Analysis of the Band Plan Framework and Response to Certain Proposals*
		Michael Katz, Philip Haile, Mark Israel, and Andres Lerner, *Spectrum Aggregation Policy, Spectrum-Holdings-Based Bidding, and Unlicensed Spectrum*
		Reply Analysis of Yeon-Koo Che and Phil Haile
3	October 29, 2013	Letter from Brian Benison (AT&T) to Marlene H. Dortch (FCC)

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		AT&T Presentation, *The 600 MHz Forward Incentive Auction: Principles for Maximizing Success*
4	October 31, 2013	Letter from Gary L. Phillips (AT&T) to Marlene H. Dortch (FCC)
		Philip A. Haile, Maya Meidan, and Jonathan M. Orszag, *The Impact on Federal Revenues from Limiting Participation in the FCC 600 MHz Spectrum Auction*
5	January 23, 2014	Reply Comments of AT&T Inc.
		Attachment 1 – Philip A. Haile, *Reply Comments on Package Bidding*
		Attachment 2 – Yeon-Koo Che, Phil Haile, and Michael Kearns, *Design of the FCC Incentive Auctions*
		Attachment 3 – *Reply Analysis of Yeon-Koo Che and Phil Haile*
6	January 29, 2013	Comments of Verizon and Verizon Wireless
7	March 12, 2013	Reply Comments of Verizon and Verizon Wireless
8	March 26, 2013	Letter from Leora Hochstein (Verizon) to Marlene H. Dortch (FCC)
9	May 6, 2013	Letter from Leora Hochstein (Verizon) to Marlene H. Dortch (FCC)
10	August 29, 2013	Letter from Leora Hochstein (Verizon) to Marlene H. Dortch (FCC)
11	September 18, 2013	Letter from Tamara Preiss (Verizon) to Marlene H. Dortch (FCC)
		Leslie M. Marx, Ph.D., *Economic Analysis of Proposals That Would Restrict Participation in the Incentive Auction*
12	September 27, 2013	Letter from Tamara Preiss (Verizon) to Marlene H. Dortch (FCC)
		Presentation, Leslie M. Marx, *The Consumer and Revenue Benefits of Open Eligibility in the Incentive Auction*
13	January 27, 2014	Letter from Leora Hochstein (Verizon) to Marlene H. Dortch (FCC)

Regards,

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RPC:ftdc

ATTACHMENT 1

Comments of AT&T Inc.
January 25, 2013

BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON D.C. 20554

In the Matter of	)	
	)	
Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions	)	GN Docket No. 12-268
	)	

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January 25, 2013

TABLE OF CONTENTS

INTRODUCTION AND SUMMARY 1

DISCUSSION 14

I. The Commission Should Adopt a Band Plan Designed to Extract Maximal Value from the Available Spectrum 14

A. General Observations 14

B. Several Components of the Commission's Proposed Band Plan Raise Significant Interference and Implementation Concerns 23

1. Interference Concerns 24

2. Implementation Issues Due to the Size of the Duplex Gap 30

C. The Commission Should Modify Its Proposed Band Plan To Address These Interference and Implementation Issues. 31

D. The Commission Should Preserve Channel 37 for Its Existing Uses 39

II. The Commission Should Enable Forward-Auction Participants to Cast Bids That Express the Greatest Value That Can Be Extracted from the Spectrum Rights Being Auctioned 40

A. The Commission Should Fine-Tune Its Proposal for "Generic Bidding" to Account for Disparities in Value Among Spectrum Blocks 40

B. The Commission Should Facilitate Efficient Package Bidding 51

C. The Commission Should Enable Bidders to Express the Additional Complementarities Derived from Horizontal and Vertical Spectrum Contiguity 58

III. The Commission Should Conduct a Single-Pass Reverse Auction Before Any Forward-Auction Bidding Rather than an Alternating Reverse/Forward Auction Format 63

A. The Commission Should Avoid the Repeated Delays Endemic to a Repeatedly Alternating Forward/Reverse Framework 63

B. Depending on the Tractability and Comparative Efficiency of Different Repacking Algorithms, the Commission Should Consider Modifying the Single-Pass Framework to Include a Proxy-Bidding Component 68

IV. The Commission Should Close Any Revenue Gap for a Given Clearing Target by Continuing Both the Forward and the Reverse Auctions Once Excess Supply And Excess Demand Are Eliminated 71

V. The Commission Should Minimize Constraints on Efficient Repacking 74

VI. To Reduce the Risk of Auction Failure, the Commission Should Not Constrain the Participation of Particular Carriers in the Forward Auction 79

CONCLUSION 81

INTRODUCTION AND SUMMARY

AT&T welcomes the opportunity to engage with the Commission on the details of this critical spectrum-reallocation initiative. The stakes are as high as the issues are complex. "[S]pectrum is the oxygen that ultimately sustains the mobile revolution,"[1] and freeing up more of it is critical to U.S. economic growth and technological leadership. This is the last spectrum auction of comparable scope that the Commission will conduct for many years, and the decisions the Commission makes here will have economic and technological consequences lasting a generation.

The Commission should therefore focus sharply on the central factor that distinguishes this auction proceeding from all others. In a typical auction, unlike this one, the Commission first defines the frequency blocks it commits to clear and simply asks carriers to bid for those blocks. If the auction rules are suboptimal, less money is deposited into the Treasury, but consumers nonetheless reap the benefits of greater bandwidth for mobile broadband applications. In *this* auction, by contrast, the Commission must persuade a variety of auction participants to satisfy the statutory auction-closing criteria for any target level of spectrum: namely, forward-auction revenues must exceed winning reverse-auction bids plus administrative and estimated repacking costs.[2] If they fall short of that benchmark, the Commission will have to settle for less cleared spectrum, and in the worst-case scenario, the auction could fail altogether.

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[1] Prepared Remarks of Chairman Julius Genachowski, Telecommunications Industry Association 2011 Summit, at 2 (May 19, 2011), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-306768A1.pdf.

[2] *See* Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, Tit. VI, § 6403(c)(2), 126 Stat. 156, 227-228 (Feb. 22, 2012) ("Spectrum Act") (codified at 47 U.S.C. § 1452(c)(2)).

That fact has profound consequences for the decisions the Commission makes in establishing a band plan, designing the forward and reverse auctions, establishing the ground rules for participation, and creating mechanisms for efficient repacking. Those decisions will determine not only how much money changes hands, and not only whether spectrum goes promptly to providers able to extract the most value from it, but also *how much spectrum* is available to such providers and their customers in the first place. Suboptimal decisions would not only reduce revenues, but deprive consumers of the primary benefit that Congress sought to achieve in the Spectrum Act: reallocating as much spectrum as possible for mobile broadband services. In Chairman Genachowski's words, this incentive auction is the Administration's "single biggest initiative to free up beachfront spectrum and address the spectrum crunch," and the Commission's first goal should be to "maximize[e] the amount of spectrum freed up."[3]

The Commission should thus take all steps needed to make this auction succeed, in the sense that the auction will meet the statutory closing conditions for the maximum possible amount of freed-up spectrum. As discussed below, the Commission has already set the stage for success by developing innovative approaches to managing the complexity inherent in this process, including its proposals for "extended families" of cleared spectrum blocks and for bidding on "generic categories" of interchangeable

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[3] *See* Notice of Proposed Rulemaking, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, 27 FCC Rcd 12357, 12547 (2012) ("NPRM") (statement of Chairman Genachowski); *see also* FCC, *Connecting America: The National Broadband Plan*, at 81 (2010) ("The broadband spectrum needs of the U.S. are growing as it is becoming more difficult to identify large swaths of spectrum—both federal and commercial—that can be reclaimed for auction. . . . Given the practical challenges of reallocation, the FCC needs to create new incentives for incumbent licensees to yield to next-generation users.").

spectrum. As the Commission recognizes, however, the NPRM's proposals are properly viewed as starting points in the discussion rather than as finished solutions in their own right. In that spirit, AT&T proposes that the Commission build on those proposals in the following respects.

Band plan. In principle, AT&T supports the Commission's basic "extended families" concept, which provides for carefully coordinated blocks of uplink and downlink spectrum across different markets depending on how much spectrum can be freed up in each. This concept is a key innovation that will allow the Commission to reallocate the greatest amount of usable spectrum while accommodating the twin realities that different amounts of spectrum will be cleared in different geographic markets and that mobile technologies cannot feasibly support a proliferation of widely disparate band plans from one location to the next. AT&T also agrees with some of the other principles underlying the Commission's proposal. For example, AT&T supports using five-megahertz building blocks, creating a significant amount of paired spectrum, and limiting the size of guard bands to what is technically necessary to avoid interference.

That said, after engaging in a detailed engineering analysis and consulting with its vendors, AT&T believes that certain aspects of the NPRM's proposal would raise significant practical concerns that would devalue the spectrum and increase the risk of partial or complete auction failure.

One key set of concerns relates to the unique interference challenges the NPRM's proposed band plan would pose. *First*, the proposed placement of television stations in the "duplex gap"—the spectrum between paired uplink and downlink blocks—would create a risk of substantial intermodulation interference in a variety of downlink

frequencies, not only in the 600 MHz band itself, but also in other bands such as the PCS ("Personal Communications Service") band. *Second*, the NPRM's proposal would place uplink spectrum in certain frequencies where a handset's transmissions would cause harmonics-related interference for the same handset's PCS and EBS/BRS ("Educational Broadband Service/Broadband Radio Service") downlink frequencies. Both forms of interference would dampen bidding for 600 MHz spectrum by increasing the risk of impaired handset performance, whether on the 600 MHz band or on other frequencies that the handset could otherwise use in combination with the 600 MHz band.

Third, because the NPRM's proposal relies so heavily on varying the number of cleared uplink blocks from market to market, depending on how much spectrum is cleared in each market, it would exacerbate the risk of co-channel interference. For example, if Channel 48 is cleared in City A but not neighboring City B, a high-power station operating in Channel 48 in City B might well interfere with base-station receivers on the same channel in City A. Such co-channel interference might arise under any band plan with variable market-by-market clearing targets, but the NPRM's proposal would magnify the risk by creating more incremental, and thus more frequent, market-by-market variation than is necessary.

It is unlikely that any of these three forms of interference could be sufficiently and efficiently alleviated through the use of filters, guard bands, or similar techniques. In contrast, ordinary adjacent-channel interference *can* be fully mitigated through the use of such techniques, but in this respect, too, the Commission's proposed band plan requires some refinement. The NPRM proposes guard bands of just six megahertz to separate any given TV station from mobile broadband uses, including downlink operations. Although

that amount would be sufficient for TV stations transmitting at 50 kW or below, a much wider guard band would be needed to protect downlink spectrum from harmful adjacent-channel interference caused by higher-power stations. One solution to this challenge lies in the repacking process: that is, in reassigning TV stations transmitting at 50 kW (or below) to slots adjacent to downlink-protecting guard bands so that those guard bands can be limited to six megahertz.

Two additional related characteristics of the Commission's proposal—the large size of the duplex gap and the location of all downlink blocks below Channel 37—would also create implementation problems by materially increasing the size of the antennas needed for devices and base stations in a 600 MHz network. That in turn would require the use of bulkier devices, and it would prevent carriers from using many existing cell sites for 600 MHz operations and make it more difficult to find new cell sites that can accommodate the larger antennas. It would also greatly complicate the deployment of MIMO ("multiple input/multiple output") technologies, which increase the efficiency of spectrum use. Alternatively, carriers that end up with lower 600 MHz spectrum could avoid the logistical burdens of larger antennas by settling for suboptimally sized antennas—for example, smaller antennas that are optimized for use in the *upper* 600 MHz band. But carriers could take that step only at the expense of degraded performance. Either way, bidders will attach substantially less value to spectrum on the lower end of the 600 MHz band than the higher. And because the paired downlink spectrum under the NPRM's proposal would all fall below Channel 37, paired blocks under that proposal would all have a lower value than they would have under an alternative that places paired downlink spectrum above Channel 37.

In light of these interference and implementation issues, AT&T proposes below an example of a modified band-plan framework that would retain some of the NPRM proposal's key characteristics but would reduce the size of the duplex gap, avoid placing television stations in that gap, place as much mobile broadband spectrum as possible in the higher frequency blocks of the 600 MHz band, and make certain other adjustments. This alternative would minimize interference concerns and avoid the need for larger handset and base-station antennas. And in every market in which twelve or more television stations are cleared, AT&T's alternative would make available (depending on the details of implementation) as much spectrum for mobile broadband use as the NPRM's proposal—and often more. AT&T has developed this alternative in consultation with other industry participants and offers it here not as a formal proposal, but merely as an illustration of how the Commission can improve upon the NPRM's proposed band plan. AT&T looks forward to working with the Commission and other stakeholders on the potential for further refinements.

Forward auction: generic bidding categories. AT&T supports both the use of an ascending clock auction and, to help manage complexity, the Commission's proposal for bidding on "'generic' categories of licenses, such as paired or unpaired licenses, in a geographic area." NPRM ¶ 56. That said, the Commission should carefully define the categories of generic licenses so that each category contains only truly interchangeable spectrum blocks of similar value. For example, if some blocks within a category have a much lower value than others, bidders will reduce their bids to hedge against the exposure risk of ending up with inferior spectrum blocks. The question is thus how best to reconcile two goals: (1) keeping the number of generic categories small and (2)

ensuring comparability of spectrum assets within each category. The Commission can best achieve these objectives by defining separate bidding categories for paired and unpaired spectrum and, within the broader class of unpaired spectrum, distinct bidding categories for each discrete "grouping" of supplemental downlink blocks (*i.e.*, each market-variable set of contiguous blocks allocated for supplemental downlink uses). Designating distinct groupings of unpaired spectrum for bidding purposes is necessary because some of those groupings will be more valuable than others, depending on their frequency locations and, just as important, on the relative number of markets nationwide in which each such grouping will be cleared.

Forward auction: package bidding and spectrum contiguity. The Commission should follow through on its proposal to permit a forward-auction participant to place "a single, all-or-nothing bid amount that would apply to a group of licenses, such as . . . the same block in multiple geographic areas." NPRM ¶ 62. Such package bidding is necessary to capture the large complementarities that regional and national carriers will derive from offering service on the same 600 MHz bands across multiple geographic areas. Indeed, in the *absence* of package bidding, bidders might exit the forward auction early to avoid the classic exposure risk of "winning" a hodgepodge of scattered spectrum assets that lack much of the value they would have presented had they been part of a seamless geographic package. That exposure risk would thus suppress forward-auction participation and increase the risk of auction failure.

In their attached white paper, Professors Che, Haile, and Kearns propose a package-bidding solution that, without introducing undue complexity, will allow forward-auction participants to express the substantial value of geographic

complementarities. Under their approach, a forward-auction participant could bid on individual EAs or on one or more permissible geographic packages. To avoid intractable computational problems, the Commission would strictly define the set of permissible package bids in a fully nested hierarchy. For example, the Commission could specify that a permissible geographic package must consist of all EAs in an MEA, of all MEAs in an REA, or of all REAs within the United States. An EA and a larger package including that EA would be treated as separate objects for bidding purposes, yet no spectrum would be set aside for packages; instead, all bidders would participate in the same ascending clock auction for the same underlying spectrum. A package bidder would win spectrum in all EAs within its geographic package if the total price it offers for the spectrum in that package exceeds the sum of the bids that would otherwise prevail in the absence of that bidder's package bid. This proposal would neither favor nor disfavor package bidders as compared to bidders for individual EAs. Instead, it would pick winners solely on the basis of which combination of bids expresses—and can be presumed to produce—the greatest economic value for consumers.

Beyond the complementarities a bidder can derive from procuring *some* 600 MHz blocks throughout a multi-EA region, a bidder can also derive substantial additional value from rights both to *the same* frequency blocks from one EA to the next ("horizontal contiguity") and to *adjacent* frequency blocks within any given EA ("vertical contiguity"). The Commission should establish clear assignment rules that will provide winning bidders with contiguous spectrum to the maximum extent possible, thereby inducing forward-auction participants to express those complementarities in the form of higher bids for generic spectrum. To the extent the rules do not specify complete

assignment outcomes, the Commission should allow for supplemental bids during a subsequent "assignment phase." But it should minimize the importance of that phase in order to increase bidding in the main (generic) phase and thus permit a prompt determination of whether the revenue conditions for a given channel-clearing target have been met.

Reverse auction. The major purpose of the reverse auction is to reveal some or all of the supply curve for potentially reallocated spectrum: *i.e.*, the prices at which various broadcasters would agree to cede the spectrum rights needed to satisfy a range of channel-clearing targets. The key design question is *how much* of that supply curve the reverse auction should reveal up front, before the forward-auction is conducted.

Under one approach, advocated in the Auctionomics proposal attached to the NPRM, the reverse auction would obtain only enough information from broadcasters to determine the revenue requirement for a single spectrum-clearing target at a time.[4] Each time the descending clock reached a price level where just enough broadcasters would cede spectrum rights that the Commission could clear a target amount of spectrum, the Commission would stop the reverse auction, convene the forward auction, and see whether forward-auction bidding has met the statutory revenue requirement for that spectrum-clearing target. If not, the Commission would have to call the broadcasters back for a new round of reverse-auction bidding at a lower spectrum-clearing target and begin the cycle anew. Broadcasters would thus have to reconvene each time the forward-auction results fall short of the statutory revenue benchmark, and the forward auction

[4] *See* Paul Migrom, Lawrence Ausubel, Jon Levin, and Ilya Segal, *Incentive Auction Rules Option and Discussion*, at 3 (Sept. 12, 2012) ("Auctionomics Proposal").

would pause for each new round of the reverse auction, including computation of repacking alternatives at the lower spectrum-clearing target.

As Professors Che, Haile, and Kearns explain, this proceeding is more likely to succeed if the Commission chooses a different approach designed to reveal at the outset as much of the supply curve as needed to show what the aggregate revenue requirements would be for all potentially applicable channel-clearing targets. In their attached analysis, they thus propose a "single-pass reverse auction" that closely resembles the Auctionomics approach except in one critical respect: it would ask broadcasters to indicate, *before* the forward auction is held, whether or not they would cede specified spectrum rights at progressively lower price levels.

The single-pass format is clearly preferable for the reasons that Professors Che, Haile, and Kearns explain. Among its other benefits, this format would greatly simplify auction participation for broadcasters by enabling the Commission to adjust the spectrum-clearing target as necessary to ensure satisfaction of the statutory auction-closing conditions *without* any need to reconvene the broadcasters (and interrupt the forward-auction bidding) each time the forward-auction results fall short of revenue requirements. The single-pass approach would thus avoid the repeated, unpredictable, and potentially lengthy delays endemic to the Auctionomics approach. A modified single-pass approach could also improve the *substantive outcomes* of the repacking analysis if, as might well happen, the Commission finds either that sequential ("greedy") repacking analyses are computationally infeasible to conduct in real time or that they would produce an unacceptable loss of repacking efficiency. If it makes either finding, the Commission could combine the single-pass approach with proxy bidding (as

described below) to produce more efficient, *non*-sequential repacking outcomes—and thus more cleared spectrum for mobile broadband.

Finally, there is no compelling reason, either conceptual or practical, to favor the Auctionomics format of repeatedly alternating forward and reverse bidding. The NPRM suggests (¶ 40) that it may be preferable to seek price information for only one channel-clearing target at a time on the theory that some broadcasters might be deterred from participating if they are required to "determine an exact bid at the beginning of an auction." But under *any* bidding format, broadcasters would have to expect that, within a constrained time period, they might well need to make multiple offers to cede their spectrum rights at successively lower price levels, either because excess supply remains or because the auction-closing conditions have not yet been met. Broadcasters would thus have to make at least rough station-value determinations at the outset of bidding even under the Auctionomics approach.

Coordinating the forward and reverse auctions. The Commission should adjust its proposal for coordinating the forward and reverse auctions to ensure that the latter auction does not, in effect, stop too soon. The NPRM anticipates that, for any given channel-clearing target, bidding in the reverse auction will stop when excess supply is eliminated, and bidding in the forward auction will stop when excess demand is eliminated. The NPRM then provides that, "[i]f the closing conditions are met, the incentive auction process would end. If not, we continue running *the forward auction* to see if the closing conditions can be met." ¶ 67 (emphasis added).

In fact, the Commission should look to additional bidding in *both* the forward auction *and* the reverse auction in these circumstances to maximize the odds of meeting

the closing conditions for a given channel-clearing target rather than settling for some lesser target. On the forward-auction side, even once the ascending clock has just eliminated excess demand, the remaining bidders may nonetheless be willing to pay somewhat higher prices for the same spectrum assets if necessary to meet the closing conditions. By the same token, on the reverse-auction side, even once the descending clock has just eliminated excess supply, the remaining broadcasters may nonetheless be willing to accept somewhat lower prices to cede the same spectrum rights if necessary to meet the closing conditions. The Commission should not acquiesce in a less ambitious channel-clearing target until after it has tested both possibilities. That fact presents another reason to conduct a single-pass reverse auction, which (when combined with intra-round bidding) will provide the Commission up front with the detailed pricing information needed to make that judgment on the reverse-auction side.

Repacking. The efficiency of the Commission's repacking solutions will be critical to the success of the overall auction, and the Commission should thus avoid placing any undue constraints on its repacking discretion. First, it should avoid any artificial geographic constraints. In particular, it should account for the daisy-chain effects of its co-channel separations policies by assessing repacking options from a region-wide (and potentially nationwide) perspective rather than a local one. Second, the Commission should also avoid reading into the operative legislation any unnecessary *legal* constraints on efficient repacking. The statute requires the Commission to "make all reasonable efforts to preserve . . . the coverage area and population served" of each licensee. The modifier "reasonable" is critical to interpretation of this mandate, and giving it effect may be necessary to free up substantial amounts of additional spectrum.

Third, the Commission should try to structure the repacking process to distinguish between TV stations that currently transmit above 50 kW (up to the maximum of 1 MW) and those that operate at 50 kW or below. The stations in the latter category pose less severe interference challenges to mobile downlink operations than higher-power stations do. In the repacking process, therefore, the Commission should assign those reduced-power stations to channels adjacent to guard bands protecting mobile broadband downlink spectrum. That step will enable the Commission to limit the size of those guard bands to six megahertz (in contrast to the much wider guard bands that would be needed for a higher-power station) and, in turn, will allow the Commission to maximize the amount of spectrum that it can reallocate to mobile broadband uses.

Fourth, the Commission should provide as much advance information as possible about how it will structure the repacking process to maximize the value of the spectrum reallocated to mobile broadband uses. Only then can it ensure that forward-auction participants will express that increased value in their bids. The Commission should thus establish clear repacking algorithms up front and make them fully available to the public.

No restrictions on auction participation. Finally, the Commission should reject any proposal to restrict the participation of particular carriers in these auctions on the basis of their existing spectrum holdings. Instead, if a winning bidder's acquisition of new spectrum would bring its total holdings in a market to a level that is determined to threaten competition, that licensee should be free to choose which spectrum it will divest to remedy the perceived anticompetitive harm. But excluding well-capitalized carriers from fully participating in this auction would undermine forward-auction competition, suppress bid levels, and threaten outright auction failure.

DISCUSSION

I. THE COMMISSION SHOULD ADOPT A BAND PLAN DESIGNED TO EXTRACT MAXIMAL VALUE FROM THE AVAILABLE SPECTRUM

A. General Observations

This auction can succeed only if the Commission's band plan is sound. Yet this auction presents the most complex band-plan challenge the Commission has ever faced. Unlike in prior auctions, the Commission cannot know in advance how much spectrum will be available for auction or exactly where that spectrum will be located, and the answers to both questions will likely vary by market. The band plan must be flexible enough to accommodate these unknowns while minimizing interference and implementation problems. As the NPRM recognizes, moreover, the band plan should provide bidders with as much advance information as possible so that they can make informed business decisions. As in the other contexts discussed throughout these comments, minimizing uncertainty and risk will be critical to ensuring robust forward-auction participation and, in turn, the overall success of this proceeding.

The NPRM takes an innovative approach to this difficult challenge, and AT&T agrees with key features of the NPRM's proposed band plan. But other features of that plan would present serious and avoidable interference risks and other implementation challenges. In Section I.B below, we discuss these concerns in detail; we then turn, in Section I.C, to an alternative proposal that illustrates one way in which the Commission could build on key attributes of the NPRM's proposal while avoiding some of the pitfalls. We begin, however, by identifying three core principles that should inform any band-plan design.

- ***Principle 1: The band plan should accommodate market-by-market variations in cleared spectrum, but it should balance that objective against the need to avoid undue interference and other implementation problems***.

The amount of UHF spectrum that TV stations agree to relinquish will inevitably vary by market. The Commission can address that reality in one of two basic ways: it can limit the available spectrum nationwide to the lowest-common-denominator markets with the fewest cleared spectrum blocks, or it can build a more flexible band plan that accommodates this variation by clearing spectrum in some markets that will remain uncleared in others. As the NPRM suggests, the latter approach is clearly preferable to the lowest-common-denominator alternative because it is the only way to maximize the amount of spectrum available for mobile broadband services, even though it will obviously increase auction complexity and create engineering challenges.

Although AT&T would configure cleared spectrum somewhat differently, AT&T also agrees with the NPRM's insight that spectrum should be allocated in a way that will create as much market-by-market consistency as feasible in the placement of downlink spectrum, both paired and unpaired. As the Commission understands, each incremental increase in market-by-market variation in cleared downlink spectrum will present a trade-off in the form of new interference challenges in markets with less cleared spectrum. Carriers with 600 MHz holdings subject to such variation will need to respond by adding multiple filters to their devices, with corresponding increases in both costs and handset size.

Consider the following simplified example of a band plan with two defined groupings of supplemental downlink blocks, one of which (Grouping 1) is cleared in all markets, and the other of which (Grouping 2) is cleared only in some:

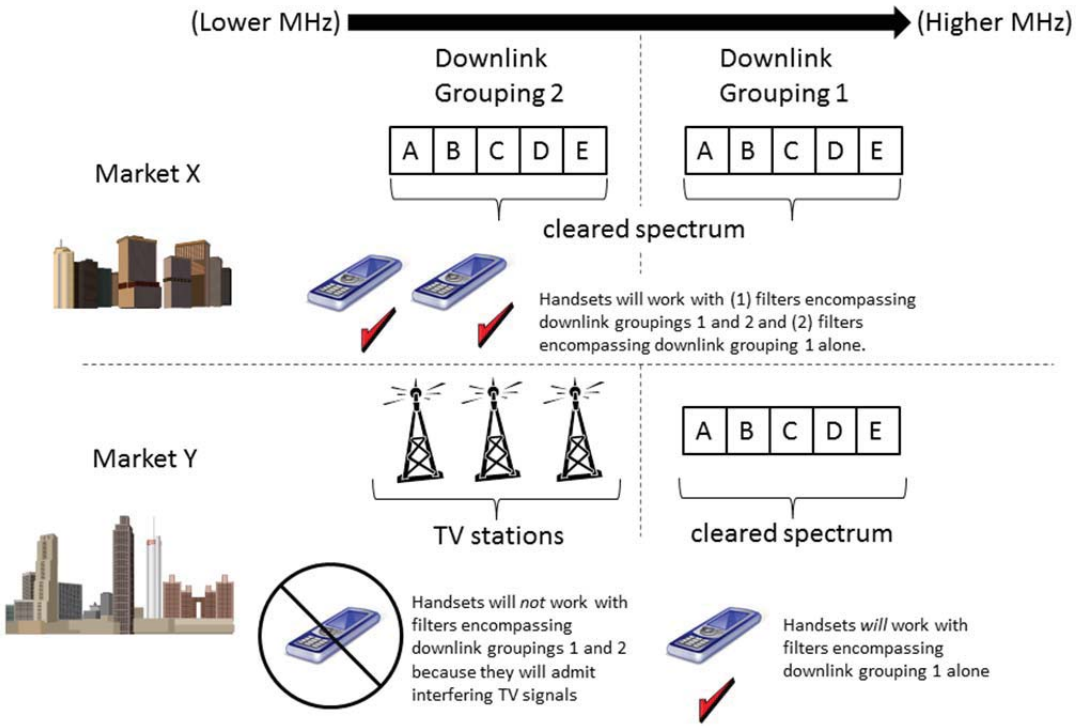

Figure 1: Effects of market-by-market variation in cleared downlink spectrum

In this example, a carrier that obtains one block apiece in Grouping 1 and Grouping 2, and wishes to use both in as many markets as possible, will need to install two filters in its mobile devices. It will need one filter that allows the device to exploit all available spectrum when a customer is in Market X (and other markets where both groupings are cleared). And it will need another filter that avoids overwhelming the handset with blocking interference from TV stations when the customer travels to Market Y (and any other market where Grouping 1 is cleared and Grouping 2 is not). And all else held equal, the more filters a mobile device contains, the bulkier and more expensive the device will be.

Again, this is not a reason to *eliminate* market-by-market variation in downlink spectrum; that approach would leave spectrum on the table by limiting the available

spectrum nationwide to the lowest-common-denominator markets with the fewest cleared spectrum blocks. But it is a reason to limit the number of different *increments* in market-by-market variation by defining fewer groupings (contiguous downlink blocks) that are cleared in some markets but not others.[5] The fewer such groupings there are, the fewer the filters that will be needed for a handset to make full use of all cleared downlink spectrum from market to market while avoiding interference from the remaining TV broadcasters.

The ultimate challenge lies in finding an optimal balance among three key objectives: (1) minimizing the number of passband filters that any given carrier must install in its handsets to accommodate market-by-market downlink variations, while (2) maximizing the spectrum that will be allocated to mobile broadband in any given market; and (3) configuring the uplink and downlink bands to avoid undue interference and other implementation problems. The NPRM's proposal accounts for the first two objectives by minimizing variation in downlink spectrum while maximizing variation in *uplink* spectrum. As discussed below, however, that approach would simultaneously thwart the third objective by creating the risk of major interference problems and requiring

[5] An extreme example illustrates the hazards of having too much market-by-market variation in downlink groupings. Suppose that the Commission were to clear Channels 42-45 for downlink in Market A; Channels 43-45 in Market B; Channels 44-45 in Market C; and Channel 45 alone in Market D. In each case, the uncleared channels would remain occupied by full-power TV stations. If a carrier installed a handset filter that allowed signals into the handset from all four of these groupings, TV-station interference would overwhelm the handset in every market except Market A and thus make the 600 MHz spectrum unusable. Yet any handset filter that avoids that problem by keeping out signals in certain of these groupings would exclude those signals even in markets where the channels have been cleared and the signals are dedicated to mobile broadband.

unnecessarily large antennas, and it should thus be adjusted to promote all three objectives rather than just the first two.

As the NPRM notes, the first objective—minimizing the number of passband filters—raises a related question about how wide a given set of adjacent downlink blocks can be while remaining supported by the same passband filter. NPRM ¶¶ 168-71. With current technology, device duplexers can effectively support a passband that is about four percent of the center frequency being used. *See* Jeffrey Reed and Nishith Tripathi, *The 600 MHz Spectrum Auction: An Analysis of the Band Plan Framework*, at 8-9 (Jan. 25, 2013) ("Reed/Tripathi Analysis") (attached as Exh. A). As a result, the maximum passband size for 600 MHz spectrum is about 25 megahertz. *Id.* Interference-related implementation concerns also counsel in favor of keeping passbands in this range. *Id.* at 9. The Commission should thus define sets of contiguous downlink blocks of 25 megahertz (five five-megahertz blocks) or less, enabling the industry to use a single passband (and a single duplexer) for any block within such a set.

- ***Principle 2: The band plan should balance the need for paired spectrum against the need to avoid interference and implementation problems.***

As a general matter, AT&T agrees with the Commission's goal to pair spectrum blocks "wherever possible." NPRM ¶ 125. Today, almost all LTE providers use Frequency Division Duplexing ("FDD") technologies and thus need separate, dedicated uplink and downlink spectrum to provide LTE service.[6] The band plan should

[6] AT&T also agrees with the NPRM's proposal to license the 600 MHz spectrum in five-megahertz blocks. NPRM ¶ 128. As the Commission notes, 3G FDD technologies today typically use 5x5 blocks of paired uplink and downlink spectrum, and the industry typically uses five-megahertz blocks to configure LTE networks. As discussed below, the forward auction should be designed to permit carriers to obtain contiguous blocks of

accommodate this reality by designating the entire 600 MHz spectrum for FDD operations and should set aside a substantial amount of paired spectrum in as many markets as feasible. The Commission should also reject any proposal to permit Time Division Duplexing ("TDD") operations in the 600 MHz band. *Cf.* NPRM ¶¶ 183-84. As the industry's experience with the 700 MHz band shows, such mixed use would expose FDD and TDD operations to substantial co-channel and adjacent-channel (and potentially intermodulation) interference problems.

Although it will be important to set aside substantial paired spectrum for FDD in as many markets as feasible, the benefits of paired spectrum must be weighed against various technological realities, and the NPRM's proposed band plan draws several of these trade-offs into sharp relief, as discussed in greater detail below. First, although the NPRM's proposal would create paired spectrum by generally designating a new paired uplink block for each additional five-megahertz of spectrum cleared in a market, it would do so at the price of placing up-to-one-megawatt TV stations in the duplex gap, a literally unprecedented arrangement that could create interference problems in the designated 600 MHz downlink blocks (among others). *See* Section I.B.1, *infra.* Second, in markets where fourteen or more stations are cleared, the NPRM's approach would require the use of Channels 42-46 for additional uplink blocks, and that step would create harmonics-related interference for handsets simultaneously using both the 600 MHz and other receive bands such as PCS and EBS/BRS. *See id.* Third, by maximizing market-by-market variability in the amount of uplink spectrum, the NPRM's proposed band plan

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adjacent spectrum, which would permit carriers to aggregate two or more five-megahertz blocks into ten-megahertz (or larger) blocks if that better suits their business plans. *See* Section II, *infra.*

would increase the risk that television stations operating in one market will create co-channel interference with base stations using cleared uplink spectrum in geographically proximate markets. *See id.* Last but not least, the NPRM's related proposal to relegate all downlink spectrum to below Channel 37 would increase the costs and engineering challenges of 600 MHz deployment by requiring larger antennas than would otherwise be necessary. *See* Section I.B.2, *infra.* In short, the Commission needs to balance the objective of greater paired spectrum against the reality that band plans maximizing paired spectrum may create more-than-offsetting technological problems that would impair the overall value of the 600 MHz band.

Moreover, in evaluating that tradeoff, the Commission should recognize the value of supplemental downlink spectrum. The Commission did just that in its recent *AWS-4 Order*, where it concluded that power restrictions that reduced the capacity of certain uplink spectrum are a necessary price for ensuring that adjacent downlink spectrum is free of interference.[7] The tradeoff here is even more stark. On the one hand, in an effort to create additional uplink spectrum, the Commission could cause interference problems that reduce the capacity and usability of downlink spectrum. On the other hand, it could avoid that interference and create fully usable supplemental downlink spectrum. The latter course is clearly preferable, particularly given that mobile broadband today uses more downlink than uplink spectrum. We discuss all of these issues in greater detail below.

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[7] Report and Order and Order of Proposed Modification, *Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands et al.*, WT Docket No. 12-70 *et al.*, ¶ 80 (rel. Dec. 17, 2012).

- ***Principle 3: The size of guard bands should be sufficient to protect against interference but no larger, and any unlicensed uses within those guard bands should be subject to appropriate limits to avoid interference with mobile broadband operations.***

The Spectrum Act directs the Commission to conduct a forward auction to "assign[] licenses for the use of the spectrum that the Commission reallocates." Spectrum Act § 6403(c)(1)(A). It authorizes the Commission to "permit the use of [any] … guard bands for unlicensed use," but it provides that those guard bands must be "no larger than is technically reasonable to prevent harmful interference [with] licensed services," and it further directs that "[t]he Commission may not permit any use of a guard band that the Commission determines would cause harmful interference to licensed services." *Id.* § 6407(b), (c) & (e). The questions are (1) how wide the guard bands should be, and (2) what operational limits the Commission should impose on any unlicensed uses to avoid "harmful interference to licensed services."

The first question requires the Commission to balance two objectives: keeping the guard bands large enough to avoid undue interference,[8] while keeping them small enough that as much 600 MHz spectrum as possible will be cleared for licensed mobile broadband uses (as Congress directed). The optimal solution will vary depending on whether the TV station on the other side of a given guard band from a mobile broadband

[8] Electromagnetic signals typically are concentrated in a specified bandwidth but, on either side, create extraneous energy that can interfere with operations in adjacent channels. No filter can fully block signals centered on frequencies that are very close to those that the filter is designed to let in, and the stronger those signals are, the farther away they can be while still creating adjacent-channel interference. Reed/Tripathi Analysis at 15-16. For example, if a filter's passband extends from 580 to 605 MHz, it will not fully block a powerful signal centered at, say, 610 MHz.

licensee is transmitting at the highest power level authorized for any broadcaster (one megawatt) or at some substantially lower power level.

According to analysis performed by AT&T and several of its vendors, a six-megahertz guard band—the size proposed in the NPRM—would be insufficient to protect mobile broadband devices against downlink interference from a 1 MW TV station. Indeed, according to AT&T's vendors, a significantly larger guard band would be required if the television station adjacent to the guard band (opposite downlink spectrum) is operating at 1 MW, which is a common power output for TV stations and the highest power level currently authorized for any TV station. Reed/Tripathi Analysis at 16, 27.[9] One way to reduce the size of the guard bands would be to use the repacking process to fill TV channels adjacent to guard bands with stations that are already operating at power levels much lower than 1 MW—for example, 50 kW or below. *Id.* at 27.[10] This approach would best carry out the statutory mandate: it would prevent interference as a technical matter, and it would maximize the amount of spectrum available at auction for mobile broadband use.

As to the second question, to the extent the Commission permits unlicensed uses in the guard bands, it should heed Congress's prohibition on "any use of a guard band that the Commission determines would cause harmful interference to licensed services." Spectrum Act, § 6407(e). In particular, the Commission should adopt appropriately low

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[9] By contrast a six-megahertz guard band *may* be sufficient to protect uplink operations because the filters used at base stations can better protect against adjacent-channel interference, though AT&T is continuing to analyze this issue in conjunction with its vendors.

[10] In the top 30 markets, there are currently television stations operating at power levels significantly below 1 MW. Reed/Tripathi Analysis at 27.

power limits and controls on out-of-band-emissions for any unlicensed uses that are permitted in these guard bands.

B. Several Components of the Commission's Proposed Band Plan Raise Significant Interference and Implementation Concerns

Although the Commission's proposed band plan has a number of innovative and useful features that AT&T believes should be part of the final band plan, it would also create the risk of significant interference and implementation problems. That risk and the resulting uncertainty about the usefulness of the 600 MHz spectrum would chill forward-auction participation and substantially devalue this spectrum for carriers and consumers alike.[11] In this section, we discuss the technological basis for these concerns before turning, in Section I.C, to some proposed solutions. For ease of reference, we reproduce here the NPRM's proposal (at ¶ 142) for a band plan with "extended families":

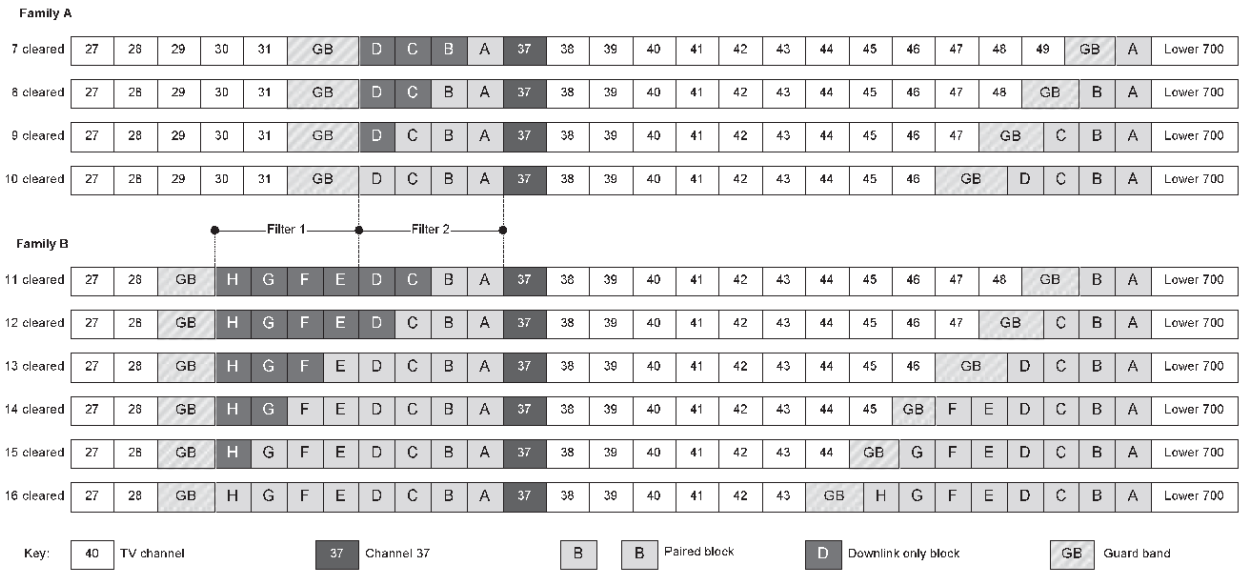

Fig. 2: NPRM's basic band plan proposal

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11 These problems would also create significant challenges for international harmonization because they would likely deter other countries from adopting the same band plan. Reed/Tripathi Analysis at 24-25.

1. *Interference Concerns*

Aspects of the Commission's proposed band plan could create substantial interference with mobile operations—in the 600 MHz band itself and in the 700 MHz, PCS, and EBS/BRS bands as well. As discussed below, it is unlikely that these interference concerns could be satisfactorily mitigated using guard bands, filters, or other technological cures. At the very least, great uncertainty about the efficacy and costs of any mitigation measures would depress participation in the forward auction and would therefore threaten this spectrum-clearing initiative.

These interference concerns arise from three aspects of the proposed band plan: (1) the placement of television stations in the duplex gap; (2) the placement of uplink spectrum in the 643-667 MHz frequencies (which overlap current Channels 42-46); and (3) the unusually high likelihood that spectrum cleared in one market will be uncleared and occupied by high-power TV stations in geographically proximate markets. We discuss each concern in turn.

Intermodulation interference from television stations in the duplex gap. The NPRM's proposed band plan would place television stations in the duplex gap—that is, in the spectrum between paired uplink and downlink blocks. That arrangement would be problematic. In particular, placing TV stations in the duplex gap, particularly stations broadcasting at power levels as great as 1 MW, would create the risk of intermodulation interference for the 600 MHz band (among other bands), resulting in degraded network performance.

Intermodulation interference arises when signals from two or more sources combine to produce new signals ("intermodulation products") that fall within a device's

receive frequencies. *See* Reed/Tripathi Analysis at 11. Under the NPRM's proposed band plan, intermodulation products would arise from the combination of (1) television signals in the duplex gap with (2) the signals created by certain components of a mobile device's transmitter. *Id.*[12] In other words, a device's *uplink* transmissions, when mixed with broadcast signals, will create interference on the same device's *downlink* frequencies.

Moreover, under the NPRM's proposal, many television stations would operate in the duplex gap, and these stations could produce multiple intermodulation products. Many of these unwanted signals would fall squarely within the downlink frequencies on which mobile devices would receive transmissions, and they would thus degrade the device's performance on those frequencies. Reed/Tripathi Analysis at 13-14. In addition, the intermodulation products would often overlap, and the total power level of the interference at a given frequency would be the sum of the power levels of the overlapping intermodulation products falling within that frequency. *Id.* at 12-13. Thus, even if each intermodulation product might be relatively weak in isolation, the cumulative strength of those products could be much higher. *Id.*.

In short, as Professors Reed and Tripathi observe, placement of multiple television stations in the duplex gap could cause substantial interference in the 600 MHz, 700 MHz, *and* PCS receive bands and substantially degrade mobile operations in those bands. *Id.* at 13. As they further explain, there is a substantial risk that this interference

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[12] The signals in question include not only the primary frequency on which the transmitters are authorized to operate, but also harmonics of those signals: *i.e.*, additional signals that arise at multiples of the primary frequency. For example, a signal at 100 MHz will produce harmonics at 200 MHz, 300 MHz, etc. Reed/Tripathi Analysis at 12.

could not be satisfactorily mitigated through the use of filters and guard bands. Although those techniques are sometimes sufficient to alleviate intermodulation interference that originates from a *single* broadcast source, they could be inadequate for that purpose where, as here, such interference arises from *multiple* broadcast sources. *Id.* at 14-15.

To begin with, as Professors Reed and Tripathi explain, some transmitter components lie "outside" a device's filter, and the filter therefore cannot prevent or attenuate even broadcast signals outside the passband frequencies from reaching those components and creating intermodulation products. *Id*. Moreover, guard bands cannot completely stop broadcast signals from reaching transmitter components (either outside or inside the filter) and thus creating intermodulation products. *Id.* at 14. To be sure, a guard band of sufficient size can *reduce* the magnitude of intermodulation interference. Moving a TV station from Channel 48 to Channel 47 and establishing a guard band at Channel 48 may help attenuate the TV station's signal before it reaches a device transmitter operating on Channel 49 and thereby reduce the strength of the resulting intermodulation product. Although such intermodulation products might be manageable if there were only one problematic broadcast source, the NPRM's proposed band plan would place many TV stations in the duplex gap. Even if a guard band attenuates each *individual* intermodulation product, that multiplicity of TV signals would create multiple overlapping products, and the signal level of those products would be cumulative. Thus, under the NPRM's proposed band plan, the interference might be highly disruptive no matter where the guard bands are placed or require inefficiently wide guard bands.[13]

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[13] Quite apart from intermodulation interference, the NPRM's proposal to employ guard bands as narrow as six megahertz would also, as discussed, cause ordinary

Harmonics from the placement of uplink spectrum. The Commission's proposed band plan would place uplink spectrum in five-megahertz blocks starting in the 693-698 MHz range and work downward, potentially to 667 MHz and below, depending on how many stations are cleared in given markets. A key problem with that plan is that, if a device makes uplink transmissions in frequencies between 643-667 MHz (which overlap with current television Channels 42-46), it will also transmit harmonics (multiples of the primary transmission frequencies) that will fall within the receive frequencies in the PCS band (1930-1990 MHz) and within the EBS/BRS band (2.5 GHz). Reed/Tripathi Analysis at 17. These harmonics could degrade the performance of that device if it is being used to operate simultaneously in the relevant 600 MHz and PCS (or EBS/BRS) frequencies and that risk would further impair the value of the underlying 600 MHz frequencies. *Id.* at 17-18. The industry already has analogous experience with this phenomenon: in some circumstances, harmonics resulting from the use of 700 MHz frequencies have significantly degraded throughput and useful capacity for devices using both 700 MHz and AWS-1 (Band 4) spectrum. *Id*.

Co-channel interference to base stations from TV stations in adjacent areas. The FCC's proposed band plan also creates a significant risk of co-channel interference to base stations in one area from TV stations operating on the same channels in neighboring areas. Consider the simplified example illustrated in the following diagram:

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adjacent-channel interference for downlink operations adjacent to high-power (up to 1 MW) TV stations. *See* Reed/Tripathi Analysis at 15-16. This concern arises both at the top of the NPRM's proposed downlink bands (where only the six megahertz of Channel 37 is situated between TV stations and downlink spectrum) and at the bottom.

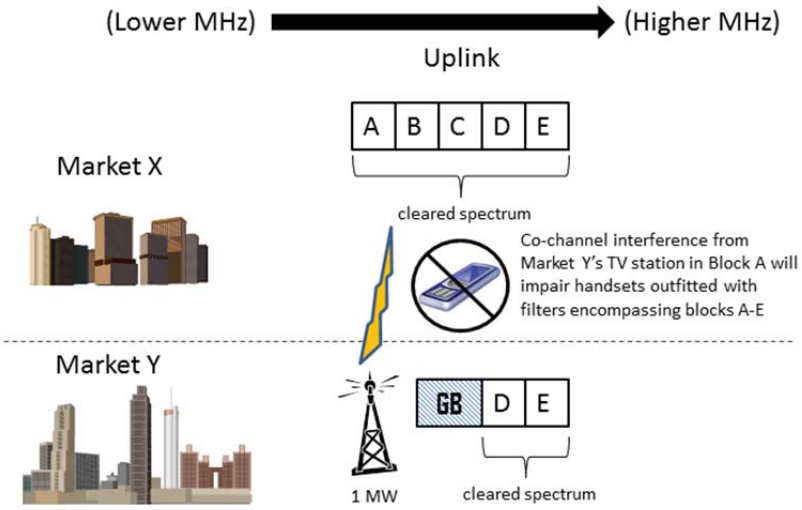

Fig. 3: Co-channel interference between adjacent markets

In this scenario, a 1 MW television station in Market Y is broadcasting on the same frequencies assigned to uplink operations in neighboring Market X (uplink blocks A and B) and is thus threatening interference with Market X base stations receiving signals in those frequencies. Reed/Tripathi Analysis at 18. Such co-channel interference is potentially most severe in the Northeast, where urban areas are spaced particularly close to one another.

To be sure, any band plan that creates variability in the number of channels cleared per market may suffer from this problem to some degree. But the NPRM's proposal would be particularly susceptible to such co-channel interference because, by design, it would maximize market-by-market disparities in the designation of uplink blocks. Although the extent and locations of co-channel interference would not be known until after the auction and repacking process are completed, the risk of such interference would suppress forward-auction bidding, and the interference that did materialize would reduce the capacity and usability of the 600 MHz spectrum.

* * *

The various interference problems created by the NPRM's proposed band plan could reduce the effective capacity of multiple spectrum bands and inflict a variety of practical harms on wireless providers. Reed/Tripathi Analysis at 19-20. Most obviously and directly, they could degrade the utility of the 600 MHz spectrum itself. Yet both intermodulation and harmonic interference could also subject carriers with 600 MHz spectrum to additional harms in *other* bands. For example, such interference could impair a provider's ability to aggregate PCS blocks as supplemental downlink together with paired 600 MHz spectrum because its 600 MHz uplink transmissions might well interfere with its supplemental PCS downlink transmissions. *Id.*.[14]

It is not possible at this stage to estimate the full extent of the interference-related impairment that the NPRM's band-plan proposal would create. Among other things, the industry has no real-world experience with cumulative interference problems of the sort described above, and any empirical analysis of the actual magnitude of interference would depend on various unknowns, such as the number of stations that would be cleared and how many would operate in the duplex gap. That said, even in the absence of a precise empirical estimate, there is a significant risk that the interference-related disadvantages of the proposed band plan would be substantial. At a minimum, that concern, along with industry uncertainty about the cost and efficacy of any mitigation measures, would depress forward-auction participation and threaten outright auction

[14] In addition, under certain circumstances, these interference concerns could keep carriers from smoothly handing off LTE customers from one cell site or network to the next if, in the process, the customers need to be transferred from the 600 MHz band to the 700 MHz, PCS, or EBS/BRS bands. Reed/Tripathi Analysis at 20.

failure. AT&T thus urges the Commission to modify the NPRM's proposed band plan in the general respects discussed in Section I.C below.

2. *Implementation Issues Due to the Size of the Duplex Gap*

Quite apart from these interference concerns, the NPRM's proposed band plan would present a substantial independent disadvantage: the extreme width of its duplex gap would necessitate the use of larger antennas and pose major engineering challenges.

Under the NPRM's proposal, paired downlink spectrum would be placed no higher than channel 36 and, depending on how many stations are cleared, would go as low as channel 30. (See Fig. 2 above.) Because, under basic laws of physics, the size of an optimally designed antenna is inversely proportional to the frequency used, the placement of downlink spectrum at such low frequencies would require larger device and base-station antennas than would the use of downlink blocks higher in the 600 MHz band. Reed/Tripathi Analysis at 22-23. Indeed, keeping performance constant, an antenna optimized for 570 MHz transmissions would need to be 22 percent longer than an antenna optimized for 614 MHz. *Id.* at 23.

Second, under the NPRM's proposal, the duplex gap between the uplink and downlink blocks would be about 70 megahertz. *See* Reed/Tripathi Analysis at 7. Any carrier using paired 600 MHz spectrum under the NPRM's proposal would thus need to deploy base-station antennas that are sized to cover at least the entire expanse of spectrum encompassing the duplex gap and the downlink and uplink blocks.[15] That, too,

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[15] In fact, the antennas may need to cover an even greater expanse of spectrum—under the NPRM's proposal, covering everything from Channel 51 down to Channel 30—because equipment parts often tend to be standardized and may thus need to work with devices used by multiple carriers that have disparate spectrum holdings throughout the 600 MHz band.

would increase the needed size of base-station antennas because antenna size generally increases in proportion to the expanse of spectrum it must cover. Reed/Tripathi Analysis at 7, 23-24.

The need for these larger antennas would present at least three undesirable consequences. First, all else held equal, a need for larger antennas would require equipment manufacturers either to create bulkier devices or free up device space by compromising on the performance of other device components (such as batteries). *See id.* at 24. Second, the need for larger *base-station* antennas would pose costly engineering challenges as well. For example, it may not be feasible to place these larger antennas on existing (or prospective) towers and other structures due to weight, size, or other limitations. *Id*. Carriers would thus have to make do with suboptimally-sized antennas in order to fill gaps in their networks, sustaining performance degradation in the process, or they would incur the costs and delays of finding new cell-site structures capable of accommodating larger antennas. Third, larger antennas would make it more difficult to deploy MIMO, a technology that increases capacity by using multi-antenna arrays on handsets and base stations. *See id*. Because it is more difficult to deploy such arrays the larger the constituent antennas become, this is yet another respect in which the use of unnecessarily low downlink frequencies would impair the value of 600 MHz spectrum.

C. The Commission Should Modify Its Proposed Band Plan To Address These Interference and Implementation Issues.

The Commission should build on the NPRM's proposal but make some modifications designed to alleviate the interference and implementation issues identified

above. In this section, we discuss some key features of such an alternative band plan and illustrate what that plan might look like. As AT&T continues to analyze the issues and confer with other industry participants, its proposal may well evolve. That said, although any band plan will involve tradeoffs, the alternative discussed below would strike a better balance among the core objectives discussed in Section I.A than would the NPRM's proposal. In particular, it would minimize interference and implementation issues, increase the value of the available spectrum, trigger greater forward-auction participation, and increase the odds that the closing conditions will be met for ambitious channel-clearing targets.

In broad strokes, AT&T's notional alternative is captured in the following diagram, which shows a band plan for each market depending on how many TV channels are cleared in each (for example, the first row shows markets where 5-7 channels are cleared, the second shows markets where 8-11 are cleared, etc.):

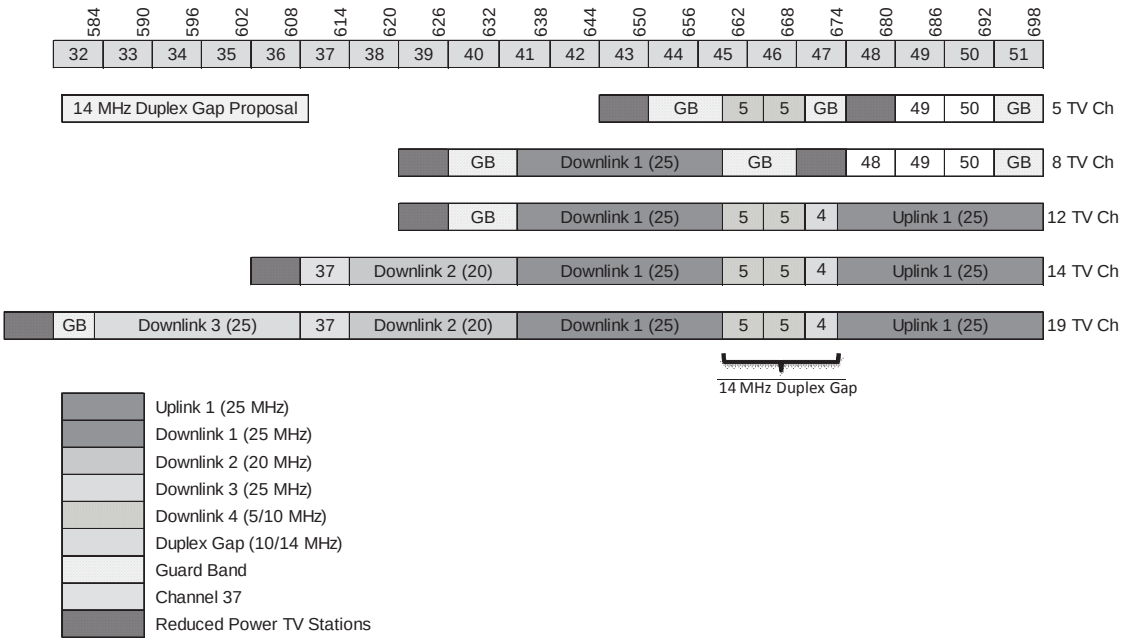

Fig. 4: Example of an alternative band plan proposal

AT&T offers this alternative not as a formal proposal, but merely as an illustration of one way to implement the general advantages discussed below.

Advantage 1: reducing the duplex gap and interference risks associated with placement of television channels in that gap.

Rather than place downlink spectrum only below Channel 37, as proposed in the NPRM, AT&T's alternative would greatly shrink the duplex gap and place the downlink spectrum just below that gap. In markets that meet robust channel-clearing targets (fourteen to eighteen channels), this approach would allow the Commission to create two groupings of downlink spectrum above Channel 37: one 25-megahertz grouping of paired downlink blocks and one 20-megahertz grouping of supplemental downlink blocks.[16] AT&T's alternative approach would thereby avoid the spectral disadvantages that, as discussed, the NPRM proposal would create by using an excessively wide duplex gap combined with lower-frequency 600 MHz downlink spectrum. In particular, it would (1) avoid the intermodulation and adjacent-channel interference concerns arising from the placement of television stations in the duplex gap and (2) permit the use of smaller (and potentially fewer) antennas.[17]

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[16] In markets where nineteen or more channels are cleared, the Commission could allocate a second supplemental-downlink grouping below Channel 37, which the diagram above identifies as Downlink 3. In one variation on this plan, it might be possible to convert that grouping into uplink spectrum instead and pair it with the downlink grouping just above Channel 37 (Downlink 2). AT&T is continuing to evaluate whether that alternative would be technically feasible.

[17] In markets where eleven or fewer stations are cleared, AT&T's proposal would create only supplemental downlink spectrum, to be used in conjunction with operations outside the 600 MHz band. Alternatively, the plan could be modified to create a very small amount of paired spectrum, with a few uplink blocks placed at the top end of the 600 MHz spectrum, much as the FCC's proposed plan does. But that approach would present a tradeoff that the Commission would have to weigh carefully: Although it

The size of an ideal duplex gap would likely range from ten to fourteen megahertz, depending on a number of factors that AT&T continues to analyze in conjunction with other industry participants. Reed/Tripathi Analysis at 27. The duplex gap shown in Figure 4 above is fourteen megahertz wide and, significantly, contains two five-megahertz supplemental downlink blocks. If inclusion of such blocks in the duplex gap is technically feasible, that approach would maximize the spectrum that the Commission could auction off for licensed mobile broadband uses, thereby increasing the likelihood of meeting the auction-clearing conditions for ambitious spectrum-clearing targets. Inclusion of these supplemental downlink blocks would require a fourteen-megahertz duplex gap, because it would be necessary to interpose a four-megahertz guard band between these blocks and the newly allocated uplink spectrum. By contrast, a smaller duplex gap of ten to twelve megahertz could potentially be sufficient if the duplex gap were not used for supplemental downlink.

Advantage 2: reducing harmonics-related interference risks.

Unlike the NPRM's proposal, AT&T's proposed alternative would not create the harmonic interference concerns presented by the NPRM's proposed band plan. Reed/Tripathi Analysis 26. As explained above, those concerns are an unacceptable by-product of the NPRM's proposal for potential uplink use of spectrum overlapping Channels 42-46. AT&T's alternative would avoid that outcome by not creating uplink spectrum below Channel 47.

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would provide a modicum of paired spectrum in such markets, it would leave television stations in the duplex gap and thus increase the risk that intermodulation interference would impair the use of the downlink spectrum.

Advantage 3: reducing co-channel interference between adjacent markets.

As discussed above, the NPRM's proposed band plan poses an undue risk that television stations operating in one market will create co-channel interference with base stations using cleared uplink spectrum in geographically proximate markets. That risk arises from the NPRM's choice of an unusually high degree of market-by-market variation in blocks of cleared uplink spectrum; indeed, for each additional station cleared in a market, the NPRM's proposal would always vary the amount of uplink spectrum. Our alternative proposal would diminish this risk of co-channel interference by reducing the degree of such variation and thus the risk that blocks used in one market for mobile broadband would be used in nearby markets for potentially interfering TV transmissions.

To be sure, our alternative presents a trade-off: in order to reduce the risk of these four forms of interference (intermodulation, adjacent-channel, harmonics-related, and co-channel), it would create somewhat less uplink spectrum in some markets and therefore somewhat less paired spectrum. By contrast, precisely because the NPRM's proposal makes the problematic technological choices that it does, it would allow the creation of incremental five-megahertz uplink blocks (and thus paired spectrum) on a market-by-market basis as additional channels are cleared (starting with markets with seven cleared channels). But whatever benefit that might bring would come at the greater risk of pervasive, value-degrading interference.

Moreover, although the NPRM's proposal would permit more paired spectrum than AT&T's illustrative alternative in some markets, it would *not* generally free up more mobile broadband spectrum overall, as shown in the following chart:[18]

# of Stations Cleared	Mobile Spectrum—AT&T	Mobile Spectrum—FCC
12	60 MHz	55 MHz
13	60 MHz	60 MHz
14	80 MHz	70 MHz
15	80 MHz	75 MHz
16	80 MHz	80 MHz
17	80 MHz	80 MHz
18	80 MHz	80 MHz
19	105 MHz	80 MHz

Fig. 5: Comparison of overall spectrum cleared for mobile broadband

To be sure, in markets with fewer than twelve cleared stations, the NPRM's proposal would allocate slightly more spectrum to mobile broadband than our alternative would, primarily by adding a new cleared uplink block with every cleared channel. Again, however, the NPRM can achieve that outcome only at the price of maintaining TV stations in the duplex gap and posing severe interference risks. Those risks would more than cancel out the benefits of the slightly greater cleared spectrum in markets with fewer than twelve cleared channels.

Finally, one indirect benefit of the NPRM's proposal is that, in *all* channel-clearing scenarios, it would repack the television stations currently operating in Channel 51, which has caused widespread interference with the Lower 700 MHz A Block. Although the NPRM's proposal would accomplish that outcome by automatically designating Channel 51 spectrum for an uplink block, *any* sound band plan—including

[18] This chart assumes that the duplex gap would be used for supplemental downlink spectrum, as described above.

AT&T's—would provide for repacking of Channel 51 TV stations whether Channel 51 is designated for mobile broadband uses or not.

As the Commission is aware, Channel 51 is immediately adjacent to the lower 700 MHz A Block spectrum allocated for mobile wireless broadband services. Recognizing the harmful interference that can be caused by adjacent broadcast and wireless operations, the Commission adopted a 60-mile exclusion zone for A Block build-out.[19] Recently, a number of A Block licensees have requested extensions of their build-out deadlines on the ground that they cannot provide adequate (or any) service because of these exclusion zones and interference from Channel 51. For example, Cincinnati Bell Wireless has claimed that the exclusion zone surrounding each Channel 51 station "effectively prevents" its deployment of wireless service in *100%* of its A Block territory.[20] Cox has noted "significant concerns" due to the interference caused by the operations of Channel 51 broadcasts,[21] and Cavalier Wireless has provided a detailed discussion of the harm from the exclusion zones and broadcast operation on Channel

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[19] *See* 47 C.F.R. § 27.60(b)(ii)(D) ("[C]ontrol, fixed, and mobile stations may affect different TV/DTV stations…. Control, fixed, and mobile stations shall keep a minimum distance of 96.5 kilometers (60 miles) from all adjacent channel TV/DTV stations. Since mobiles and portables are able to move and communicate with each other, licensees must determine the areas where the mobiles can and cannot roam in order to protect the TV/DTV stations.").

[20] Cincinnati Bell Wireless, LLC Request for Waiver or Extension, WT Docket No. 12-332, at 4-5 (filed Nov. 13, 2012) (The rules "impose[] a 60 mile exclusion zone surrounding each Channel 51 station.... [T]his exclusion zone effectively prevents deployment in the absence of cooperation from or agreement with the Channel 51 licensee…. This means, from a geographic perspective, that ***100 percent*** of CBW's licensed territory – the entire 3,558 square miles – is unusable for the wireless broadband that CBW plans to provide.") (emphasis in original).

[21] *See* Request of Cox Communications, Inc. for Extension of the Lower 700 MHz A Block Build-Out Deadline, WT Docket No. 12-332, at 7 (filed Oct. 12, 2012).

51.[22] In short, the presence of broadcast operations on Channel 51 prevents the full deployment of wireless broadband operations in the adjacent A Block spectrum. Thus, any 600 MHz band plan should clear Channel 51 of broadcast operations, as both the NPRM's and AT&T's proposals would do.

Advantage 4: reducing the risk of interference by selective repacking.

One additional aspect of AT&T's alternative warrants discussion even though it could and should be implemented in connection with virtually any band-plan proposal. As shown in Figure 4, our proposal addresses two categories of repacked TV stations: high-power and reduced power—*i.e.*, 50 kW or less. As previously discussed, a six-megahertz guard band is insufficient to keep high-power TV stations from interfering with downlink operations. Again, the solution to this concern is not to leave mobile broadband spectrum on the table by enlarging guard bands, but, if possible, to design the repacking process so as to place a reduced-power TV station on the other side of the guard band adjacent to downlink spectrum. *See* Section I.A, *supra.* Similarly, to reduce the residual risk of co-channel interference between neighboring markets, the Commission could place reduced-power TV stations in the spectrum blocks that are variably cleared in some markets but not others.

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[22] Cavalier Wireless, LLC Request for Limited Extension of Initial Construction Requirements, WT Docket No. 12-332, at 7-13 (filed Nov. 13, 2012) (detailed discussion of Channel 51 interference issues). *See also* Comments of King Street Wireless, L.P., *Petitions for an Extension of Time to Meet the First Interim Construction Benchmark for Lower 700 MHz Licensees*, WT Docket No. 12-332, at 2 (filed Dec. 13, 2012) ("King Street agrees that Channel 51 complications generally present an independent basis for the relief requested").

D. The Commission Should Preserve Channel 37 for Its Existing Uses

As the NPRM explains, Channel 37 (608-614 MHz) is currently used for receive-only radio astronomy observations and wireless medical telemetry systems (WMTS). NPRM ¶ 199. The Commission seeks comment on, among other things, whether these services should be relocated in order to make Channel 37 available for use by mobile broadband providers. *Id.* AT&T's current understanding is that it would likely be cost-prohibitive to relocate wireless medical telemetry devices from Channel 37 and that, therefore, the channel will likely remain unavailable for assignment to mobile broadband providers. These devices are used in hospitals and other health care facilities to transmit patient data (such as pulse) to a nearby receiver. It would be challenging to relocate this large installed base of wireless medical telemetry devices that currently use Channel 37.

Because Channel 37 is currently adjacent to full-power television operations, the services using that channel will certainly face no greater risk of harmful interference than they already face today when Channels 36 and 38 are reallocated to mobile broadband uses.[23] Under the Commission's rules, television operators are not required to protect WMTS from adjacent band interference.[24] When such interference exists, users of wireless medical telemetry devices can move to the other bands designated for WMTS,[25] or "can design equipment to provide sufficient protection from adjacent channel

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[23] *See* NPRM ¶ 155 ("Because the proposed in-band and out-of-band emissions of the 600 MHz downlink band are significantly lower than those of the television stations, we do not propose a guard band between the 600 MHz downlink band and Channel 37.").

[24] *See* Report and Order, *Amendment of Parts 2 and 95 of the Commission*'s *Rules to Create a Wireless Medical Telemetry Service*, 15 FCC Rcd 11206, 11213 ¶ 19 (2000) ("*WMTS Order*").

[25] NPRM ¶ 209 (explaining that wireless medical telemetry services operate on a protected basis in three different bands, including Channel 37).

interference as is current practice."[26] Those same options will remain available once adjacent channels are converted to mobile broadband use, and there is no policy basis for granting medical telemetry operators new protections that would further restrict adjacent mobile operations. That said, the Commission should continue to study the issue to confirm there are no significant interference issues that would undermine the value of mobile spectrum located next to Channel 37.[27]

II. THE COMMISSION SHOULD ENABLE FORWARD-AUCTION PARTICIPANTS TO CAST BIDS THAT EXPRESS THE GREATEST VALUE THAT CAN BE EXTRACTED FROM THE SPECTRUM RIGHTS BEING AUCTIONED

A. The Commission Should Fine-Tune Its Proposal for "Generic Bidding" to Account for Disparities in Value Among Spectrum Blocks

This proceeding presents one of the most complex challenges in auction theory that any regulatory authority has ever been asked to address, and the Commission has prudently begun by searching for ways to promote simplicity in the auction process. For the forward auction, the NPRM proposes two basic features that are well-designed to minimize complexity. First, it proposes the use of an *ascending clock* auction, in which the Commission (rather than any bidder) designates the price level for each round of bidding, and bidders simply indicate how much spectrum they wish to buy at various price levels as that level is raised. As Professors Che, Haile, and Kearns explain, this format is both simpler than the traditional SMR ("simultaneous multiple-round") format

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[26] *WMTS Order*, 15 FCC Rcd at 11213 ¶ 19.

[27] If the Commission preserves Channel 37 for its current uses, the Commission would need to evaluate whether a guard band would be needed if, as both the NPRM and AT&T band plans propose, the Commission allocates a mobile wireless downlink block in the immediately adjacent spectrum.

and less susceptible to bidder manipulation, and the Commission should adopt it for the forward auction.[28]

Second, the NPRM proposes to define "'generic' categories of licenses, such as paired or unpaired licenses, in a geographic area." NPRM ¶ 56. Under this approach, the forward auction will treat all frequency blocks within each defined category as fungible and will require bidders to make generic bids for them. Unlike in past auctions, where participants bid on individual frequency blocks, each participant here will bid to win *some* block (or blocks) within a defined category of interchangeable blocks, and the assignment of *particular* blocks to particular bidders will occur in a separate phase. For example, if there are four blocks of 5x5 paired spectrum for sale in a given market, auction participants would not bid individually on each block; each participant would bid only for some number of blocks within the group, and winners would find out only later which actual blocks they will be licensed to use. As Professors Che, Haile, and Kearns explain, this approach presents key advantages over block-by-block bidding: it will greatly simplify the auction process, and it will also ensure denser (and thus more efficient) competition for the spectrum assets at issue. *See* CHK Analysis at 5-6.

That said, it is essential to define the categories of generic licenses to ensure that each category contains only genuinely interchangeable spectrum assets of comparable value. If bidders face uncertainty about the value of the spectrum they will ultimately receive after they "win" an auction, they will discount their bids to reflect that uncertainty, thereby increasing the risk that forward-auction revenues will be insufficient

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[28] Yeon-Koo Che, Phil Haile, and Michael Kearns, *Design of the FCC Incentive Auctions*, at 5-7, 22-23 (Jan. 25, 2013) ("CHK Analysis") (attached as Exh. B).

to meet the closing conditions for a given spectrum target. By analogy, if an auctioneer sought to elicit efficiently high bids for distinct generic categories of "economy compact cars" and "luxury full-size sedans," he would exclude Yugos from the latter category because the exposure risk of "winning" a Yugo would inefficiently depress all bids for luxury sedans.

Theoretically, the Commission could try to rectify the exposure problem caused by poorly defined "generic" categories by placing greater emphasis on a subsequent "assignment" phase in which participants submit supplemental bids for rights to specific spectrum blocks within those categories. *See* NPRM ¶ 64. Under that approach, however, bidders could be expected in the first bidding phase to set their bids on the basis of the least valuable license in each improperly defined "generic" category. The Commission would thus often have to wait until after the supplemental (non-generic) bidding phase before making any determination about whether the statutory closing conditions have been met. As a practical matter, therefore, defining "generic" bidding categories to include objects of incommensurate value would substantially prolong the auction process and potentially deter broadcasters from participating. Indeed, the extra time that would be needed under that scenario to complete both the generic and assignment phases would seem to defeat the goal of speeding up the process via generic bidding. This is not to say that supplemental assignment-round bidding is *inappropriate*; it may indeed be an efficient and appropriate means of assigning actual licenses, as discussed below. But to avoid delay, the Commission should structure the overall auction to avoid reliance on such supplemental bidding in order to satisfy the closing conditions. To that end, it should ensure that the generic-bidding round is the main event

and that any assignment-round bidding is as inconsequential as possible to individual bidders.

The question is thus how best to optimize the main "generic bidding" round in order to balance two goals: (1) controlling bidding complexity by keeping the number of generic categories to a minimum and (2) reducing the exposure problem by ensuring comparability of spectrum assets within each category. As an initial matter, the Commission can do much to satisfy these goals by choosing an appropriate band plan. If, as AT&T proposes, the Commission designs the band plan to minimize the interference concerns discussed above, it will reduce valuation disparities among the spectrum blocks it is auctioning off and thereby increase the utility of generic bidding. For example, the Commission should keep high-power television stations out of the duplex gap to avoid creating intermodulation interference that, depending on geographic location, would create disproportionate interference within certain spectrum blocks. Similarly, as also discussed above, the Commission should avoid creating uplink blocks that would create third-order harmonic interference in the PCS bands used by a number of carriers.

No matter what band plan the Commission adopts, however, substantial variations in value will warrant the division of spectrum blocks into several discrete "object classes," which will be the subjects of separate generic auctions. Although these object classes will vary depending on the details of the particular band plan the Commission ultimately adopts, we can make several general observations that will likely hold true irrespective of any given band plan's details.

Separate object classes for paired and unpaired spectrum. First, as the NPRM appears to propose (*see* ¶ 56), the Commission should define 5x5 megahertz pairs of

uplink and downlink spectrum as a separate object class. In general, paired spectrum commands substantially higher prices than unpaired, and no auction participant would bid the full value of paired spectrum blocks if it believes that it may end up with an equivalent amount of unpaired downlink spectrum.

Multiple object classes for supplemental downlink spectrum. As discussed in Section I.C, AT&T's alternative band plan proposal would create a uniform set of paired spectrum blocks for every market that contains paired spectrum, and the blocks within that set would be more or less interchangeable. The same would not be true, however, of unpaired supplemental downlink spectrum, under AT&T's proposal or the NPRM's. Instead, under either approach, the number of supplemental downlink blocks would vary widely by market depending on how much spectrum the Commission succeeds in reallocating in each market. As discussed below, the Commission should create a separate object class of supplemental downlink spectrum for each grouping of such spectrum that the Commission is able to free up in any given market.[29] And if the Commission adopts any band plan with multiple groupings of *paired* spectrum blocks that vary significantly either by market or by band, it should also define separate objects for each such grouping, for essentially the same reasons given here with respect to unpaired spectrum.

Some blocks of supplemental downlink spectrum will be more valuable than others depending on, among other considerations, whether a block lies at the lower or

[29] We are using the term "grouping" here to denote a defined set of contiguous blocks of spectrum, which will be cleared in some markets but not others depending on the number of channels cleared in each market. For example, under the alternative band-plan proposal shown in Figure 4 above, "Downlink 2" and "Downlink 3" are separate groupings of supplemental downlink spectrum.

upper end of the 600 MHz band and the number of markets nationwide in which that block has been cleared. Those valuation differences strongly support holding separate auctions for separate groupings of supplemental downlink spectrum. Suppose, for example, the Commission designates paired uplink and downlink spectrum on the upper end of the band and additional groupings of unpaired downlink spectrum in markets where successively greater numbers of TV stations are cleared. In particular, suppose that in markets 1, 2, and 3, the Commission clears enough spectrum to auction off several 5 MHz blocks of supplemental downlink spectrum substantially above Channel 37 ("Supplemental Downlink Grouping 1"). And suppose that in markets 4, 5, and 6, the Commission clears yet more spectrum—enough to auction off not only *that* supplemental downlink spectrum, but also several additional 5 MHz blocks of such spectrum below Channel 37 as well ("Supplemental Downlink Grouping 2").

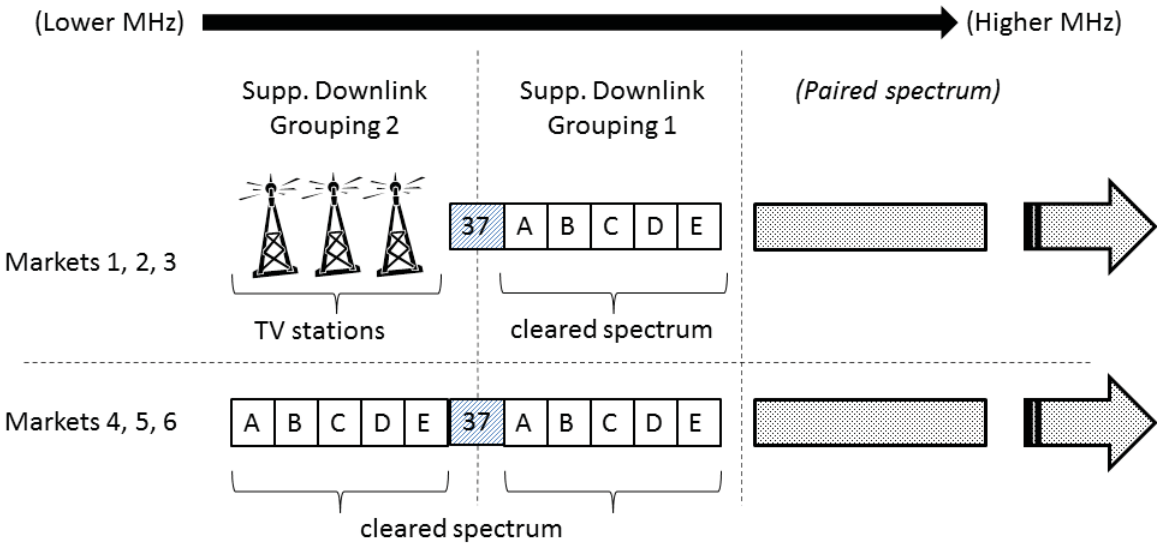

Fig. 6: market-by-market variation in supplemental downlink groupings

All else held equal, bidders will tend to value the generic blocks in Supplemental Downlink Grouping 1 more than the generic blocks in Supplemental Downlink Grouping

2. To begin with, as discussed in Section I, lower-frequency blocks may require the use of larger antennas, and larger antennas require bulkier handsets, pose weight and wind-shear challenges for cell sites, and complicate efforts to enhance capacity through MIMO technologies.

Just as important, a bidder will value given blocks of spectrum more highly if they are cleared in a greater number of markets (here, those in Grouping 1) than other blocks of such spectrum used for the same function (here, those in Grouping 2). First, auction participants seeking a regional or nationwide spectrum footprint will be able to place a block in Grouping 1 to greater use than a block in Grouping 2 while using handsets with a nationally uniform set of filters. Second, handsets with filters designed to work with Grouping 1 will be subject to less co-channel interference from TV stations in geographically proximate markets than handsets with filters designed to work with Grouping 2. For example, if a carrier deploys handsets with filters designed to use Grouping 2 spectrum in Markets 4, 5, and 6, those handsets may be subject to co-channel interference if one or more of those markets are geographically close to Markets 1, 2, or 3, where the same spectrum is used for television broadcasts.

For these reasons, the Commission should define, as a separate object class, the blocks within each grouping of supplemental downlink spectrum. Again, within each grouping, the blocks will be viewed as roughly interchangeable, and auction participants will thus bid generically for blocks within that grouping. For example, if the Commission clears Channels 33 to 36 to free up five blocks of supplemental downlink spectrum, any participant that wishes to purchase one of those five blocks will have to bid generically for it, in competition with every other participant that wishes to purchase any

of those five blocks. But that auction will be held separately from any auction for blocks of supplemental downlink in cleared Channels 38 to 41; participants will bid separately for those in a distinct auction. This approach strikes an appropriate balance between, on the one hand, the beneficial simplicity of generic bidding and, on the other hand, the need to reduce exposure risks to bidders who would otherwise discount their bids to reflect uncertainty about whether, if they "win," they will actually receive what they paid to obtain.

The band-plan implications of a generic bidding format. The considerations just discussed underscore an additional shortcoming of the NPRM's proposed band plan: that band plan would contain excessive market-by-market variation in uplink spectrum and would thus frustrate efforts to design an efficient generic auction with a manageable number of generic object classes.

Again, where possible, the Commission should avoid placing two blocks in the same generic bidding category if each is cleared in a different number of markets because most bidders will attribute far greater value to blocks cleared in all markets than in only a few. That observation applies to paired uplink/downlink spectrum as well as to supplemental downlink spectrum. Suppose, for example, that a given bidding category contains four paired blocks, A through D, and that the A Block is cleared in all markets within a populous geographic region and the D Block is cleared in only one. The uplink operations of a winning bidder that is assigned the D Block in that market would be vulnerable to co-channel interference from TV stations that would continue to operate in the D Block in neighboring cities (see Fig. 3 above). In contrast, if the same carrier were assigned the A Block in that market instead, it would be subject to no such uplink

interference, and its spectrum holdings would therefore be more valuable. If both the A and D Blocks were grouped within the same generic bidding category, auction participants would discount their bids across the board to reflect the risk of being assigned the interference-prone D Block.

The NPRM's proposed band plan would present exactly this exposure problem because, by design, it would create radical market-by-market disparities in the amount of cleared uplink spectrum. For example, as shown in Figure 9 of the NPRM (at ¶ 142), the D Block would presumably appear in the same generic bidding category as the A Block even though the A Block would be cleared in many more markets and would have much greater value. In contrast, AT&T's band plan proposal would avoid that exposure problem because the blocks within any given grouping would all be cleared—or not cleared—within any given market.

Border interference concerns. The need for separate bidding arises whenever the objects to be auctioned are not truly interchangeable. For the reasons discussed, paired spectrum is not interchangeable with unpaired spectrum, and one market-variable supplemental downlink grouping is not interchangeable with another; that is why AT&T recommends a distinct auction for each of these object classes. Depending on the facts, a similar issue may arise with respect to interference for particular spectrum blocks along the Canadian and Mexican borders, although the industry currently lacks the information it needs to propose a considered solution to that problem.

This border-interference concern is well-known. In key metropolitan areas along the borders, such as Detroit, San Diego, and El Paso, some blocks will face greater interference than others from Canadian and Mexican TV stations, which the Commission

obviously cannot reassign to new frequencies. Although confined to border areas, such interference tends to depress the value of affected blocks *throughout the U.S.*, at least for carriers with a national footprint, because each such carrier will wish to sell the same handsets to its customers no matter where they live or travel.

That said, there is probably no spectrum block within the 600 MHz band that will be free of such interference in every major U.S. market. AT&T's preliminary research suggests that interference from Canadian and Mexican television stations may be somewhat evenly distributed across the spectrum the Commission is likely to reallocate in this proceeding, and in some key border markets, most of the available spectrum blocks may be impaired. But AT&T and other private entities lack the full information needed to assess that issue because the exact locations, frequencies, and power levels of Canadian and Mexican television stations are not easily accessible. To address these concerns, the Commission should seek further information on those topics by issuing a separate notice specific to border-area interference and soliciting the input of Canadian and Mexican regulatory authorities.

This block-by-block checkerboard of border interference concerns, however, points to another benefit of holding separate auctions for different object classes of supplemental downlink spectrum. In particular border markets, certain blocks set aside for supplemental downlink may be subject to more severe interference problems than others. Dividing supplemental downlink blocks into two or more object classes will give bidders greater control over the quality of the spectrum they will obtain in those markets. Specifically, it will allow them to avoid the bid-suppressing exposure risk that they will end up with supplemental downlink spectrum that is largely useless because the block

assigned to them (or a nearby block included in the same passband filter) is subject to interference from cross-border television stations. Suppose, for example, a bidder wishes to obtain supplemental downlink spectrum in a metropolitan area that is subject to interference from a Canadian TV station operating in Channel 40. Under AT&T's proposed band plan, the bidder could achieve that objective by bidding only in the auction for spectrum in cleared Channels 33 through 36 and by avoiding the separate auction for spectrum in cleared Channels 38 through 41.

Moreover, creating two or more object classes of supplemental downlink spectrum will allow bidders with regional or nationwide footprints (current or planned) to diversify their spectrum assets so that their customers' handsets can make use of at least one supplemental downlink block in the 600 MHz band even in markets subject to cross-border interference. For example, if a bidder wishes to establish a national footprint with 600 MHz spectrum, it could bid separately for spectrum in each of the separate object-class auctions noted above. If successful in each auction, it could then install separate passband filters in its handsets: say, one that accepts signals between Channels 33 and 36, and one that accepts signals between Channels 38 through 41. When a customer travels to a market where the first passband filter would admit unacceptable interference from a cross-border TV station, the handset could rely on the other passband filter for supplemental downlink capacity. And the reverse would be true when the customer travels to another market where the *second* passband filter would admit unacceptable interference but the first would not.

Of course, no matter how the Commission defines these object classes, the industry-wide standards-setting process will and should continue playing its longstanding

role: establishing standards for passband filters, which may or may not accommodate all of the spectrum within a given object class. For example, within an object class defined by the spectrum range between Channels 33 and 36, the process could hypothetically create standards for three passband filters: one that accommodates all signals within that range; a second that passes signals only the lower end of that range; and a third that passes signals only for the higher end. That flexibility may be essential for a carrier that, within a particular market, would otherwise face interference that does not originate from the specific spectrum block the carrier has won and that the carrier could thus exclude by the use of a narrow passband filter.

The NPRM does not propose to supplant this standard-setting process with regulatory mandates for the use of particular filters, and for good reason: that step would be unprecedented and would substantially reduce the projected value of all this spectrum for many bidders. In short, the Commission should *not* micro-manage the process of extracting the most value from 600 MHz spectrum after the auction is over, but it *should* enhance the market's ability to accomplish that objective by structuring this auction in a way that maximizes both (1) bidders' certainty about the value of the assets they are seeking to acquire and (2) their subsequent flexibility to derive the greatest value from assets they do acquire.

B. The Commission Should Facilitate Efficient Package Bidding

Quite apart from any given spectrum block's value in the abstract, the value to a carrier of any particular block of 600 MHz spectrum will vary depending on that carrier's *other* spectrum assets in the 600 MHz band because of the various complementarities discussed below. To increase forward-auction participation and thus the odds of meeting

the closing conditions for any given target level of spectrum clearing, the Commission should take the steps needed to allow bidders to express the value of those complementarities. We begin with the issue of geographic package bidding.

Many carriers will wish to invest in 600 MHz technology in a particular geographic area only if they can be assured of having 600 MHz spectrum holdings throughout a larger set of geographic areas, such as their regional or national service footprints. An inability to place all-or-nothing bids for geographic packages would present a classic exposure problem, in which auction participants suppress their bids lest they "win" geographic areas that have limited value to them unless their spectrum holdings in those areas can be combined with similar spectrum holdings in other geographic areas. Both the Commission and the academic literature have confirmed that this exposure risk can reduce spectrum valuations and suppress bidding.[30] That exposure risk would be a concern in any auction, but it presents a particular danger in this one, with its stringent statutory closing conditions. Simply put, if the Commission precludes

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[30] *See* CHK Analysis at 7-8, 23-26; *see generally* Second Report and Order, *Service Rules for the 698-746, 747-762 and 777-792 MHz Bands et al.*, 22 FCC Rcd 15289, 15396-97 ¶¶ 287, 290 (2007) ("[A] bidder whose business plan is premised on realizing economies of scale may need to win a large number of licenses in order to justify the bid that it would make if it could win all of them. The risk of winning less than all the licenses needed to support the amount of the aggregate bid is sometimes known as the 'exposure problem.' . . . [W]e conclude that package bidding with respect to licenses in the Upper 700 MHz Band C Block would serve the public interest by reducing the exposure problem that might otherwise inhibit bidders."); Sang Won Kim *et al.*, *Measuring the Performance of Large-Scale Combinatorial Auctions: A Structural Estimation Approach*, at 1 (June 11, 2012), http://www.columbia.edu/~gyw2105/GYW/GabrielWeintraub_files/PAPER% 20MS120502-post.pdf. ("The main advantage of package bidding is that it allows bidders to express cost synergies in their bids. In contrast, if bidders were allowed only to submit bids for each unit separately they would face the risk of winning some units but not others. This phenomenon, known as the *exposure problem*, makes the bidders less aggressive[.]").

forward-auction participants from expressing the full value of geographic complementarities in their bids, it will substantially increase the risk that the auction will fail.

A concrete example helps illustrate the nature of this exposure problem and the need for a package-bidding solution. Suppose that an auction contains no package-bidding mechanism, but that, because of scale economies, Bidder X can profitably build out a 600 MHz footprint in *some* Northeastern metropolitan areas only if it can deploy 600 MHz technology in *most or all* major Northeastern metropolitan areas. Bidder X may find it unprofitable to invest in 600 MHz handsets and base-station equipment that can be used in Buffalo and Boston but not in New York and Philadelphia. And it will therefore wish to avoid paying substantial sums for 600 MHz licenses in Buffalo and Boston if it does not win licenses in New York and Philadelphia. Depending on how the auction is structured, however, Bidder X may get stuck "winning" such unwanted licenses if it bids separately in all four cities at once. For example, the Buffalo and Boston forward auctions might conclude early and leave Bidder X as a high bidder, while the bidding proceeds to such high levels in New York and Philadelphia that Bidder X can no longer afford to remain in those auctions. Faced with that prospect, Bidder X would have a strong incentive to exit the auction process inefficiently early in order to avoid the risk of paying for spectrum that later turns out to be much less valuable than it would have been as part of a multi-area package.

To minimize this exposure problem and thus encourage forward-auction bidders to express the value of such scale economies, the Commission should follow through on its proposal to permit those bidders to place package bids. Specifically, it should permit

"a single, all-or-nothing bid amount that would apply to a group of licenses, such as . . . the same block in multiple geographic areas." NPRM ¶ 62. As the Commission adds, "[p]ackage bidding options generally complicate an auction, although such complexity can be limited if certain restrictions apply to the ways bidders can group licenses." *Id.* One of the Commission's key challenges will be to balance the need to manage complexity against the equally important need to maximize the value of the spectrum being auctioned.

The attached white paper by Professors Che, Haile, and Kearns proposes a detailed package-bidding mechanism for meeting that challenge within the general auction structure the Commission has proposed. *See* CHK Analysis at 14-15, 34-54. Among its other benefits, this proposal—

- will allow bidders to express the substantial value they attribute to geographic packages and horizontal and vertical contiguity;
- will nonetheless avoid introducing significant complexity to the bidding process;
- will not require setting aside spectrum for packages;
- will not require equalized clearing of spectrum on a regional or national basis; and
- will create no advantage for package bidders vis-à-vis bidders for individual EAs.

The first step in designing an efficient package-bidding mechanism is to define the set of allowable packages and how they relate to the elemental geographic building block, which AT&T agrees should be the EA ("Economic Area"). As Professors Che, Haile, and Kearns explain, the Commission should reduce computational complexity by specifying allowable package bids such that each pre-defined package is fully nested within the next-larger pre-defined package in a clear hierarchy. *See* CHK Analysis at 35, 37-39. Such a nested hierarchy is readily available in the established categories of EAs,

MEAs ("Major Economic Areas"), and REAs ("Regional Economic Areas"). *See generally* NPRM ¶¶ 145-48. Each EA is fully included in an MEA, and each MEA is fully included in an REA (of which there are six in the continental United States):

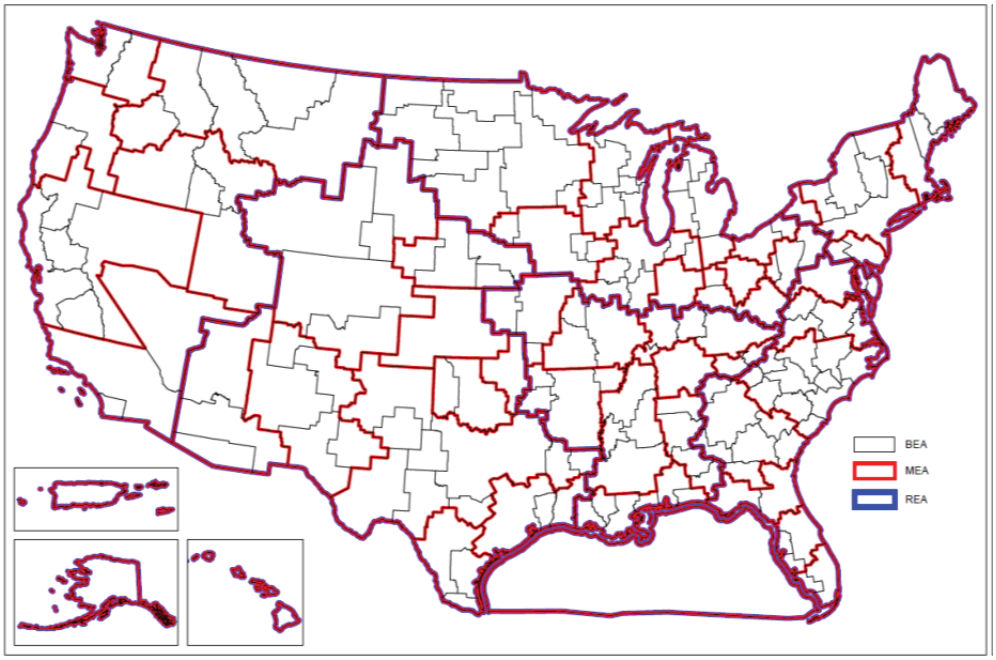

Fig. 7: EAs, MEAs, and REAs

Under the Che/Haile/Kearns proposal, bidders could bid on an EA, on a package consisting of all EAs within an MEA, on a package consisting of all EAs (and thus MEAs) within an REA, or on a package consisting of all EAs (and thus MEAs and REAs) within the United States. But a participant could *not* place a package bid for some subset of multiple EAs within an MEA, for some subset of multiple MEAs within an REA, or for various EAs scattered across the country. *See* CHK Analysis at 36-39 & n.14. For example, a participant could not make its bid for the Los Angeles EA contingent on winning its bid for the New York City EA. This nested hierarchy of permissible packages will help solve the exposure problem for bidders while avoiding the

severe computational complexity the Commission would face in picking winners if it simply allowed bidders to define their own, partially overlapping packages.[31]

Under another key feature of the Che/Haile/Kearns proposal, an individual EA and a larger geographic package are presented as separate objects for sale, even when the latter encompasses the former. Thus, if an auction participant bids for spectrum in an EA both on an EA-specific basis and as part of a package containing that EA, any spectrum that it wins in the EA-specific auction is separate from and in addition to any spectrum it wins as part of the package bid. For example, if a bidder successfully bids for a five-megahertz block of spectrum in the Boston EA auction and for a five-megahertz block in the separate auction for the upper-New England MEA (which includes the Boston EA), the bidder will obtain both a five-megahertz block for the entire MEA and an additional five-megahertz block for the Boston EA, for a total of ten megahertz in that EA. Similarly, a package bid for an REA is a separate object from a package bid for a nested MEA, and a package bid for the U.S. is a separate object from a package bid from a nested REA.

The Che/Haile/Kearns proposal further addresses the need to coordinate the ascending-clock bidding for individual EAs with the distinct ascending-clock bidding for various types of packages in order to maximize the total value expressed in the aggregate forward-auction bidding—and thus to meet the closing conditions for the greatest possible spectrum targets. CHK Analysis at 40-54. As a general rule, a package bidder

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[31] *See generally* Public Notice, *Comment Sought on Competitive Bidding Procedures for Auction 901 and Certain Program Requirements*, 27 FCC Rcd 530, 539 ¶ 32 (2012) (proposing to limit the number of package bids based on census blocks because selecting winning bidders "can be difficult . . . with large numbers of partially overlapping package bids").

would win the specified amount of spectrum in all EAs within its geographic package if the total price it offers for the spectrum in that package exceeds the sum of the bids that would otherwise prevail in the absence of that bidder's package bid. To take a highly simplified example, if there is only one five-megahertz block available in each of the EAs within an MEA, a package bidder offering $1 million for that block throughout the MEA could prevail only if (1) no one else offers that much for the same MEA-wide block and (2) the sum of the bids for the individual EAs within that block falls short of $1 million.

The Che/Haile/Kearns proposal fleshes out this mechanism in greater detail in a variety of more complex scenarios, such as those where different amounts of spectrum are available in the various EAs within a package. *See id*. The common denominator is that the proposal neither favors nor disfavors package bidders as compared to bidders for individual EAs. Instead, it picks winners solely on the basis of which combination of bids expresses—and can be presumed to produce—the greatest economic value for consumers. In particular, by enabling bidders to express the substantial complementarities they can achieve through geographic packages, the Che/Haile/Kearns proposal would promote economic efficiency and help maximize the odds of satisfying the closing conditions for a given spectrum-clearing target. It would also satisfy the substance of the Commission's statutory mandate to "consider assigning licenses that cover geographic areas of a variety of different sizes." Spectrum Act § 6403(c)(3).

Finally, the Commission asks whether it should facilitate package bidding not only for licenses across geographic areas, but also for "a group of licenses, such as more than one block in a [single] geographic area." NPRM ¶ 62. In fact, no specific rules are needed for that purpose because the structure of an ascending clock auction already

accommodates multi-block package bidding. For example, if a bidder wishes to place an all-or-nothing bid for two blocks of spectrum in a given EA, it need only express its wish to buy two such blocks in response to any price offer below its reserve value for those two blocks—and then exit the auction for both blocks in unison if the price level rises above that value. It will never be stuck "winning" one block but not the other.[32]

C. The Commission Should Enable Bidders to Express the Additional Complementarities Derived from Horizontal and Vertical Spectrum Contiguity

To this point, we have addressed the complementarities that providers can derive from winning rights (1) to *some* 600 MHz spectrum in all EAs within a larger geographic category (whether or not the frequencies it wins are the same from place to place) and (2) to two or more blocks *somewhere* in the same object class of 600 MHz spectrum within a given EA (whether those blocks are adjacent or not). Beyond those threshold complementarities, however, providers can also derive substantial additional value from rights (1) to *the same* frequency blocks from one EA to the next and (2) to *adjacent* frequency blocks within any given EA. The Commission should establish clear assignment rules that increase the likelihood that successful package bidders will realize

[32] That and related features of any clock auction produce a separate challenge, however: scenarios in which isolated blocks of spectrum remain unsold once the ascending clock stops for a given EA. In those scenarios, the Commission should hold out the prospect of supplementary bidding to fill the gaps, perhaps by means of a sealed-bid approach. *See* CHK Analysis at 54-57. To avoid creating perverse incentives to underbid in the main bidding round, the Commission should restrict such supplementary bidding to blocks that no bidder has "won" at the conclusion of the clock auction, and it should also announce beforehand that it will exercise discretion whether to conduct such supplementary bidding in the first place. *See id.* Of course, this supplementary round would still involve generic bidding: bidders would still be seeking rights to *some* spectrum block (or blocks) within a generic category but would not yet know *which* precise block (or blocks) they will ultimately be assigned.

these two additional types of complementarities—and that they will therefore express the value of those complementarities in the main bidding round.

We begin by briefly explaining the technological reasons such contiguity is important. Suppose that Carriers X and Y both operate in adjacent Markets 1 and 2, that Carrier X has A Block spectrum in Market 1 and C Block spectrum in Market 2, and that Carrier Y has just the reverse: C Block spectrum in Market 1 and A Block spectrum in Market 2. Each carrier must limit the field strength of its signals at the boundary to prevent interference with the other carrier's network, whether as a matter of FCC rules or as a result of a negotiated agreement. *See* Reed/Tripathi Analysis at 35-37.[33] The result is often the creation of a "dead zone" at the boundary, where reduced signal levels severely degrade capacity and throughput and cause frequent dropped calls. *Id.* at 35 (discussing dead zone running through the middle of Oklahoma City). The Commission will thus increase the value of spectrum for consumers and bidders alike to the extent its assignment rules yield as much horizontal contiguity as possible. The fewer the boundaries a carrier faces with different co-channel licensees on the other side, the more

[33] Such agreements can be difficult to negotiate, in part because one party often has less of an incentive than the other to strike a deal. *See* Reed/Tripathi Analysis at 36. Even when the parties can strike an agreement, the result is still a substantially less efficient use of spectrum than the networks could achieve if each held the same spectrum on either side of the boundary. *See id.* Negotiations also would not necessarily lead the carriers in our hypothetical to swap spectrum holdings in order to create greater contiguity. To begin with, in deciding which spectrum swaps to make, each carrier cannot consider one boundary and co-channel neighbor in isolation; throughout its network, it will have many other boundaries and neighbors to take into account as well. Moreover, because co-channel neighbors are often competitors, negotiations could break down whenever one carrier would benefit more from a proposed swap than the other and thus perhaps at the expense of the other.

efficiently the carrier and its customers can exploit its spectrum resources and the fewer coordination negotiations that carrier must try to reach with its co-channel neighbors.

As this discussion suggests, horizontal contiguity is most important for immediately neighboring geographic areas. For example, to avoid co-channel licensee complications, a given carrier would place a high value on uniform spectrum blocks in the heavily traveled corridor between Washington and Boston. It may be less important for a given carrier to have uniform spectrum holdings in non-neighboring areas, such as Los Angeles and New York, unless that non-uniformity would create an otherwise avoidable need for additional passband filters. In general, therefore, the Commission should place a higher premium on ensuring REA-wide contiguity than on nationwide contiguity if the two objectives are in conflict. It should also give priority for these purposes to winning package bidders over auction participants that bid only on individual EAs and happen to win several adjacent ones. A participant that bids only on a non-package basis is signaling that it would not derive the same complementarities from winning multiple neighboring areas as a package bidder would, and it can be fairly presumed to attach less value to horizontal spectrum contiguity as well.

Second, in any given geographic area, even if Blocks A, B, and C are equivalent in all other respects, a bidder seeking multiple blocks within the same band will generally attach value to holding those blocks in the form of *vertically contiguous* spectrum: *i.e.*, neighboring blocks A and B (or B and C) rather than A and C. Although a carrier can use A and C in combination, it will lose spectral efficiencies in the process; all else held equal, the combination of A and C will provide less capacity than the combination of A and B. *See* Reed/Tripathi Analysis at 34-35. An efficient auction design would thus

avoid those costs altogether by arranging for winners of multiple blocks to receive vertically contiguous spectrum.

In short, both horizontal (EA-by-EA) and vertical (block-by-block) contiguities present substantial efficiencies. If bidders have a strong expectation of obtaining those efficiencies with a winning package bid, they will express those efficiencies in the form of higher package bids, increasing the odds that the forward auction will meet the auction-closing conditions for a given target level of spectrum.[34] Indeed, the Auctionomics framework already appears to facilitate the assignment of vertically contiguous spectrum within any given EA. *See* CHK Analysis at 26; *see also* NPRM at ¶ 64. But the Commission should also establish, from the outset of the auction, clear rules that maximize a package bidder's expectation of horizontal contiguity as well.[35] In particular, it should show how its assignment process will give priority to carriers that have successfully bid for a larger geographic package of spectrum across multiple EAs because those carriers are the ones that intend to exploit the efficiencies inherent in contiguity. The Che/Haile/Kearns proposal would address this challenge by defining geographic package bids as bids for horizontally contiguous spectrum, and winning

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[34] *See generally* NPRM ¶ 63 ("If bidders are allowed to specify packages or other contingencies, the assignment procedures would take those conditions into account in determining a set of best bids that are consistent with our forward auction objective of maximizing the aggregate amount of the bids that we accept for the available licenses.").

[35] *See* NPRM ¶ 64 ("We anticipate that if generic blocks are made available in the forward auction, the assignment procedures would assign contiguous blocks to bidders that bid for multiple blocks in the same geographic area and could take into account the need to coordinate frequencies across adjacent areas.").

package bidders would thus generally obtain such horizontal contiguity. *See* CHK Analysis at 37 & n.12.[36]

Finally, the Commission seeks comment on whether it should create "an additional auction phase to assign specific frequencies for generic licenses, which could be based on accepting additional bids." NPRM ¶ 64; *see also* Auctionomics Proposal at 17-18. Of course, if the Commission first conducts bidding for generic spectrum blocks, it will have to create some mechanism for assigning specific frequencies to the winners of those generic blocks. That will be true even after the Commission makes provision for horizontal and vertical contiguity for package bidders. For example, suppose that there are five spectrum blocks within an object class (A, B, C, D, and E); that Package Bidders X, Y, and Z each win one block apiece within that object class for a given MEA; and that non-package bidders win the remaining blocks within individual EAs. Under the Che/Haile/Kearns proposal, Bidders X, Y, and Z will each be entitled to horizontally contiguous spectrum throughout the MEA by virtue of winning MEA-wide package bids. Yet the Commission must still decide *which particular* block each such bidder will obtain throughout the MEA. It may well be efficient to require X, Y, and Z to bid against one another for any jointly preferred block within this object class.

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[36] In the event that the Commission does not provide for package bidding, Professors Che, Haile, and Kearns alternatively propose to improve upon the random-priority regime in the Auctionomics proposal by allowing bidders to rank-order alternative *combinations* of frequency blocks *across different EAs* rather than restricting bidders to rank-ordering alternative frequency blocks in each EA separately. *See* CHK Analysis at 57-62. As they explain, however, either of those approaches would be inferior to package bidding. *Id.* at 57.

That said, if the Commission has defined the object class optimally, so that the class contains only interchangeable blocks of roughly equivalent value, the bidding in this supplemental round should be very low because each bidder will be almost indifferent to which block it obtains. The assignment-phase bidding could be high only if the blocks have substantially different values and bidders have thus artificially reduced their bids in the generic-round bidding to account for the exposure risk of "winning" lower-value blocks. As discussed, that outcome would be highly problematic because the Commission—and auction participants—need to know at the conclusion of the main (generic bidding) round, not much later in any assignment round, whether the closing conditions have been met for a given channel-clearing target.

III. THE COMMISSION SHOULD CONDUCT A SINGLE-PASS REVERSE AUCTION BEFORE ANY FORWARD-AUCTION BIDDING RATHER THAN AN ALTERNATING REVERSE/FORWARD AUCTION FORMAT

A. The Commission Should Avoid the Repeated Delays Endemic to a Repeatedly Alternating Forward/Reverse Framework

The NPRM seeks comment on two design options for the reverse auction: "sealed bid" and "multiple-round descending clock." Under the "sealed bid" approach, "bidders would specify, during a single bidding round, the payment they would be willing to accept in exchange for relinquishing various spectrum usage rights." NPRM ¶ 38. In contrast, under a "multiple round" descending clock auction, "bidders would indicate their willingness to accept iteratively lower payments in exchange for relinquishing rights." *Id.* ¶ 39. The Auctionomics proposal adopts the latter approach and would further limit the reverse auction to determining only how much broadcaster compensation is needed to meet a single spectrum-clearing target at a time. *See* Auctionomics Proposal at 3. In other words, the reverse auction would "ask[] only for

the information it needs: no winning bidder [would] reveal[] any information about how low it would have been willing to go." *Id*.

The problem with that aspect of the Auctionomics proposal is that, by statutory design, this auction cannot close, and no spectrum can be reallocated, unless forward-auction revenues exceed (1) the amount the Commission must pay to winning reverse-auction participants plus (2) estimated repacking costs and certain administrative expenses. As the Commission recognizes, that statutory requirement will likely require it to make repeated adjustments to its channel-clearing targets in order to match supply (spectrum freed up by broadcasters at particular prices) with demand (bidders seeking to buy spectrum rights at particular prices). And the Auctionomics approach would thus require the Commission to reconvene broadcasters repeatedly for additional rounds of reverse-auction bidding (each combined with new repacking computations) whenever the forward-auction results fall short of a given statutory revenue benchmark, and those new rounds would in turn interrupt the forward-auction bidding.[37] The likely result would be repeated and prolonged delays, and that prospect would depress auction participation and increase the risk of auction failure.

In their attached white paper, Professors Che, Haile, and Kearns propose a "single-pass" descending clock auction that builds on the Auctionomics approach but

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[37] *See* NPRM ¶ 67 ("If the closing conditions are met, the incentive auction process would end. If not, we continue running the forward auction to see if the closing conditions can be met. If the closing conditions cannot be met, another auction stage would be run, this time using a smaller provisional quantity of cleared spectrum and correspondingly smaller number of licenses available in the forward auction. If closing conditions were met at the end of this stage, the process would end. If not, additional stages would be run with the quantity of spectrum sought to be cleared further reduced, until the auction results met them.").

modifies it to avoid these endemic delay problems. Under the single-pass approach, as under the Auctionomics framework, the Commission would begin by announcing a very high bid level designed to reveal what the aggregate revenue requirement would be for the greatest realistically achievable spectrum-clearing target in a given market, taking repacking considerations into account. But the bidding would not stop whenever the descending clock has ticked down to the price level needed to eliminate excess supply for (*i.e.*, just meet) that target. Instead, the clock would continue ticking down to identify the revenue requirements for successively less ambitious channel-clearing targets, each time in conjunction with a repacking analysis. The reverse auction would stop only when the bidding reveals the price needed to clear the smallest number of channels necessary to support a viable mobile wireless band plan—say, seven or eight. In each round, the Commission would also elicit intra-round bidding to identify any intermediate point at which broadcasters would agree to cede just enough spectrum rights to satisfy the channel-clearing target.[38]

The results of this single-pass reverse auction would thus confidentially reveal to the Commission the entire relevant supply curve—*i.e.*, the prices at which broadcasters disclose that they would agree to cede spectrum rights for the range of feasible channel-clearing targets—*before* any forward-auction activity reveals the demand for the spectrum at issue. It would thus enable the Commission, once it begins the forward

[38] In intra-round bidding, a participant in a descending clock auction submits a sealed bid indicating the specific price between two announced price levels at which it would reduce the supply it offered at the first price level. Suppose, for example, that Station X offers to go off the air at an announced price level of $110, and the Commission announces a new price of $100. If Station X would exit the auction at that price but stay in the bidding at $103, it may disclose that fact to the Commission.

auction, to adjust the spectrum-clearing target as necessary to ensure satisfaction of the statutory auction-closing conditions *without* any need to reconvene the broadcasters and interrupt the forward-auction bidding. Specifically, if the forward-auction bidding falls short of the closing conditions for a given spectrum target, the Commission could immediately resume that bidding for the next-lower target without stopping to call the broadcasters back because it will already know, from the single-pass reverse auction, what the revenue requirements are for that lower target. The single-pass approach would thereby avoid the repeated, unpredictable, and potentially lengthy delays endemic to the Auctionomics approach.[39] It would also avoid a potential bid-distorting dynamic in the reverse auction by ensuring that all binding bids of winning broadcasters will be made in the same bidding session, on the basis of the same basic market information, rather than many weeks apart and on the basis of changed market information, as could happen under the Auctionomics proposal. *See* CHK Analysis at 72-73.

The NPRM suggests that the Auctionomics proposal's narrow focus on identifying the revenue requirements for only one channel-clearing target at a time may be a virtue, in that broadcasters might prefer to avoid "determin[ing] an exact bid at the beginning of an auction." NPRM ¶ 40. But under *any* reverse-auction format, broadcasters would have to expect that, within a constrained time period, they might well need to make multiple offers to cede their spectrum rights at successively lower price

[39] As discussed in Section IV below, a single-pass approach would also (and for similar reasons) give the Commission the supply-side information it will need to maximize the odds of closing any revenue gap for a given clearing target by determining how much lower the existing reverse-auction winners would go in their compensation demands after *excess* supply is eliminated for that target but before *sufficient* supply is eliminated.

levels, either because excess supply remains or because the auction-closing conditions have not yet been met. That expectation would lead most broadcasters to make at least rough station-value determinations at the outset of bidding, no matter what the auction format is. In short, the single-pass approach would not appear to place any major new burden on broadcasters that they would not already face under any other approach to the reverse auction, including the Auctionomics proposal.

Of course, under the single-pass format proposed here, broadcasters will likely give the Commission a greater amount of confidential information in the aggregate than would be necessary under the Auctionomics proposal (depending again on how many rounds of bidding they would ultimately need to participate in under the Auctionomics proposal before excess supply is eliminated and the auction-closing conditions are satisfied). As an initial matter, that should be a concern to them only if they have some reasonable basis to fear that their confidential information will be leaked to third parties. The Commission can effectively address that concern by adopting strong protections against the disclosure of confidential data, as it has successfully done in many other contexts. In any event, a broadcaster *that ultimately keeps its license* would generally reveal no additional confidential information under the single-pass approach than under the Auctionomics approach. In general, the only broadcasters that will confidentially reveal to the Commission "unnecessary" price information—how low they would have gone beyond the compensation level needed to meet the prevailing channel-clearing target—are broadcasters that will win the reverse auction and will cede their licenses. *Those* broadcasters should have only attenuated confidentiality concerns.

B. Depending on the Tractability and Comparative Efficiency of Different Repacking Algorithms, the Commission Should Consider Modifying the Single-Pass Framework to Include a Proxy-Bidding Component

Like the Auctionomics proposal, the basic single-pass approach just discussed would entail a *sequential* repacking analysis in conjunction with each round of the reverse auction. Each round of bidding for a given channel-clearing target would produce basic decisions about which stations are subject to repacking and which will be "frozen" (excused from further bidding because they cannot be feasibly repacked), and those decisions would then have preclusive consequences for subsequent repacking analysis under progressively less ambitious channel-clearing targets.[40] For example, if Station X is slated for repacking at one spectrum-clearing target, it will also be slated for repacking at all subsequent targets (albeit potentially in a different channel location). The difference between the two proposals is that the single-pass framework would complete this sequential repacking analysis for all spectrum-clearing targets before any forward-auction bidding begins.

Under *either* proposal, however, this sequential approach to repacking is appropriate only if two conditions hold. First, the Commission must determine that it will be computationally feasible to conduct the repacking analysis in real time, while broadcasters wait to bid on new price levels from the descending clock. It is not yet clear that it will be. As Professors Che, Haile, and Kearns explain, the sequential "feasibility checking" procedure outlined in the Auctionomics proposal "takes the form of a 'graph coloring problem,' which is known to be computationally hard in the worst case," and

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[40] *See* NPRM ¶ 46 (discussing "sequential algorithm approach"); *see also* Auctionomics Proposal at 10-11; CHK Analysis at 10-12, 80-83.

"[w]ithout knowing the fine details of repacking constraints, it is impossible to determine whether the feasibility checking required by the [Auctionomics] proposal is itself computationally feasible." CHK Analysis at 76.

Second, the Commission must also determine that its sequential repacking algorithm will not produce radically less efficient repacking outcomes than would result from a feasible *non*-sequential repacking analysis—*i.e.*, an analysis that could identify an optimal (or close-to-optimal) repacking solution for any given channel-clearing target, *without* taking as given any repacking choices made in prior rounds. This second condition is as important as the first. The more efficiently the Commission can repack stations, the more stations it will be able to repack, the less it will need to compensate the remaining stations for ceding spectrum rights—and thus the more likely it will be that the Commission can meet the statutory closing conditions for a given channel-clearing target.[41] The Commission should therefore place a high premium on any mechanism that is needed to optimize the efficiency of the repacking process because that mechanism will be critical to freeing up the most new spectrum for mobile broadband uses. And it is not yet clear that a computationally feasible sequential algorithm is available that could avoid substantial losses in repacking efficiency as compared to a non-sequential approach. *See* CHK Analysis at 75-76, 83-86.

If either of these conditions *fails* to hold—*i.e.*, if the Commission determines either that an efficient repacking analysis is infeasible to compute in real time or that any

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[41] Of course, the Commission must factor "the estimated costs" of repacking into the equation for determining whether the closing conditions are met, *see* Spectrum Act § 6403(c)(2)(B)(iii), but the cost of repacking a given station is likely to be far lower than the cost of paying that station to cede spectrum rights.

feasible sequential approach would produce unacceptably suboptimal repacking outcomes—the Commission should consider modifying the single-pass framework to include proxy bidding. Under that approach, broadcasters would confidentially tell the Commission their reserve prices (the lowest prices at which they would cede given spectrum rights), and a computer algorithm would then bid for them. That algorithm would select winners on the basis of their comparative bids and would assign them compensation on the basis of what, in a descending clock auction (with infinitesimal decrements), the price level *would* be at the point where excess supply is eliminated—a level that might well substantially exceed the winners' reserve prices.[42] This approach would avoid the need for the Commission to engage in the repacking analysis in between each round, would therefore allow the Commission to complete the single-pass reverse auction quickly, and might well yield more optimal repacking solutions than a sequential algorithm would permit.

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[42] The pricing rule under this approach would produce exactly the same results as a conventional descending-clock auction where broadcasters reveal their reserve prices only where when the clock ticks down to them. Consider the example of a conventional reverse auction where, at the original price of $110, the Commission needs to induce only one broadcaster to exit the auction in order to eliminate excess supply (*i.e.*, too many stations vying for compensation to vacate channels needed for a given channel-clearing target). Suppose that Stations X and Y both exit at the next announced price level ($100); that Station X submits an intraround bid stating that $103 is the lowest price it would have accepted to go off the air; and that Station Y submits its own intraround bid stating that $107 is the lowest price *it* would have accepted. Under this scenario, Station X wins the auction and will be compensated at the level of Station Y's intra-round bid ($107), which is also the point at which Station X would have won if the descending clock auction had proceeded in infinitesimal decrements rather than $10 decrements. This result is equivalent to a single-pass proxy auction with threshold pricing, which "would pay a winning bidder the highest amount it could have bid and still have had its bid accepted." NPRM ¶ 51.

IV. THE COMMISSION SHOULD CLOSE ANY REVENUE GAP FOR A GIVEN CLEARING TARGET BY CONTINUING BOTH THE FORWARD AND THE REVERSE AUCTIONS ONCE EXCESS SUPPLY AND EXCESS DEMAND ARE ELIMINATED

The NPRM anticipates that, for any given channel-clearing target, bidding in the reverse auction will stop when excess supply is eliminated, and bidding in the forward auction will stop when excess demand is eliminated. The NPRM then provides that, "[i]f the closing conditions are met, the incentive auction process would end. If not, we continue running *the forward auction* to see if the closing conditions can be met." ¶ 67 (emphasis added). In fact, the Commission should look to additional bidding in *both* the forward auction *and* the reverse auction in these circumstances to maximize the odds of meeting the closing conditions for a given channel-clearing target rather than settling for some lesser target. This point is subtle but important and warrants some brief background on the mechanics of clock auctions.[43]

For any channel-clearing target, a descending clock auction stops when just enough broadcasters say "no" to a particular price level (and thus drop out of the auction) that there is no longer excess supply to meet that target. Critically, however, that price level may substantially exceed the reserve valuations of the still-participating broadcasters to cede the necessary spectrum rights. To take a simplified example, suppose that the Commission sets a spectrum-clearing target of eleven stations in a given market; fourteen stations offer to go off the air at $150 apiece; and successive $5

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[43] The advantage discussed in this section is similar to but distinct from the advantage discussed in the previous section. The issue here addresses efficient mechanisms for trying to *maintain* an ambitious channel-clearing target even after initial bidding reveals a gap between the revenue requirement and the forward-auction bidding. The prior section addressed efficient mechanisms for promptly moving from one channel-clearing target to the next once it is determined that the revenue condition for the first target *cannot* be met.

reductions in the price level bring the number of still-participating stations down to the desired eleven at a price of $100 apiece.[44] Again, under the Auctionomics proposal, the reverse auction must stop there because it is designed to "ask[] only for the information it needs: no winning bidder reveals any information about how low it would have been willing to go." Auctionomics Proposal at 3.

That approach, however, would reduce the odds of meeting the auction-closing conditions for any given spectrum-clearing target because, in effect, the reverse auction would stop too soon. And that outcome would harm not only consumers (by consigning them to less mobile broadband spectrum), but also broadcasters and forward-auction bidders (by depriving them of economically beneficial opportunities). *See* CHK Analysis at 96-97. In our hypothetical, suppose that the revenue generated in the forward auction falls just short of what is needed to meet the closing conditions for clearing the channels for the eleven "winning" stations at $100 apiece. It is entirely possible that those same eleven stations still would have agreed to go off the air at $95 or even $90. If so, the Commission could meet the statutory closing conditions for clearing eleven channels simply by accepting those lower compensation offers, and consumers would benefit from the reallocation of those eleven channels to mobile broadband uses. Under the Auctionomics proposal, however, the Commission would not know that the eleven stations would have vacated their channels at $95 or $90 because it never would have

[44] This example is simplified in the sense that any determination of whether the statutory closing conditions have been met is inherently national in scope. *See* Spectrum Act § 6403(c)(2). The relevant revenue requirement is thus set by reverse-auction participants nationwide, not in any particular market. In future submissions, AT&T will address how the national character of this closing requirement may affect the optimal strategy for assigning different spectrum-clearing targets to different local markets, depending on the initial outcomes of the reverse and forward auctions.

asked them. Thus, unless it could extract enough extra revenue from the forward auction to close the entire gap, it would have to move immediately to a less ambitious channel-clearing target.

The Auctionomics proposal recognizes that a similar dynamic could arise on the forward-auction side, but it offers a fix: additional bidding. Auctionomics Proposal at 16-17. Suppose, for example, that the Commission solicits bids in a forward auction for a clearing target of eleven channels, and excess demand for that amount of spectrum disappears once the ascending clock auction reaches price level X, which is just below the amount needed to meet the statutory revenue requirement. In contrast to its approach for the reverse auction, the Auctionomics proposal does not call for the Commission in those circumstances to re-run the forward and reverse auctions at a reduced channel-clearing target. Instead, it calls for additional bidding at higher price levels in the forward auction to see if the auction-closing conditions can still be met *for the same channel-clearing target*. *Id.*; *accord* NPRM ¶ 67. And those conditions might indeed be met, and more spectrum would be freed up, if the remaining forward-auction bidders all value the spectrum at a price somewhat higher than X.

That mechanism is entirely appropriate, but it should be supplemented by a parallel mechanism on the reverse-auction side. If, for a given channel-clearing target, a gap remains between revenue requirements and revenue results after the reverse auction has eliminated excess supply and the forward auction has eliminated excess demand, the Commission should try to close the gap through additional bidding *on both sides* (while taking various steps to help prevent overshooting). *See* CHK Analysis at 97-102. In particular, the Commission should test whether there are incrementally lower prices at

which the same broadcasters would agree to cede the same spectrum rights. In contrast, if the Commission tried to close the gap *only* through additional forward-auction bidding, it would substantially reduce the odds of success in meeting the statutory closing conditions for that spectrum-clearing target, and it would therefore increase the risk of settling for less cleared spectrum than is achievable.

These considerations underscore yet another reason for conducting a single-pass reverse auction. By revealing the entire relevant supply curve, the single-pass approach, unlike the Auctionomics approach, would give the Commission in advance the information it may need to close the gap between revenue requirements and revenue results without compromising on the amount of spectrum it frees up.[45]

V. THE COMMISSION SHOULD MINIMIZE CONSTRAINTS ON EFFICIENT REPACKING

The repacking analysis is as critical to the success of this proceeding as it is formidably complex. Because repacking is "part of the process for determining which broadcaster bids will be accepted" (NPRM ¶ 43), it will determine how much spectrum is available in the forward auction.[46] Done flexibly and well, repacking will free up more capacity for mobile broadband while protecting the interests of households that still rely

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[45] To be sure, the Commission could obtain that information by slightly modifying the Auctionomics proposal to require, for each channel-clearing target, additional reverse-auction bidding at successively lower price levels until the number of channels cleared would fall *below* that target. In other words, whereas the Auctionomics approach would stop the reverse-auction bidding whenever *excess* supply is eliminated, this slight modification would continue that bidding down to the price level at which supply is no longer *sufficient*. As under the single-pass approach, the Commission would then know, for example, that the next-lower price decrement (or some point in between) presents the lowest possible revenue requirement for any given clearing target. Although preferable to the unmodified Auctionomics approach, however, this modified version would still be inferior to a single-pass approach for the reasons identified in the previous section.

[46] *See also* NPRM ¶ 5 ("[T]he amount of spectrum available in the forward auction will depend on reverse auction bids and repacking[.]").

on over-the-air signals for television viewing. Done poorly, repacking would free up less spectrum, impose greater demands on the reverse auction to induce more broadcasters to go off the air altogether, and impose commensurately greater demands on the *forward* auction to produce the extra revenues needed to compensate those extra market-vacating broadcasters. In short, inefficient repacking could dramatically increase the risk of auction failure. That risk presents a compelling reason for the Commission to avoid placing any undue constraints on the repacking process.

Although AT&T will address repacking issues in greater detail in future submissions, it wishes to stress the following points up front. *First*, the Commission should avoid undue geographic constraints on its repacking discretion and should thus assess repacking options from a nationwide rather than local perspective. One key challenge will be to account for the interdependence of television frequency assignments in neighboring metropolitan areas. Television stations are currently licensed with very large "co-channel separations." This means, for example, that a channel licensed to a broadcaster in New York City cannot be licensed to another broadcaster in Bridgeport, Connecticut, and vice versa. As a result, a broadcaster that "goes dark" in Bridgeport may free up spectrum not only there but also in New York. As the attached Che/Haile/Kearns white paper explains, the Commission should use a repacking algorithm that takes these "daisy-chain" effects into account and assesses efficient repacking solutions across very wide geographic regions. That holistic approach will be particularly critical in the Northeast, where such effects are most prevalent and complex, but it may well be important elsewhere as well.

Of course, the potentially national scope of this repacking analysis will instill a potentially national dimension into the reverse auction itself. On one level, broadcasters seeking compensation for ceding spectrum rights will obviously be competing against broadcasters in the same market with similar signal contours. But on a separate level, *groups* of broadcasters will also effectively be competing against other groups of broadcasters region-wide and potentially nationwide. Within the limits of algorithmic feasibility, the Commission's optimization analysis will require taking long-distance daisy-chain relationships into full account. *See* CHK Analysis at 67-68, 77-78.

Second, the Commission should also avoid reading into the operative legislation any unnecessary *legal* constraints on efficient repacking. The Spectrum Act directs that, "[f]or purposes of making available spectrum to carry out the forward auction," the Commission may "make such reassignments of television stations that the Commission considers appropriate." Spectrum Act § 6403(b)(1), (b)(1)(B)(i). This broad authority to repack stations as the Commission "considers appropriate" is limited by a single directive: the Commission must "make all *reasonable efforts* to preserve, as of the date of the enactment of this Act, the coverage area and population served of each broadcast television licensee, as determined using the methodology described in OET Bulletin 69 of the Office of Engineering and Technology of the Commission." *Id.* § 6403(b)(2) (emphasis added).

As the Commission recognizes, the "reasonable efforts" standard gives it great flexibility to perform repacking in light of the overarching goals of the Spectrum Act. In the Commission's words, "[w]hile the statute does not define the term 'all reasonable efforts,' that phrase is not uncommon: its meaning depends on the circumstances

involved, and comports with the common meaning of the word 'reasonable,'" which includes "[f]it and appropriate to the end in view."[47] When Congress instructs an agency to take "reasonable" steps to accomplish any goal, it grants the agency considerable discretion to apply that term to suit the circumstances, and courts will grant the agency "substantial deference" when it does so.[48] Here, the overwhelming objective of the Spectrum Act is to reallocate more spectrum for mobile broadband purposes, and Chairman Genachowski has underscored that the Commission's first goal should be to "maximize[e] the amount of spectrum freed up."[49] Against that backdrop, it is hardly *unreasonable* for the Commission to repack spectrum as efficiently as possible to free up the most spectrum for mobile broadband.

Third, the Commission should try to structure the repacking process to distinguish between TV stations that currently transmit above 50 kW (up to the maximum of 1 MW) and those that operate at 50 kW or below. As discussed in Section II, the latter stations pose far fewer interference challenges to mobile broadband operations than higher-power stations do. In the repacking process, therefore, the Commission should assign those stations to channels that are adjacent to guard bands protecting mobile broadband downlink spectrum. Choosing such reduced-power stations for those locations will enable the Commission to limit the size of those guard bands to six megahertz (in

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[47] NPRM ¶ 105 (citing, *inter alia*, Black's Law Dictionary 1265 (6th ed. 1990)) (footnotes omitted).

[48] *Capital Network Sys., Inc. v. FCC*, 28 F.3d 201, 204 (D.C. Cir. 1994). Indeed, the Supreme Court has said that the same phrase used in the Spectrum Act—"reasonable efforts"—is a directive that, when no further statutory guidance is found, will "obviously vary with the circumstances," and confers significant flexibility on the administrative decisionmaker. *See Suter v. Artist M.*, 503 U.S. 347, 360 (1992).

[49] *See* NPRM (statement of Chairman Genachowski).

contrast to the much wider guard bands that would be needed for higher-power stations) and, in turn, will allow the Commission to maximize the amount of spectrum that it can reallocate to mobile broadband uses.[50]

Fourth, the Commission should provide as much advance information as possible about how it will structure the repacking process to maximize the value of the spectrum reallocated to mobile broadband uses. Only then can it ensure that forward-auction participants will express that increased value in their bids. The Commission should thus establish clear repacking algorithms up front and make them fully available to the public. Greater insight into the repacking process will also help broadcasters make fully informed choices about participation in the reverse auction. For example, the more information a broadcaster has about the location of repacked channels, the better able it will be to make an educated decision about whether to cede spectrum altogether or, alternatively, to enter into a channel-sharing arrangement with another station.

Finally, the Commission should establish a clear and expeditious timetable for the repacking process once the auction is complete. There is generally no need for a lengthy delay before broadcasters who remain on air must switch channels. The Commission has noted that, "of the more than 100 licensees whose requests to substitute channels were granted towards the end of the digital transition, most completed construction within 12 months of receiving a construction permit." NPRM ¶ 322. Establishing a much

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[50] To the extent possible, the Commission should also consider minimizing co-channel interference by assigning additional reduced-power stations to the frequency blocks that are cleared in some markets but not others. For example, if Channel 42 is reallocated to mobile broadband uses in City X but not nearby City Y, the cleared mobile broadband spectrum in City X will face far less interference if the co-channel television licensee in City Y is broadcasting at 50 kW rather than 1 MW.

lengthier transition would also depress forward-auction participation: bidders would substantially discount their bids to reflect the risk of lengthy delays in their ability to make actual use of 600 MHz spectrum.

VI. TO REDUCE THE RISK OF AUCTION FAILURE, THE COMMISSION SHOULD NOT CONSTRAIN THE PARTICIPATION OF PARTICULAR CARRIERS IN THE FORWARD AUCTION

As AT&T has explained elsewhere, the Commission should reject proposals to impose *ex ante* limits on the spectrum that particular carriers can obtain through this auction.[51] In brief, if a winning bidder's acquisition of new spectrum would bring its total holdings in a market to a level that is determined to threaten competition, that licensee should be free to choose which spectrum it will divest to remedy the anticompetitive harm. *See* NPRM ¶ 384. Such flexibility will allow a licensee to achieve efficiencies by rationalizing its spectrum holdings, and it will create no risk to competition. In contrast, if the Commission adopted rules that would limit the participation of well-capitalized market actors in this auction, it would sabotage forward-auction competition and undermine prospects for obtaining the bid levels needed to meet the statutory closing conditions for any given channel-clearing target.

Such competition-suppressing rules would thus thwart the Commission's central statutory mission. This is a once-per-decade opportunity to create immense consumer value by repurposing spectrum for bandwidth-constrained mobile broadband services, and the more spectrum the Commission can unleash for that purpose, the greater the consumer benefit will be in the form of increased capacity and lower prices per unit of

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[51] *See* Comments of AT&T Inc., *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, at 11-12, 59 (Nov. 28, 2012); *see also id.*, Attach. A at ¶¶ 67-69 (Declaration of Mark Israel and Michael Katz).

capacity. It is difficult to imagine a policy more inimical to that objective, and more likely to trigger outright auction failure, than unnecessary regulatory constraints on forward-auction participation.

The NPRM acknowledges that, "under current spectrum aggregation policies, the Commission would apply its spectrum screen and undertake its competitive analysis only after the auction." *Id.* But it suggests that this practice is somehow in tension with the need "to have certainty for bidders in this auction." *Id.* This concern is difficult to understand. Certainty is "of particular importance" (*id.*) here insofar as it will reduce bid-suppressing exposure risks and thereby increase revenue-generating participation, which in turn will increase the spectrum that can be reallocated to mobile broadband. Against that backdrop, it makes little sense to invoke "certainty" as a rationale for taking steps that are guaranteed by definition to *reduce* revenue-generating participation and threaten to *slash* the amount of spectrum that can be unleashed for the benefit of mobile broadband consumers. Instead, any "certainty" rationale for *ex ante* restrictions on auction participation would have to rest on a false premise: that if the Commission decides after the auction that a winner now has "too much" spectrum, the Commission would have no alternative but to withhold 600 MHz licenses from that winner. Again, however, the Commission could avoid any such uncertainty by allowing the winner to divest *other* spectrum holdings to bring its overall holdings below any cap. That approach would accommodate certainty concerns while allowing for more efficient spectrum allocation and increasing the odds of auction success.

CONCLUSION

The Commission should take the steps outlined in these comments to derive the greatest value from the 600 MHz band and ensure that as much of it as possible is reallocated to mobile broadband uses.

Respectfully submitted,

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EXHIBIT A

THE 600 MHz SPECTRUM AUCTION:
AN ANALYSIS OF THE BAND PLAN FRAMEWORK

Professors Reed[1] and Tripathi[2]

Abstract

The Federal Communications Commission ("FCC") plans to reallocate to mobile wireless services 600 MHz spectrum that is currently used for over-the-air broadcast TV services. This reallocation will be implemented through two auctions. In the first auction (a "reverse auction"), current holders of 600 MHz spectrum licenses (*i.e.,* owners of television broadcast stations) will have an opportunity to sell their spectrum rights. In the second auction (a "forward auction"), the FCC will accept bids from cellular service providers to acquire licenses for the newly available 600 MHz spectrum. Given the nature of these auctions, the FCC will not know precisely how much, or which, spectrum will be available for mobile broadband use until both auctions end. The FCC has proposed a band plan "framework," which describes the band plans that it will implement upon completion of the auctions depending on the quantity of spectrum "cleared" in each license area. Under this approach, rather than bidding on specific spectrum, mobile providers will bid on categories of "interchangeable" spectrum blocks. The FCC's Notice of Proposed Rulemaking ("NPRM") seeks comment on this innovative band plan framework. We have examined the FCC's proposal, and have received additional input from AT&T engineers and other industry participants, including infrastructure manufacturers, device manufacturers, chipset makers, and manufacturers of various other handset components. We have identified certain aspects of the FCC's proposed framework that raise significant potential interference and implementation concerns. Building on the FCC's innovative concepts, we discuss core principles that, if implemented, will address these concerns, while still promoting the FCC's policy goals for these auctions. Although further collaboration with the FCC and other industry participants is essential before any band plan is finalized, we provide an illustrative band plan that implements these core principles. We also explain the importance of auction rules that ensure that successful forward auction bidders are assigned spectrum rights in blocks that are both vertically (within a license area) and horizontally (across adjacent license areas) contiguous in frequency.

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1. Executive Summary.

The FCC's reallocation of 600 MHz spectrum from television broadcasters to mobile broadband providers using auctions poses numerous unique technical challenges. Ordinarily, the FCC establishes band plans ahead of auctions that identify both the specific spectrum that will be available at auction and the spectrum's permissible uses. Service providers can then examine the band plan and make informed decisions as to the relative value of the available spectrum blocks. In the case of the 600 MHz auctions, however, the amount of available spectrum depends on the results of the auctions, and hence the FCC cannot, before the auction, develop a specific and final band plan that identifies the precise spectrum that will be made available. As a result, the FCC faces a significant challenge in providing potential bidders with sufficient information to attract their full participation in the auction and to ensure the spectrum is ultimately auctioned at appropriate prices.

The FCC has developed an innovative approach to address this issue. Rather than developing a single specific band plan, the FCC has proposed a band plan "framework" that is designed to be sufficiently flexible to accommodate the potential availability of different amounts of spectrum in different license areas, while still providing sufficient information about the characteristics of the spectrum to facilitate a robust auction. Under this framework, the FCC explains how spectrum will be allocated depending on how much spectrum is ultimately relinquished from television stations. This framework is an attempt to create spectrum blocks that, at least by design, share certain important characteristics (*e.g.*, size, paired/unpaired, propagation characteristics, and susceptibility to interference), so that service providers are able to bid on such generic spectrum blocks even though they do not know precisely which spectrum block or blocks they will ultimately be assigned. We agree with this general approach. However, certain aspects of the band plan framework proposed by the FCC carry a substantial risk of harmful interference for multiple spectrum bands (not only 600 MHz, but also 700 MHz, PCS, and BRS/EBS) and may also create significant implementation problems.

A central feature of the FCC's proposed framework is an unusually large duplex gap between the downlink and uplink frequencies combined with the placement of television stations in that duplex gap. This central feature, and the way the relinquished spectrum surrounds these television stations in such a framework, creates a risk of harmful interference for services offered in the 600 MHz (and other, *e.g.,* 700 MHz and PCS) bands, in three important respects. First, the placement of television stations in the duplex gap would create significant potential for both intermodulation interference and adjacent channel interference. Under the FCC's proposal, the uplink signal from a 600 MHz device would interact with the television station signals in the duplex gap to create a third signal, called the intermodulation product, that would fall within the device's downlink frequencies. Intermodulation products interfere with a device's ability to communicate with the base station, reducing downlink and uplink data speeds or even causing dropped connections. The risk of harm here is exacerbated by the fact that, under the FCC's proposed plan, there could be multiple television stations operating in the duplex gap, creating multiple overlapping and additive intermodulation products falling within the device's downlink frequencies. In addition, placing very high power television stations in

the duplex gap would create adjacent channel interference in the 600 MHz device's downlink bands, which could also degrade the receiver performance.

Second, the FCC's proposed framework would result in harmonic signals that could interfere with PCS and BRS/EBS mobile downlink spectrum. In recent similar circumstances (relating to harmonic signals involving 700 MHz and AWS spectrum), the 3GPP found that this type of interference increases desensitization in devices by about 7 dB, which can result in a significant reduction in throughput.

Third, the FCC's design for uplink spectrum would likely result in co-channel interference caused by televisions stations operating in nearby geographic areas. For example, under the FCC's proposal, a television station operating in "City 1" may end up using the same 600 MHz frequencies that a mobile provider is using for uplink in nearby "City 2." In that situation, the television station in City 1 could cause significant interference for base stations operating in City 2, thus degrading the performance of 600 MHz mobile networks in City 2.

The large duplex gap in the FCC's proposed band plan framework also raises significant practical implementation concerns by increasing the sizes of the devices, the size of the base station antennas, and the number of device antennas that providers seeking to use 600 MHz spectrum would need. As a matter of wireless physics, to achieve the same desired efficiency levels, antennas in mobile devices and at base stations must be larger when they support lower frequencies, and they must be larger yet when they also have to support a wider range of frequencies. The FCC's band plan effectively maximizes the size of the antenna needed to maintain desired efficiency (and hence throughput and capacity) in the 600 MHz frequencies, by employing a very large duplex gap results in both the use of very low frequencies for downlink and very wide frequency ranges overall. The need for larger antennas creates significant challenges to maintaining small form factors for devices and to placing base stations in desired locations. Larger antennas also make it more difficult to exploit technologies that increase throughput and efficiency, such as MIMO, which requires the use of two or more antennas with a certain minimal amount of separation.

In our opinion, these problems can be addressed by adherence to a core set of band plan principles that represent relatively modest changes to the FCC's proposal and would still promote the laudable goals the FCC enumerates in the NPRM: "utility, certainty, interchangeability, quantity, and interoperability."[3] In particular, any 600 MHz band plan framework should adhere to the following core principles: (1) spectrum should be auctioned in 5 MHz blocks; (2) the framework should seek to incorporate significant amounts of paired spectrum; (3) the framework should be based on uniform blocks of downlink spectrum that are consistent across geographic areas; (4) the framework should not place television stations in the duplex gap and should seek to minimize interference from television stations; (5) the

[3] Notice of Proposed Rulemaking, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, Docket No. 12-268, ¶ 125 (rel. Oct. 2, 2012) ("NPRM").

framework should incorporate a reasonably sized duplex gap; (6) the framework should seek to allocate spectrum relinquished for mobile services above Channel 37 in the first instance, and below Channel 37 only after spectrum has been fully allocated above Channel 37; (7) spectrum in the duplex gap and the guard bands should be used efficiently, and any use of the duplex gap and guard bands should not be allowed to cause interference in the auctioned spectrum; (8) the FCC should promote global harmonization by adopting a framework that could be readily adopted in other countries; and (9) the framework should preserve Channel 37 for its existing uses but there should be no new interference protections for those services from mobile providers.

We discuss below an example of an alternative band plan framework that follows these core principles, to illustrate how these principles could be implemented. We believe that this type of alternative proposal would provide considerable net engineering benefits over the NPRM's lead proposal, and by addressing these engineering concerns, such an alternative would also better promote the FCC's stated policy goals. We acknowledge, however, that these issues are complex, and that AT&T and other industry participants are continuing to study various aspects of possible alternative frameworks. We look forward to continuing to work together with the Commission and the industry to design an alternative framework that will avoid the interference and implementation risks inherent in the NPRM's proposal.

The remainder of this paper is organized as follows.

In Section 2, we examine the key features of the FCC's proposed band plan framework. The FCC's framework facilitates deployment and expansion of Frequency Division Duplexing ("FDD") Long Term Evolution ("LTE") networks.[4] Accordingly, the framework divides uplink and downlink spectrum into 5 MHz blocks, and pairs that spectrum where possible. It also places guard bands between mobile spectrum and broadcast television spectrum. These are all desirable attributes of the FCC's band plan framework that we fully support.

In Section 3, we examine in detail the interference and implementation risks inherent in the FCC's band plan framework, which could result in significant interference for devices and networks operating in 600 MHz, 700 MHz, PCS, and EBS/BRS spectrum bands, and could also create significant implementation challenges for network operators, component makers, infrastructure vendors, and device manufacturers.

In Section 4, we discuss a set of core band plan principles that avoid or minimize these problems. We also provide a specific and detailed example of the type of alternative band plan framework that we believe would avoid or significantly reduce many of these interference and

[4] Even though the FCC does not limit the cellular technology that could be deployed at 600 MHz, LTE is widely expected to be the technology of choice for cellular operators in the U.S. and around the globe in the foreseeable future.

implementation concerns in a manner that results in net benefits relative to the FCC's lead band plan proposal and would more effectively balance the FCC's policy goals.

In Section 5, we address certain technical and engineering issues that the FCC should consider to ensure a successful auction. It is very important that each block of spectrum within a category of blocks to be auctioned on a generic basis share the same known characteristics. The FCC must avoid implementing a band plan that results in interference (or creates significant uncertainty about interference) within some spectrum blocks in a category but not others, which would undermine the interchangeability of blocks, and force bidders to hedge their bids. Moreover, to ensure that 600 MHz spectrum can be deployed most efficiently, it will be important that the spectrum be assigned to successful bidders in a manner that provides for both vertical contiguity (*i.e.,* bidders that win multiple blocks in a given license area should be assigned blocks in adjacent frequencies) and horizontal contiguity (*i.e.* bidders that win spectrum in multiple license area should be allocated the same frequencies in adjacent geographic areas).

2. The FCC's Proposed Band Plan.

As the FCC correctly notes, "[c]reating a band plan from relinquished broadcast spectrum usage rights . . . presents unique challenges."[5] Because of the nature of the incentive auction, the FCC cannot know in advance precisely how much 600 MHz spectrum will be available for mobile services in any particular area. Thus, the FCC is not in a position before the auction occurs to specify a band plan that identifies the specific spectrum blocks that will ultimately be available and allocated to winning bidders.

To address this unique challenge, the FCC has proposed an innovative approach. Rather than proposing a specific band plan, the FCC has instead proposed a band plan "framework" designed to be "flexible enough to accommodate varying amounts of spectrum from relinquished broadcast television spectrum usage rights in different locations" while at the same time providing "as much information and certainty as possible, to enable interested wireless providers to make informed business decisions about whether, and how, to bid for and use 600 MHz spectrum."[6]

Under the proposed band plan framework, the FCC would identify categories of spectrum to be made available for mobile use that are interchangeable from the point of view of bidders, so that bidders can bid for blocks of spectrum within a category even if they do not know the precise spectrum blocks within that category they will ultimately be assigned. If bidders are confident that spectrum within each category is truly interchangeable, then they can bid on spectrum within each category without having to hedge their bids to account for the possibility

[5] NPRM, ¶ 123.

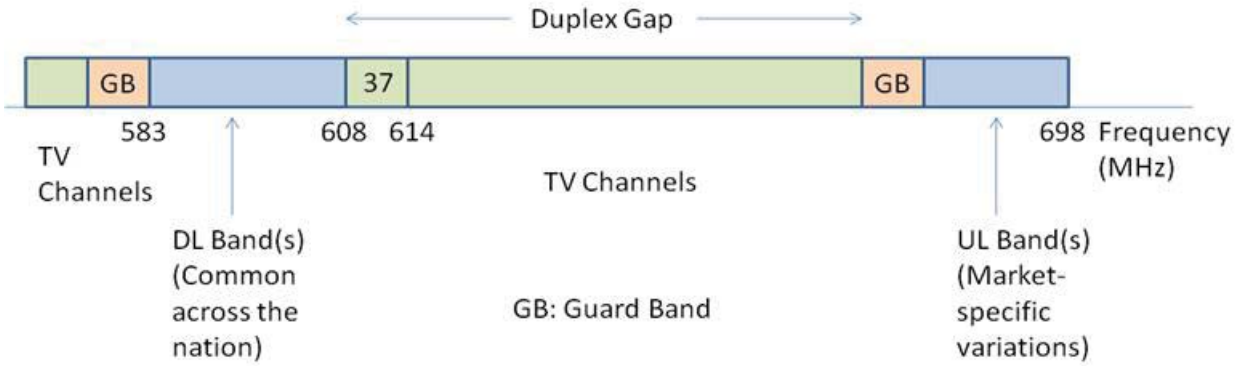
[6] NPRM, ¶ 123.

that they will be assigned blocks that are materially inferior to other spectrum within the same category.

The FCC explains that the ideal band plan framework would balance "five key policy goals: utility, certainty, interchangeability, quantity, and interoperability."[7] Our understanding is that "utility" refers to maximizing the capacity and usefulness of available spectrum, "certainty" refers to providing potential bidders with certainty as to the characteristics of the spectrum on which they are bidding, "interchangeability" refers to developing spectrum blocks that have very similar utility so that they are interchangeable from the point of view of the provider, "quantity" refers to maximizing the amount of spectrum bandwidth made available by this auction, and "interoperability" refers to allocating spectrum in a manner that permits the development of band classes that can be used nationally or as broadly as possible.

The band plan framework proposed by the FCC is based on the assumption that the most efficient use of the 600 MHz spectrum given today's technologies will be in a mobile network using FDD LTE technology. We agree with this assumption. The FCC's proposed framework is therefore centered around the allocation of uplink and downlink frequencies. The FCC's general framework is depicted in Figure 1.

Figure 1. The Lead Band Plan Proposed by the FCC.



As shown in Figure 1, the FCC's plan provides a certain amount of common spectrum for the downlink across the country and varies the amount of uplink spectrum based on the market-specific spectrum availability. On the downlink side, the FCC's proposed framework allocates downlink frequencies in 5 MHz blocks starting with the frequencies immediately below television channel 37, and adding 5 MHz blocks moving down in frequency from there to the extent sufficient spectrum is relinquished from television stations in the auctions and repacking processes. The number of downlink bands in any given area will depend on the total number of 5 MHz downlink blocks that become available in that area. The goal under the FCC's band plan is to make the downlink bands common across all geographic areas. Thus, for example, the FCC's approach would first build a 25 MHz downlink band in the spectrum immediately below

[7] NPRM ¶ 125.

channel 37 that is common in all geographic areas. It would then add another 25 MHz downlink band below that in geographic areas where additional spectrum is available, and so on.

For uplink, the FCC's proposed framework allocates 5 MHz blocks first to the frequencies immediately below the current 700 MHz A Block, with the first block being from 693 MHz to 698 MHz (*i.e.*, current UHF Channel 51), and adding 5 MHz blocks moving down in frequency from there. Within an uplink band, the number of 5 MHz uplink blocks depends on the amount of spectrum freed up in a given market. Some markets may have only one uplink block, while other markets may have multiple uplink blocks. These uplink blocks will be paired with the downlink blocks, starting with the 5 MHz downlink block immediately below Channel 37 and moving down in frequency. Unlike the downlink bands, the number of blocks within each uplink band may vary throughout the country.

This proposed framework has certain unique features, compared to the band plans for other mobile spectrum. For example, the proposed placement of 600 MHz mobile uplink and downlink frequencies creates a very large "duplex gap." The duplex gap refers to the range of frequencies between the frequencies used for mobile uplink and downlink services. Under the FCC's proposed plan, the duplex gap could be as much as 70 MHz. Ordinarily, duplex gaps are smaller relative to the frequency of the spectrum at issue. As we explain below, such a large duplex gap at these relatively low frequencies raises significant implementation issues. For example, it can significantly increase the size of antennas that would need to be incorporated into small form factor devices.

Another unprecedented feature of the FCC's lead band plan framework is that it would place numerous television stations in the duplex gap. As we discuss below, the placement of high powered broadcasts in the duplex gap creates significant interference concerns, including intermodulation interference, adjacent channel interference, harmonic interference, and co-channel interference.

The FCC's proposed band plan framework also includes an innovative feature that ensures uniform nationwide downlink bands of spectrum. This concept is meant to address the fact that different amounts of spectrum will become available in different areas, which will create significant challenges in developing devices that will be free from interference in all areas. For example, if 20 MHz of downlink is made available in Chicago, but only 10 of that 20 MHz is available for downlink in New York, then manufacturers seeking to build mobile devices that can be used in both New York and Chicago are limited to building devices that are open to the 10 MHz of spectrum that is common to both areas. If the device were also open to the additional 10 MHz of spectrum that is available only in New York, that device would not work properly in Chicago, because television stations would still occupy those frequencies in Chicago and would interfere with the device's ability to communicate with the base station. An alternative approach would be to build devices with multiple filters and passbands, which would increase costs and complexity and constrain the device form factors.

The FCC seeks to partially address this issue by allocating the spectrum that becomes available in the auction in a way that creates consistent nationwide bands of *downlink* spectrum

common to all (or most) areas in the U.S. To do this, the FCC's approach varies the number of uplink spectrum blocks available in each area. In an area where relatively less spectrum becomes available, most of it would be allocated to the downlink to ensure that the area has a certain number of available downlink blocks that match those in other areas of the country, with only a small number of blocks allocated to the uplink. In areas where "extra" spectrum is available, the FCC's framework would first create additional uplink blocks to maximize the number of paired blocks of spectrum, and any remaining spectrum blocks would be allocated to the downlink, which could be used for carrier aggregation or in other ways that do not require a paired uplink block.

The FCC's approach therefore creates two categories of spectrum, with the goal that spectrum in each category is interchangeable. The first category includes symmetric paired uplink and downlink spectrum blocks, and the second category includes unpaired downlink blocks. Mobile providers will bid on these generic categories of spectrum, even though they will not know *a priori* the precise frequencies that they will ultimately be allocated.

One question raised in the NPRM relates to the maximum passband for downlink spectrum. As the FCC correctly recognizes, "base station and user equipment . . . have pairs of filters, called duplexers, which screen out certain frequencies to allow the equipment to both transmit and receive data while minimizing interference."[8] The spectrum ranges for signals that duplexers allow to be transmitted and received by the device are referred to as "passbands." The NPRM seeks comment on whether technical limitations may dictate maximum sizes of those passbands. Passbands are typically limited to about 4 percent of the center frequency of the spectrum being used, which for 600 MHz spectrum would be about 25 MHz, which is consistent with the passbands currently set forth in the FCC's framework. In Table 1, we present the ratio of the passband size to the center frequency for several 3GPP/LTE bands. As shown in Table 1, the 3GPP standard has so far defined maximum passband sizes that are no larger than about 4 percent of the carrier frequency (and are typically significantly less than 4 percent).

[8] NPRM ¶ 161.

Table 1. Passband, Duplexer Gap, and Duplexer Spacing for Popular FDD Bands.

3GPP Band (FDD)	Left Edge (Uplink)	Right Edge (Uplink)	Left Edge (Downlink)	Right Edge (Downlink)	Passband	Duplexer Gap (minimum separation between Tx and Rx RF filters)	Duplexer Spacing (separation between UL channel and DL channel)	Ratio of Passband to Center Carrier Frequency (%)
2 (PCS, A to F blocks)	1850	1910	1930	1990	60	20	80	3.19
25 (PCS, A to F plus G)	1850	1915	1930	1995	65	15	80	3.45
12	699	716	729	746	17	13	30	2.4
13	777	787	746	756	10	41	31	1.28
17	704	716	734	746	12	18	30	1.69
4 (AWS)	1710	1755	2110	2155	45	355	400	2.6
3 (AWS)	1710	1785	1805	1880	75	20	95	4.29

Larger passbands would likely raise technical challenges for equipment manufacturers and would certainly raise interference issues. For example, consider a 40 MHz passband, of which the upper 20 MHz frequencies in the passband are subject to interference in certain areas of the country. Even if the device is using only the lower 20 MHz of spectrum that is not subject to interference, the device will still experience interference because the interfering signals will pass through the 40 MHz-wide passband. Depending upon the bandwidth of the interfering signals, a large amount of spectrum within the 40 MHz spectrum could be impaired in these geographic areas. If there were instead two passbands, each with 20 MHz, a device configured with the passband comprising the lower 20 MHz of the original 40 MHz passband would be free from interference overlapping the upper 20 MHz spectrum. Devices could therefore be configured to the passband suitable for the geographic areas,[9] or with both passbands and equipped with a mechanism to effectively turn off the 20 MHz passband that is subject to interference in areas where such interference exists. Thus, the flexibility provided by the use of multiple smaller passbands (20 MHz to 25 MHz) allows more efficient, unimpaired use of spectrum in more geographic areas.

[9] For example, in LTE networks, the information about the system is carried in the System Information Blocks, where the devices in the idle mode can be provided the available RF carrier frequencies. The devices in the connected mode can be sent the information about the carrier frequencies via dedicated Radio Resource Control (RRC) signaling. The device will then use the correct filter for communications.

3. Concerns Raised By The FCC's Proposed Band Plan.

At AT&T's request, we have collaborated with AT&T's engineers, with input from AT&T's vendors, to critically analyze the FCC's band plan framework. Based on this analysis, we conclude that although the FCC's approach is an elegant solution to many of the challenges associated with the upcoming auctions, it also raises important interference and implementation concerns.

3.1. Interference Concerns.

Interference is always a significant concern for mobile services. Mobile devices must be able to operate in a wide variety of radio environments, not just in the best or even average radio conditions, because customers expect their devices to work well everywhere and that their devices will not perform poorly, run slow, drop connections, or fail to connect at all, when they pass through certain areas. Accordingly, an assessment of the FCC's band plan framework must consider radio environments where consumers will have the expectation of connectivity but the devices will be most prone to interference. For example, mobile devices are more prone to interference when they are transmitting at higher power (*e.g.* when transmitting video or operating farther from the base station or indoors), because high-powered transmissions create higher-powered intermodulation products and harmonics that interfere with downlink reception. In addition, when interfering signal levels (*e.g.*, television broadcasts) are strong relative to the mobile downlink signal, devices are more prone to interference.

As we explain below, the FCC's proposed band plan framework creates significant potential for harmful interference, because it results in multiple sources of interference that could overlap and are thus cumulative. The full impact of this interference is extremely difficult to evaluate at this stage, because neither the FCC nor the industry have experience with a band plan that incorporates so many different and overlapping sources of interference. This uncertainty would make it very difficult for potential bidders accurately to assess the value of the spectrum, which in turn could adversely affect the success of the auction.

We have identified three sources of interference that are directly linked to the FCC's proposed band plan framework. The first source of interference is from television stations operating in the duplex gap. These television stations could cause intermodulation interference (both ordinary intermodulation and reverse intermodulation) and adjacent channel interference. The second source of interference is from harmonics caused by the use of frequencies formerly occupied by certain television channels – *i.e.*, portions of channels 42-46 covering the frequency range from 643 MHz to 667 MHz – for the mobile uplink. The third source of interference, called co-channel interference, comes from television stations operating in neighboring cities and towns that a cellular base station is using to receive the uplink signals from the mobile devices, thus interfering with the base station's ability to communicate with mobile devices. These sources of interference have the potential to degrade the performance of the proposed 600 MHz networks (due to intermodulation, adjacent channel interference,

and co-channel interference), and *existing* 700 MHz (due to intermodulation), PCS (due to intermodulation and harmonics), and BRS/EBS (due to harmonics) mobile networks.[10]

3.1.1 Interference Caused By Television Stations In The Duplex Gap. One of the main features of the FCC's proposed band plan is that it permits television stations to operate within the duplex gap. Television stations are authorized to transmit at very high power levels (up to 1 MW). When television stations transmit in the frequencies that are near the frequencies used by mobile devices, as is the case when television stations operate in the duplex gap, there is significant potential for harmful interference to mobile services, resulting in degraded performance. Where the interference is very substantial, it can even prevent the device from connecting to the LTE network. There are two main mechanisms by which television stations operating in the duplex gap create potential harmful interference: (1) intermodulation (regular and reverse) and (2) receiver adjacent channel interference.

Intermodulation Interference. Intermodulation occurs when signals from two or more different transmitters combine to produce new signals – called "intermodulation products" – that fall within a device's receive frequencies. In the context of cellular transmissions and television transmissions, the two signals that mix are the television transmission and the signals generated by non-linear components of a mobile device.[11] The stronger the original mixing signals, the stronger is the resulting intermodulation product, and the greater the potential for harmful interference.

There are two types of intermodulation at issue here. "Ordinary" intermodulation occurs where the television signals and the transmit signal of the mobile device enter and mix on the *receive* side of the device, creating intermodulation products in the receive side of the device. "Reverse" intermodulation occurs where the television signal enters the *transmit* side of the device. When reverse intermodulation occurs, the television signal mixes with signals produced by non-linear components of the device on the transmit side and the intermodulation products then cross over to the receive side of the device by passing across the duplexer. For ordinary intermodulation, there are several nonlinear components in the mobile device that could lead to intermodulation products including, for example, the duplexer, local oscillator, low noise amplifier, and the mixer. In both cases (ordinary intermodulation and reverse intermodulation), the intermodulation product finds its way to the receive side of the device, where it can interfere with the device's ability to receive desired signals from the base station.

When the intermodulation products fall within mobile devices' receive frequencies (*i.e.*, within the passband of the receive filter), they cannot be filtered. Consequently, the potential for

[10] These sources of interference may also cause harmful interference to frequencies used for non-mobile services such as WLAN services. This paper focuses on interference to licensed mobile bands. Furthermore, this paper focuses on third-order intermodulation interference and third- and fourth-order harmonics. Higher-order harmonics may become important sources of interference but are not considered in this paper.

[11] A non-linear component is one in which its output is not linearly proportional to its input.

harmful interference is entirely a function of the relative power of the intermodulation product and the desired downlink signal. Where the signal level of the intermodulation product is sufficiently high relative to the desired mobile signal, the device will experience degraded performance.

The FCC's proposed band plan, by permitting several television stations to operate in the duplex gap and by allowing several TV signals to stay within the uplink passband, creates very significant potential for harmful intermodulation interference. With current mobile band plans, there is typically no more than one intermodulation product to assess (*e.g.,* the impact of existing UHF channel 51 on lower 700 MHz mobile wireless services). But under the FCC's proposed band plan framework, there could be multiple strong television signals close to the mobile transmission frequencies, which in turn can create numerous intermodulation products that will fall within multiple mobile receive frequency ranges.

Moreover, these multiple intermodulation products will often overlap in the mobile receive frequencies (especially given that, as explained below, the bandwidths of the intermodulation products are quite wide), creating a more significant cumulative impact than in more typical scenarios where there is only one intermodulation product resulting from one nearby TV signal. Fundamental signal processing principles confirm that the total power level of the intermodulation interference falling within any particular receive frequency range is the sum of the power levels of all of the individual overlapping intermodulation products falling within that frequency range. Consequently, the potential for interference is greater than if there were only one television station in the duplex gap and thus only one potential intermodulation product within the receive frequencies.

The total number of intermodulation products, cumulative power levels, and the exact receive frequencies in which these intermodulation products will fall cannot be accurately determined until the band plan is finalized, market-specific spectrum situations are known, and device-specific characteristics are measured. The actual number and geographic and frequency locations of the television stations in the duplex gap and the uplink would also significantly affect the overall intermodulation interference. But our analytical calculations described below confirm that given reasonable assumptions there will be multiple intermodulation products falling within multiple receive bands at the mobile device.

Consider the example of ordinary intermodulation. The mathematical formula for identifying the center frequencies of the ordinary intermodulation products at issue here (the "third order" intermodulation products) is ($mf_1 \pm nf_2$), where m and n are integers, f_1 is the center frequency of the first signal and f_2 is the center frequency of the second signal. The "order" of the intermodulation product is the sum (m+n). For example, a "third order" intermodulation product will occur when m=1 and n=2, or when m=2 and n=1. The approximate bandwidth of the third-order intermodulation product is typically estimated with the following formula: ($mBW_1 + nBW_2$), where m+n=3, and where BW refers to the bandwidth of the original signals. Using these formulas, it is straightforward to confirm that there will be overlap of ordinary intermodulation signals.

For example, under the FCC's proposed band plan, a 5 MHz portion of former television channels 45 and 46 may be assigned to uplink using the frequency range 658-663 MHz. But in this scenario, television channels 39-41 would continue to operate. Television channel 39 would create intermodulation products that fall within the 577.25-593.75 MHz range; television channel 40 would create intermodulation products that fall within the 589.25-605.75 MHz range; and television channel 41 would create intermodulation products that fall within the 601.25-617.75 MHz range. Because these intermodulation products each fall within the proposed passbands for the devices, they will not be attenuated by the device filters and each can cause interference and impair device performance. Moreover, these intermodulation products *overlap* in the 589.25-593.75 MHz and 601.25-605.75 MHz ranges, and the overlapping interference is cumulative, and will thus have an even greater interference potential for adverse impacts on device performance.

These formulas also confirm that ordinary intermodulation can result in interference to the PCS downlink bands under the FCC's proposal. For example, under the FCC's proposed band plan, a 5 MHz portion of former television channel 46 may be assigned to uplink using frequency range 663-668 MHz, while television stations would continue to operate in television channels 38-44. In this scenario, television channels 38 and 39 would each mix with the 5 MHz uplink block in the 664-668 MHz range to create interference in PCS downlink bands. Television channel 38 would create intermodulation products that fall within the 1940.5-1955.5 MHz range, which overlaps with the PCS downlink. And, television channel 39 would create intermodulation products that fall within the 1946.5-1961.5 MHz range, also overlapping with the PCS downlink. Each of these intermodulation signals alone can potentially cause harmful interference and impair device performance. Moreover, these intermodulation products overlap in the 1946.5-1955.5 MHz range and are cumulative, resulting in even greater potential impairment to PCS downlink passbands.

Similar calculations show that *reverse* intermodulation signals will fall within the 600 MHz and 700 MHz downlink passbands, creating potential for harmful interference and impairment of device performance.[12] As one example, the FCC's proposed band plan provides for a 5 MHz uplink block in the 693-698 MHz range, while permitting television stations to operate in channels 38 to 49. In this scenario, signals from television channels 42 through 46 would each result in reverse intermodulation products that fall within 700 MHz downlink passbands. In aggregate, these intermodulation products would cover the 700 MHz frequency ranges from 718.5-757.5 MHz (covering the 700 MHz A, B, C, and E block downlink passbands). Moreover,

[12] The mathematical formula for identifying the center frequencies of the third order intermodulation products for reverse intermodulation is ($mf_1 \pm nf_2$), where m and n are integers, f_1 is the center frequency of the first signal and f_2 is the center frequency of the second signal. The "order" of the intermodulation product is the sum (m+n). For example, a "third order" intermodulation product will occur when m=1 and n=2, or when m=2 and n=1. The bandwidth of reverse intermodulation products is implementation-specific and difficult accurately to predict. For the purposes of simplified interference analysis, however, it can reasonably be assumed to have the same bandwidth as ordinary intermodulation.

there is overlap in the intermodulation products caused by each of television channels, and the interference caused by these overlapping intermodulation products is cumulative.

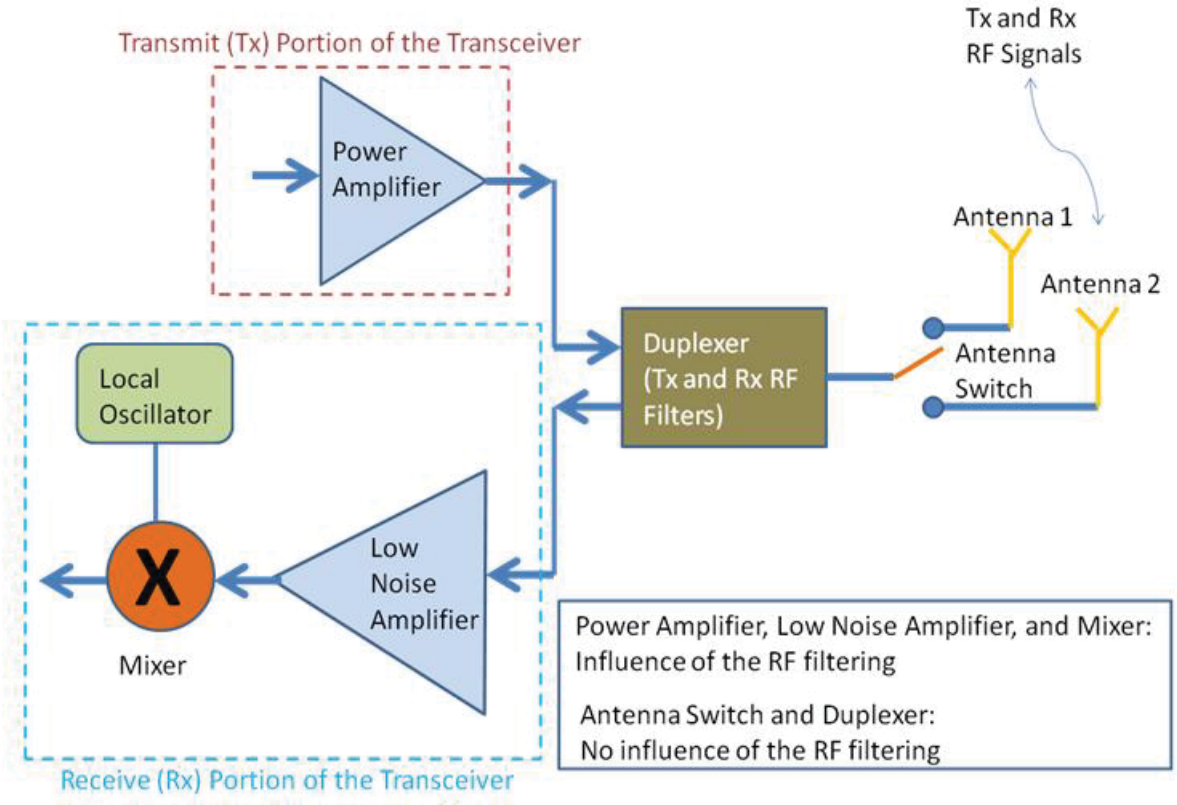
The interference to the PCS bands and 700 MHz bands will occur in devices attempting to simultaneously transmit using 600 MHz bands while receiving in the PCS or 700 MHz bands. As one example, this potential interference could impair a cellular provider's ability to use carrier aggregation techniques to use 700 MHz or PCS spectrum as supplemental downlink together with 600 MHz spectrum. We recognize that in the short term it is far more likely that carriers will seek to use PCS as supplemental downlink with 600 MHz spectrum, but future deployments may combine 600 MHz and 700 MHz spectrum as well. As another example, it is our understanding that many of Verizon's LTE dual-receiver devices today use PCS frequencies for the downlink reception of legacy 3G technologies even without carrier aggregation.

These analyses illustrate why guard band sizes used to protect against intermodulation interference in other frequency bands may not be sufficient under the FCC's band plan proposal. In these other situations, there is typically only one television station and thus one intermodulation product falling within any receive band. In this case, however, even if the guard band results in relatively low individual intermodulation signal levels, there is not just one intermodulation product to worry about – there are several, and the signal levels from these multiple intermodulation products are cumulative whenever they overlap in frequency.

It is also important to recognize that the device filters may not be able significantly to influence the strengths of some of the intermodulation products. As noted earlier, the power level of intermodulation products is positively correlated to the power level of the mixing signals, which in this case are television signals and the signals created by non-linear components of the device. If all of the non-linear components of the device were located behind the device filter, then the power level of the television station that is outside of the passband of the filter would be attenuated before mixing with the signals created by the non-linear device components, which in turn would reduce the power level of the intermodulation products.

For example, the power amplifier is a non-linear component that is located behind the device's filter, and the device's filter (*i.e.*, the transmit filter of the duplexer in the case of reverse intermodulation) therefore can be useful in attenuating the source television signal that causes such interference, thus attenuating the resulting intermodulation product. But mobile devices also contain multiple non-linear components that create intermodulation products before the RF filter has any opportunity of attenuating the TV signals. For example, the duplexer, antenna tuner, and the antenna switch, are non-linear components that are located at or in front of a mobile device's receive filter, so that the full received power of the television signal mixes with the signals created by these non-linear components. Figure 2 provides a simplified schematic of a typical device and shows the various non-linear components that are located in front of, at, or behind the device's RF filters.

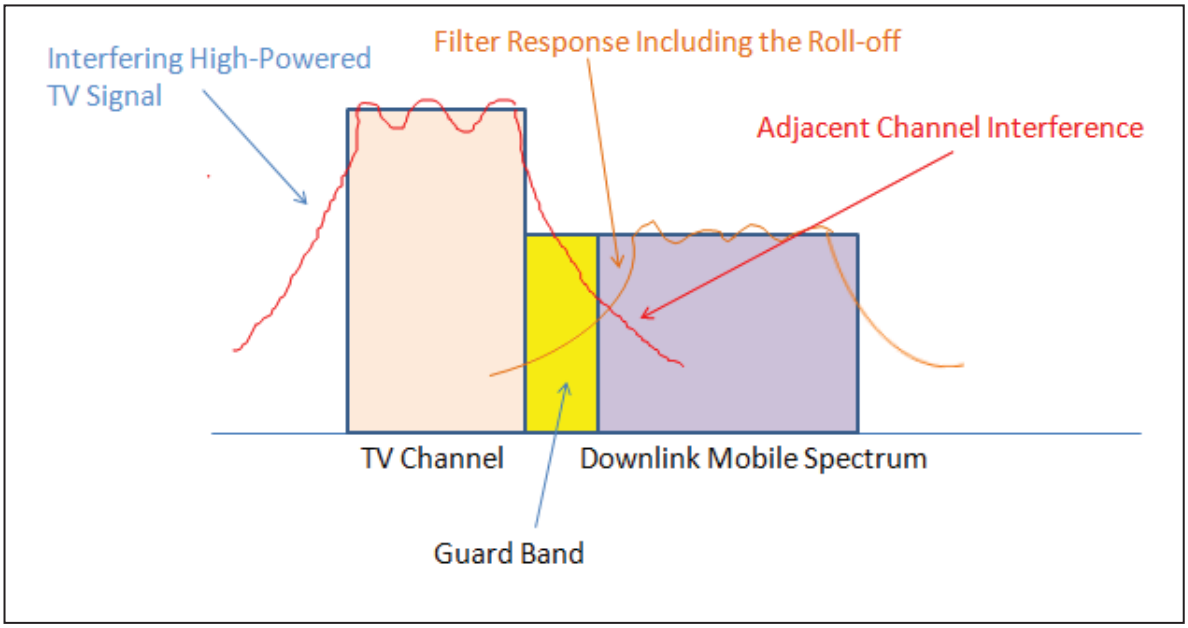
Figure 2. Examples of the Non-Linear Components Within The User Equipment Transceiver.



For all of these reasons, permitting television stations in the duplex gap has the potential to cause substantial intermodulation interference, which could result in significant reductions in effective capacity or throughput and other problems (discussed below) for 600 MHz devices, as well as for devices that use 700 MHz and PCS bands.

Adjacent Channel Interference. No filter can block all transmissions emanating from immediately adjacent frequencies. All filters experience "roll off," which means that a filter designed to block transmissions below a particular frequency (the edge of the passband) will actually achieve a gradually decreasing attenuation for frequencies closer to the passband. In other words, the filter cannot fully attenuate the transmissions immediately adjacent to the passband and those transmissions will enter the device at a relatively high level. Adjacent channel interference refers to interference that occurs when signals generated in frequencies adjacent to a mobile device's passband enter the receive side of the device. The higher the power of the adjacent transmissions, the higher the power of the adjacent channel interference. Thus, for example, high-powered television broadcasts in an immediately adjacent frequency range can cause significant interference to a mobile device. Figure 3 illustrates adjacent channel interference.

Figure 3. Receiver Blocking from the Adjacent Channel Interference.



As shown in Figure 3, signals emitted by high-powered television stations are generally concentrated in the frequencies to which they are assigned, but they also extend to adjacent frequencies at power levels that gradually diminish for frequencies that are farther away from the assigned frequencies (shown by the red line). Because filters used in mobile devices experience roll-off (the orange line), they may not be able to fully attenuate these transmissions from adjacent television transmissions. As a result, these adjacent transmissions could enter the mobile device's receive components with a relatively high signal strength and could therefore cause harmful interference.

The FCC's band plan framework attempts to reduce the potential for adjacent channel interference by creating a 6 MHz guard band (*i.e.*, Channel 37) between the frequencies used by the television stations in the duplex gap and the frequencies used by mobile devices to receive (*i.e.*, the downlink frequencies). However, under the FCC's proposed band plan framework, there would be several television stations operating in the duplex gap, each potentially transmitting at signal levels as high as 1 MW and resulting in additive adjacent channel interference to the mobile downlink frequencies. AT&T's vendors have reported that, according to their initial analyses – which are still ongoing – guard bands would have to be substantially greater than 6 MHz to adequately attenuate adjacent channel interference to avoid harmful interference from 1 MW TV transmitters.

To our knowledge, a configuration with multiple high-powered channels located in the duplex gap and transmitting simultaneously is unprecedented. In the past, we have examined whether a 6 MHz guard band is sufficient to avoid adjacent channel interference to the 700 MHz lower B and C block mobile receive frequencies from transmissions from television broadcasts from the

700 MHz E block (located in the lower 700 MHz duplex gap). But in that situation, the 700 MHz E block is authorized to transmit at maximum power levels of 50 kW.

3.1.2 Harmonics Signals From The 600 MHz Uplink Frequencies. Another central feature of the FCC's proposed band plan framework is that it would place uplink spectrum in the upper portion of the 600 MHz range, in 5 MHz blocks, starting at the highest frequency of 698 MHz and potentially extending all the way down to 614 MHz. This approach could create very significant "harmonic" interference issues. Uplink transmissions using spectrum in the 643-667 MHz frequencies (currently assigned to TV channels 42-46) create harmonics that have centers within the PCS and EBS/BRS receive frequencies used for mobile services, and thus could cause significant interference to devices that are designed to use those receive frequencies along with 600 MHz frequencies.

In particular, nonlinearities of the device components such as the power amplifier create harmonics, which are higher frequency signals that can fall within other receive bands. The formula for computing the center frequency and bandwidth of harmonic signals is straightforward. The center frequency for a third order harmonic is the center frequency of the transmission multiplied by three, and the center frequency of a fourth order harmonic is the center frequency of the transmission multiplied by four. The bandwidth (frequency range) of the third and fourth order harmonic signals are roughly the bandwidth of the original uplink signal multiplied by three and four, respectively. For example, 5 MHz uplink 658-663 MHz will produce a third order harmonic signal centered at 19381.5 MHz (PCS bands 2 and 25 downlink) with a bandwidth of about 15 MHz (1974.75-1988.25), which is within the PCS band. The fourth order harmonic for this uplink would occur at 2642 MHz with a bandwidth of 18 MHz (2633-2651), which is in EBS TDD-LTE Band 41. Note that the center of the harmonic does not need to fall within the receive frequency range to cause interference; the center of such harmonic could fall outside of the receive frequency range but could also have sufficiently large bandwidth such that it overlaps with the receive frequency range. Moreover, it is important to recognize that the harmonics caused by these uplink channels will overlap and are cumulative in their adverse impact on device performance.

As these examples show, these harmonics fall squarely within the frequencies licensed for downlink in the PCS and the EBS/BRS bands. As a result, they could cause harmful interference in devices seeking to simultaneously operate in the 600 MHz and PCS and EBS/BRS bands. As discussed further below, this interference could thus impair the ability to use carrier aggregation techniques that combine PCS downlink spectrum with 600 MHz spectrum, and this interference could impair Verizon's ability to operate dual-receiver 600 MHz spectrum with PCS spectrum (*e.g.*, as Verizon does today with 700 MHz LTE and PCS band 1x and 1xEV-DO).

Based on past experience, these harmonic signals can cause significant degradation in performance for the affected bands, even when they do not overlap and result in cumulative interference levels. A similar situation currently exists in the 700 MHz frequencies, and it has significantly reduced the achievable capacity or throughput in AWS-1 (Band 4) spectrum. According to 3GPP, the third order harmonic resulting from the 700 MHz operation causes

about a 7 dB reduction in the receiver sensitivity in devices using the AWS-1 (*i.e.,* Band 4) spectrum.[13] This reduction in receiver sensitivity directly reduces the effective signal-to-noise ratio, which reduces capacity and throughput. When faced with this issue, the 3GPP recognized that devices seeking to use lower 700 MHz frequencies simultaneously with AWS-1 would experience this interference and would be unable to satisfy the existing 3GPP specifications for AWS-1 downlink performance. As a result, the 3GPP relaxed its device specifications for such devices, so that these lower performing devices could comply with 3GPP specifications.

As was the case for the 700 MHz/AWS harmonic issue, there are significant technical and practical impediments to avoiding the harmonic interference at issue here. First, the 7 dB in desensitization recognized by the 3GPP was effectively the desensitization levels that occurred assuming some method to attenuate interference (*e.g.,* a harmonic filter). Documents presented in 3GPP suggest that absent the use of such filters or other strategies, desensitization could be much higher (*e.g.,* 20 dB).[14] Second, the addition of a harmonics filter designed to address harmonic interference in the transmitter portion of the user equipment would create insertion los*s* that would itself reduce the cell-edge reliability and uplink throughput at 600 MHz. Third, any such filter would occupy additional space, creating further constraints on device form factors and the ability to implement higher order MIMO technologies. This size issue is more challenging in the 600 MHz band than in higher frequency bands, because devices using 600 MHz will already require relatively large antennas.

3.1.3. Co-Channel Interference To Base Stations From TV Stations In Neighboring Areas. The FCC's proposed band plan framework also creates significant risk of co-channel interference to base stations caused by television stations operating in neighboring areas. An example best illustrates this concern. Suppose that the auction results in the "7 cleared" solution under the FCC's plan for "City 1," and in the "10 cleared" solution for nearby "City 2." Under the FCC's band plan, mobile providers in City 2 would be using former television channels 47-51 for mobile uplink (*i.e.,* base stations would be receiving in these frequencies). In City 1, however, television stations would continue to broadcast in television channels 48-49. To the extent these cities are in close proximity – as is the case for many cities throughout the U.S. – the television transmissions in Channels 48 and 49 will very likely cause interference to the base station receivers operating in City 2. There would be no way for the base station receivers in City 2 to filter these interfering City signals, because they are operating in the same frequencies (hence the name "co-channel interference") and they would be inside the passband of the uplink RF filter of the duplexer. As this example illustrates, the problem of co-channel interference arises under the FCC's plan because the FCC's approach uses permits the use of different uplink frequencies in adjacent geographic locations.

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[13] 3GPP 36.101, "User Equipment (UE) Radio Transmission and Reception," Release 11.

[14] R4-120442, "Way forward for inter-band CA Class A2," TSG-RAN WG4 Meeting #62, Dresden, Germany, Feb 6th – 10th, 2012.

3.1.4 Impact of Interference. At this stage it is not possible to determine the precise impact of the various forms of interference that will occur under the FCC's proposed band plan framework. However, it could be significant. This is not a situation where there is only one potential interfering signal in a mobile device receive frequency. This is a situation where there will often be many interfering signals within various mobile device receive frequencies. The intermodulation interference alone creates several overlapping interference signals within the receive frequencies of the proposed 600 MHz spectrum, as well as within the receive frequencies used by 700 MHz and PCS mobile spectrum. In addition, the harmonic interference creates additional interfering signals in the PCS frequencies, and it also creates potential interference to the EBS/BRS mobile frequencies. The potential adjacent channel interference adds to the intermodulation interference in the 600 MHz mobile receive frequencies, as does the co-channel interference. As a result of all of this interference, the FCC's plan creates a risk that the usefulness of 600 MHz, 700 MHz, PCS, and BRS/EBS mobile spectrum could be impaired.

First, and most obviously, this interference could significantly reduce the effective capacity of the 600 MHz, 700 MHz, PCS, and EBS/BRS spectrum. For example, as interference levels rise relative to the "desired" signal, more data packets will be corrupted. When the device records a corrupt data packet, the base station typically retransmits that data packet, but this retransmission uses up network resources that could otherwise have been used to send new data packets to that device or others served by the base station. Such retransmissions slow throughput as the device awaits the resent packet. Similarly, mobile devices will more often fail to receive resource allocation messages from base stations due to increased interference, which means that the mobile devices could completely miss data packets sent by the base station. The base station would have to resend the data packets and the resource allocation messages in such cases, using up additional network resources. In addition, when mobile devices send data packets to the base station, increased interference can cause the mobile device to more frequently fail to receive the needed confirmations from the base station indicating that the uplink packets were received, resulting in the devices resending the data packets to the base station, which again utilizes additional network resources and slows uplink data throughput.[15]

Second, the interference caused by the use of 600 MHz to the 700 MHz and PCS frequencies under the FCC's proposed band plan framework could significantly impair the use of 700 MHz or PCS spectrum as supplemental downlink together with 600 MHz spectrum in carrier aggregation arrangements. These carrier aggregation techniques may require the device to transmit in the 600 MHz frequencies while receiving in the 700 MHz or PCS bands. Because the 600 MHz transmissions would interfere with the 700 MHz or PCS downlink transmissions under

[15] *See*, *e.g.*, Jeffrey H. Reed and Nishith D. Tripathi, Impact of Channel 51 and E Block Interference On Band 12 and Band 17 User Equipment Receivers (June 1, 2001), attached to Comments of AT&T Services Inc., Promoting Interoperability in the 700 MHz Commercial Spectrum; Interoperability of Mobile User Equipment Across Paired Commercial Spectrum Blocks in the 700 MHz Band, WT Docket No. 12-69 (June 1, 2012).

the FCC's proposed band plan framework, service providers' ability to effectively implement these carrier aggregation techniques would be substantially impaired.

Third, it is our understanding that many of Verizon's LTE dual-receiver devices use PCS frequencies for the downlink reception of legacy 3G technologies even without carrier aggregation. Where LTE is available, these devices use LTE, but constantly monitor the legacy PCS 3G network to ensure seamless and fast handover to 3G in areas where there is an insufficient LTE signal. When a dual-receiver device is transmitting in 600 MHz LTE while observing the legacy 3G PCS network, the third order harmonic can interfere with the PCS downlink measurements and cause handover delay (or call drops if the handover delay is excessive) as the device travels from the LTE coverage area to a 3G-only coverage area. In addition, we understand that dual-transceiver devices offered by Verizon (such as the HTC ThunderBolt, which can simultaneously operate on the 700 MHz LTE band and a legacy 3G band) may be configured to permit data communications using 600 MHz spectrum while simultaneously permitting voice communications using PCS spectrum. In these instances, harmonics from the 600 MHz spectrum could interfere with the device's ability to obtain or maintain voice connections using PCS spectrum.

Fourth, the potential interference caused by the use of 600 MHz to the 700 MHz, PCS, and EBS/BRS frequencies could, in certain circumstances, impede seamless roaming from LTE networks using 600 MHz frequencies to networks using 700 MHz, PCS and EBS/BRS downlink frequencies (*e.g.,* where 700 MHz, PCS, or EBS/BRS bands are used as supplemental downlink with 600 MHz spectrum). In a typical roaming transition, as a dual-receiver device using 600 MHz spectrum reaches the edge of 600 MHz coverage, it observes the downlink signals transmitted by the adjacent network to manage seamless mobility between the two networks. But when a dual-receiver device is transmitting on the 600 MHz spectrum, the interference to the 700 MHz, PCS, and EBS/BRS downlink bands may impede the device's ability to receive signals from an adjacent network using those frequencies. As a result, the roaming transition may not take place seamlessly and can result in decreased throughput or dropped connections.

3.1.5 Mitigating Interference. It should go without saying that the FCC should avoid adopting any band plan framework that would, at the outset, require licensees to implement significant interference mitigation measures in order to use that spectrum. Such an approach would create enormous uncertainty that could threaten the success of the auctions, because it is not at all clear at this stage whether and to what extent the interference concerns at issue can be mitigated, or how much any such mitigation mechanism would cost. The band plan framework itself should eliminate as many interference concerns as possible while meeting the FCC's overall policy goals.

In any event, mitigating the interference concerns created by the FCC's proposed band plan presents unique challenges and in many instances may not be technically or practically achievable. As to the existence of television stations in the duplex gaps, we have already explained that the guard bands used for other spectrum bands are unlikely to be sufficient to avoid interference for the 600 MHz frequencies. Similarly, we have already explained that

additional filters to combat the harmonics may not fully address the interference concerns and would cause their own performance problems (*e.g.,* insertion loss), and they may be impractical to implement in small form factor devices.

It has been suggested in other FCC proceedings that interference from television stations can be avoided by collocating LTE base stations at the television station transmitter. The theory behind this approach is that the intermodulation products and blocking signals are greatest – and most likely to cause harmful interference – when devices are closer to the television station, and that by collocating an LTE base station at the television transmitter, the LTE signal would be sufficiently high to overcome such interference. There are numerous problems with this "collocation" approach. As an initial matter, it is not necessarily true that television signals are strongest right near the transmitter. Rather, television stations are designed to transmit signals over long distances, and thus typically direct transmissions towards the horizon. As such, television signals are often strongest at some distance away from the transmitter. As a result, collocating an LTE base station at the television transmitter will not entirely eliminate interference. Rather, LTE base stations would have to be placed such that the LTE signal level is high when the television signal levels are high. But it is not possible to know prior to the auction precisely where these circumstances will occur, and whether locations for base stations in those areas will be available.

Moreover, there are multiple practical impediments to the deployment of base stations. RF network planning and design, which is a non-trivial matter, would need to be done for each newly added LTE cell site and modified for existing LTE cell sites. RF design modification is an iterative process. Implementation of the modified RF design would consume significant engineering and non-engineering human resources, and would delay the ability to deploy such interference mitigation measures.

After the initial RF design that reflects interference caused by television stations is done, it would be necessary to determine whether the new cell site locations recommended by the RF design process could actually be used to deploy eNodeBs (*i.e.,* LTE base stations). In general, the places where new cell sites could be of help will have very specific locations. Given the very specific locations where cell sites would be needed, in many instances a suitable location for a new cell site may not be available. And, even where new cell sites are available, it can take many months and sometimes years to make a new cell site operational due to factors such as requirements for zoning approvals, leaving the interference from television stations unaddressed for a significant period of time.[16]

Placing new television interference mitigation constraints on the RF design would further restrict the degrees of freedom to tune the network to achieve optimal LTE performance. Network optimization is a critical component in the lifecycle of a cellular technology. Network

[16] *See*, *e.g.*, Comments of AT&T, Acceleration of Broadband Deployment: Expanding the Reach and Reducing the Cost of Broadband Deployment by Improving Policies Regarding Public Rights of Way and Wireless Facilities Siting, WC Docket No. 11-59 (July 18, 2011).

optimization leads to enhanced network performance and user experience, as well as lower cost. Example mechanisms to optimize the RF performance include changes in antenna-related parameters (*e.g.,* tilt, azimuth, beamwidth, and antenna height), changes in configuration parameters (*e.g.*, Physical Cell Identities), and operational parameters (*e.g.*, handover and power control parameters). RF optimization is already limited by LTE constraints such as the amount of intra-LTE interference. Modifying antenna parameters and other network characteristics to overcome interference from television stations would very likely degrade the LTE network performance in numerous cell sites and not just the first tier of LTE cell sites surrounding the television stations. For example, when the LTE antenna azimuth is changed to focus more energy toward the area with strong interference from a television station, it may create coverage holes in the existing LTE network, reducing the network throughput and user throughput in multiple cell sites.

Finally, as to the separate interference issue relating to harmful interference to the downlink spectrum in the newly allocated 600 MHz bands and in the existing downlink PCS bands and EBS/BRS bands, we have already explained why interference mitigation is not possible. This interference is created within the handset, so there is no escaping it.

3.2. Implementation Issues.

The FCC's lead band plan framework proposal also raises significant implementation concerns, both in terms of practicality and in terms of spectral efficiency. The FCC's proposed band plan framework effectively maximizes the size of the antennas that will be needed within devices and at base stations, and further may require the use of additional antennas. This need for larger and additional antennas raises several issues. First, it can make it more difficult for device manufacturers to maintain the small, thin form factors that customers clearly prefer. Second, it raises significant engineering issues for placement of antennas at base stations in terms of weight and wind loading, and these issues are particularly important as providers are increasingly seeking to deploy small cells on smaller structures that are closer to street level, such as lampposts and traffic signals. Third, larger and more antennas make it more difficult to exploit the benefits of MIMO and other technologies that permit significant increases in the efficiency with which spectrum can be utilized, but that usually require *two or more antennas* to be placed within the device with at least a certain minimum amount of separation.

There are two features of the FCC's lead band plan framework proposal that significantly increase the size of the antennas that would have to be used to support the added 600 MHz spectrum bands: (1) the use of very low frequencies; and (2) the use of a very wide range of frequencies in the 600 MHz range.

3.2.1. The Use Of Very Low Frequencies. The size of the antenna used within the mobile devices and at base stations needed to maintain desired gain levels is inversely proportional to the frequency being used.[17] That is, to maintain a given gain level, antennas must be larger for

[17] Gain reflects the ability of the antenna to capture the RF energy. The antenna gain is bi-directional and is specified relative to a reference antenna such as a theoretical isotropic

lower frequency spectrum than for higher frequency spectrum. These size limitations are governed by the physics of wireless engineering. For example, one form of antenna can be viewed as the linear array of half-wave dipoles (*i.e.,* half-wavelength dipole antennas). The more dipole antennas composing the array, the higher the overall antenna gain (and directionality). Simultaneous transmission of signals on multiple dipoles results in more electric energy in a given direction, leading to the greater effective antenna gain compared to a single dipole. The size (*i.e.,* length) of each half-wave dipole is one half the wavelength of the RF signal. The wavelength λ of the RF signal is related to the carrier frequency f_c and c (the speed of light), $\lambda = c / f_c$. Thus, for example, at f_c=614 MHz (just above Channel 37), the dipole has the length of 0.215 m (or 215 mm) and at f_c=570 MHz (Channel 27), the dipole has a length of 0.263 m, or 263 mm. In other words, the antenna for the 570 MHz frequency must be 22 percent longer than the one for 614 MHz. The same principles apply to the device antenna sizes. Antennas used in devices operate at much lower gain levels, and they use additional equipment and technology to increase gain and efficiency using a very small antenna. However, to achieve a given level of gain, a longer antenna is still needed for lower frequency devices, for the reasons explained above.

For these reasons, when lower frequency spectrum is incorporated into a mobile network, either the size of the antennas used in the devices and at the base stations must be increased, or the efficiency of the antennas must be compromised (resulting in less coverage and capacity all else being equal).

3.2.2. The Use Of A Wide Frequency Range. The size of the antenna is also a function of the range of frequencies that the antenna must cover. The larger the range of frequencies that the antenna must cover, the larger the antenna needs to be to maintain desired gain levels. The efficiency of an antenna of a given size is often measured in terms of its "radiation Q factor" or "Q_{rad}." Q_{rad} is always proportional to f_c/BW_{3dB}, where f_c is the center frequency and BW_{3dB} is the 3dB bandwidth of the antenna.[18] As this formula illustrates, when bandwidth (BW) increases, the radiation Q factor falls, thus reducing the efficiency of the antenna. To increase efficiency, a larger antenna is required, as shown by the work of Davis, *et al.* [19] As demonstrated by Davis, *et. al.*, the minimum Q_{rad} ("Q^{min}_{rad}") is equal to $P_{rad} / (P_{in} a^3 k^3)$, where "P_{rad}" is the power radiated, "P_{in}" is the antenna input power, "k" is the wave number (defined as $2\pi/\lambda$), and "*a*" is the radius of a sphere that just encloses the antenna. Note from the formula that a requirement to support an increased 3dB bandwidth means an increase in the size of the antenna ("*a*") if all other factors such as the target radiation efficiency remain the same. Hence according to this formula that bounds antenna size and performance, a larger antenna is a fundamental necessity if the bandwidth requirement is increased.

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antenna or a practical dipole antenna. If the antenna gain is 12 dB, the signal transmitted by the antenna and the signal received by the antenna experience 12 dB gain.

[18] Davis, W.A., Yang, T., Caswell, E.D., and Stutzman, W.L., "Fundamental limits on antenna size: A new limit," *IET Microwaves, Antennas and Propagation*, 2011, Issue 5, pp. 1297-1302.

[19] Davis, *et. al.,* pp. 1297-1302.

3.2.3. Practical Implementation Issues Caused by The Need For Larger Antennas. The larger device and base station antennas that would be needed under the FCC's lead band plan framework proposal create practical implementation issues. First, the need for larger device antennas affects device form factors and performance. Customers clearly prefer devices to be smaller and thinner. A band plan that requires the use of lower spectrum frequencies than necessary means that devices must choose one of the following approaches: (1) incorporate larger antennas and possibly more antennas resulting in larger devices; (2) incorporate much larger antennas and possibly more antennas while reducing the size of the battery or other device components resulting in reduced device performance or fewer features; or (3) incorporate smaller and/or fewer antennas that provide less gain resulting in decreased device performance.

Second, the need for larger base station antennas may create significant engineering challenges. As noted, to maintain the same gain levels, the base station antenna would need to be larger than the largest existing antenna. It may not be feasible to place these larger antennas on existing towers and structures for many reasons. For example, they may not fit, they may be too heavy, and their increased sizes may increase wind loading. For these same reasons, larger base station antennas may limit the locations where new antennas can be placed, particularly in urban areas where they are most needed.

Third, the need to place larger antennas in devices and on base stations creates additional potential challenges to exploiting MIMO and other antenna technologies, which provides for significant increases in spectrum efficiency. The need for larger antennas for 600 MHz devices would make it much more difficult to implement higher-order MIMO in these devices. With larger antenna sizes, it will be more difficult to place two of them in a device. Moreover, with larger antennas it will be difficult to obtain sufficient spacing needed between the antennas for MIMO to work well. The MIMO technique of spatial multiplexing (also called single user MIMO or SU-MIMO in LTE) relies upon the antennas seeing different propagation channels to extract different information traveling on the same radio sources. The more dissimilar the received signals are at the antennas, the lower the cross-correlation between signals at these antennas, and the easier it is for the receiver to successfully retrieve the information. The closer together the antennas are, the higher the cross-correlation, resulting in less efficiency. Thus, larger antennas in the same small device space make it less likely to achieve the desired degree of cross-correlation between the antennas to achieve substantial efficiencies.

3.3. International Harmonization.

Another concern we have with the FCC's proposed band plan is that it creates significant challenges for international harmonization. As we explained above, certain features of the FCC's band plan – and particularly the very large duplex gap where high-powered television stations will be permitted to operate – are highly unusual and can result in harmful interference. As a result of these unusual features, it is less likely that other countries will adopt the same band plan to the extent they also deploy 600 MHz spectrum for mobile use,

and U.S. providers and customers would thus fail to achieve the benefits of such future harmonization.

4. An Alternative Approach To A Band Plan Framework.

In our opinion, the interference concerns associated with the FCC's proposed band plan framework can largely be avoided by adherence to a simple set of core band plan principles that represent relatively modest changes to the FCC's proposal and would still promote – and indeed improve upon – the goals the FCC enumerates in the NPRM: "utility, certainty, interchangeability, quantity, and interoperability."[20] In this section, we describe these core principles. In addition, we discuss an example of a band plan framework that conforms to these core principles to illustrate how these principles could be implemented. We acknowledge, however, that the band plan issues are complex, and that AT&T and other industry participants are continuing to study various aspects of improved frameworks. We look forward to continuing to work together with the Commission and the industry to design an improved framework that will avoid the interference and implementation risks inherent in the NPRM's proposal.

4.1. Core Principles For An Improved Band Plan Framework.

Based on our analysis of the FCC's band plan and discussions with AT&T's engineers (who were further informed by discussions with numerous other industry participants), we agree that the most efficient use of 600 MHz spectrum that best satisfies the Commission's policy goals would follow certain core principles. We emphasize that these issues are extremely complex and that the specifics of how best to implement these principles are subject to ongoing analyses by AT&T's engineers, as well by various other industry participants, including Qualcomm, Ericsson, Alcatel-Lucent, Avago, Intel, Verizon, RIM, and others. In this section, we describe these fundamental principles, explain their importance to an efficient 600 MHz band plan framework, and identify the issues that are still subject to significant ongoing analyses.

1. 5 MHz Blocks. Spectrum should be auctioned in 5 MHz blocks. The Commission correctly points out that legacy mobile wireless technology relies on 5 MHz blocks, and that various globally-standardized technologies, including Wideband-Code Division Multiple Access (W-CDMA), High Speed Packet Access (HSPA), and their variants use 5x5 MHz paired blocks when deployed using Frequency Division Duplex ("FDD") technologies.[21] Moreover, 5x5 MHz blocks are compatible with current and future varieties of LTE services.[22] Allocating spectrum in 5 MHz blocks also permits bidders to seek to accumulate 10 MHz or 20 MHz of paired spectrum, which are the ideal spectrum blocks for currently deployed LTE systems.

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[20] Notice of Proposed Rulemaking, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, Docket No. 12-268, ¶ 125 (rel. Oct. 2, 2012) ("NPRM").

[21] NPRM, ¶ 127.

[22] NPRM, ¶ 127.

2. Paired Spectrum. The FCC's lead band plan framework proposal correctly recognizes that one of the most efficient ways to deploy 600 MHz spectrum for mobile services is as paired spectrum using LTE technology.[23] We agree. The 600 MHz band plan framework should seek to incorporate significant amounts of paired spectrum, even in areas where a relatively small number of television station frequencies are re-allocated for mobile use. At the same time, however, it is important that the band plan framework balance the benefits of paired spectrum against the harms of adding uplink spectrum in certain 600 MHz frequency ranges that can cause significant interference. As we demonstrated above, 25 MHz of spectrum is effectively available for uplink in the 600 MHz frequencies above channel 37 (specifically, the frequencies currently used for television channels 47-51), because use of the remaining frequencies (television channels 38-48) for uplink would create interference caused by intermodulation and harmonics that could impair the capacity and throughput of 600 MHz spectrum, as well as 700 MHz, PCS and EBS/BRS spectrum. The FCC should thus endeavor to adopt a 600 MHz band framework that maximizes the availability of paired spectrum, but not at the expense of causing significant interference to the 600 MHz downlink frequencies, and to other downlink frequencies.

3. Geographic Uniformity For Downlink Bands. The FCC's band plan framework proposal also correctly recognizes that any workable band plan must be based on uniform blocks of downlink spectrum that are consistent across geographic areas. That is, the band plan framework should seek to make the same 600 MHz downlink bands available in the maximum number of areas. As explained above, this characteristic of a band plan framework is critical to ensuring that devices that rely on a particular downlink band will be free from interference when the user travels to areas where smaller amounts of 600 MHz spectrum have been relinquished for mobile services.

4. Minimize Interference To Mobile Services From Television Stations & No Television Stations In The Duplex Gap. As discussed above, the very high powered broadcasts from television stations – as high as 1 MW – can potentially cause significant interference to mobile services when television stations operate in frequencies near the uplink or downlink frequencies used by mobile services. Thus, a core principle of any 600 MHz band plan framework must be to seek maximum separation between the frequencies used for mobile services and those used for television stations.

There are two important corollaries to this important principle that any 600 MHz band plan should seek to accomplish.

First, the band plan should not place television stations in the duplex gap for mobile services. As we have shown, the placement of television stations in the duplex gap effectively maximizes the potential for harmful interference through intermodulation and adjacent channel interference.

[23] NPRM, ¶ 132.

Second, the band plan should include adequate guard bands between television spectrum and mobile spectrum that minimize the potential for intermodulation, reverse intermodulation, and adjacent channel interference. Based on discussions with AT&T engineers and input from Qualcomm, Ericsson, Avago, and others, it appears at this preliminary stage that a guard band of as much as 14 MHz would be needed between frequencies used for 1 MW television broadcasts and frequencies used for mobile downlink, and that a guard band of as much as 6 MHz would be needed between a 1 MW television station and mobile uplink spectrum. We emphasize, however, that analysis of the proper guard band sizes is ongoing.

In addition, we note that one additional way to minimize interference from television stations would be to ensure that the television stations located adjacent to guard bands (or in the duplex gap, if the FCC chooses a band plan that includes television stations in the duplex gap) transmit at power levels well below 1 MW. We are not suggesting that any television station should be required to reduce its power level. Instead, we suggest that to the extent that some television stations are already broadcasting at a relatively low power level, the FCC should place such television stations adjacent to the guard bands at the "repacking" stage. We understand that even in top 30 television markets, there are currently television stations operating at power levels significantly below 1 MW.

5. Reasonably sized duplex gap. As we discussed above, larger duplex gaps create significant implementation issues by increasing the overall bandwidth that must be covered by mobile devices' antennas, and by forcing devices to operate in lower frequencies with larger antennas. To address this issue, another core principle of any band plan should be to use duplex gaps that minimize the overall frequency range that must be covered by 600 MHz devices, and that confine the spectrum allocated to mobile services to the highest possible frequencies. The most efficient size of the duplex gap depends on a number of factors, including the potential uses to which the spectrum in the duplex gap may be applied. Technical analyses of the most efficient size of the duplex gap are ongoing. At this stage, it appears that the most efficient duplex gap will fall within the 10 MHz to 14 MHz range, depending on a number of factors that are still being studied by AT&T and others in the industry.

6. Focus on Spectrum Above Channel 37. As shown above, deployment of networks that use very low frequency spectrum, and that seek to cover a very large range of frequencies within the 600 MHz band, raises significant practical challenges. To minimize these challenges, the band plan framework for the 600 MHz band should allocate higher frequency spectrum in the 600 MHz band – especially the frequencies above television Channel 37 – to mobile services whenever possible, and then deploy lower frequency spectrum only after the higher frequency spectrum has been allocated.

7. Efficient Use Of Spectrum In The Duplex Gap & Guard Bands. The band plan framework should ensure that the duplex gap and guard bands are used efficiently. There are a number of possible uses for the spectrum allocated to guard bands and the duplex gaps. For example, it may be possible for spectrum in the duplex gap to be used for unlicensed services, although any such uses must be limited to uses that would not interfere with the licensed use of adjacent

spectrum. Alternatively, the spectrum in the duplex gap could be used to develop a supplemental downlink band (much like the E block in the 700 MHz spectrum duplex gap). Whether the duplex gap and guard bands should be allocated for such purposes depends mainly on the extent to which doing so would cause interference or otherwise prevent providers from using 600 MHz spectrum efficiently for mobile services. We understand that AT&T and others in the industry are in the process of examining these issues. It is thus unclear at this stage whether the most efficient use of the duplex gap(s) and guard bands is to leave them empty (thus ensuring no interference with mobile services) or whether this spectrum can be put to use in a manner that would not significantly impair the efficient use of 600 MHz spectrum for mobile use.

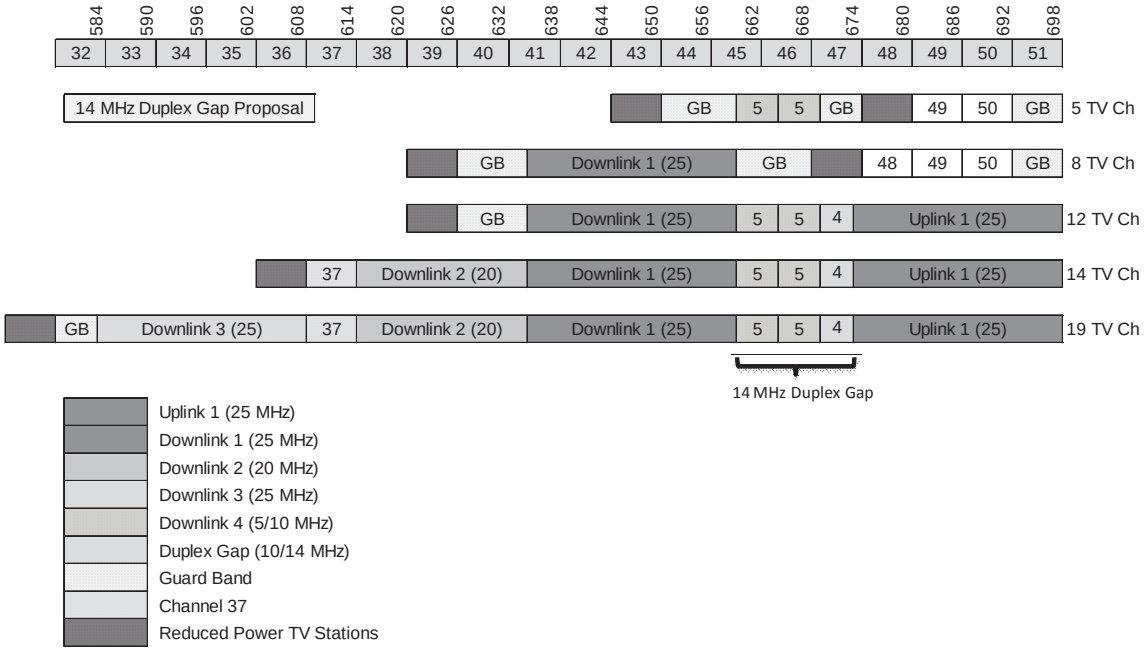
8. International Harmonization. Another core principle should be to adopt a band plan that can be feasibly adopted by other countries to achieve the benefits of global harmonization. The unusual features of the FCC's proposed band (*e.g.*, large duplex gap with television stations operating within it) make it far less likely that other countries will adopt that band plan. An approach that follows the principles set forth herein, however, is much more likely to be adopted by other countries.

9. Channel 37. Channel 37 is used for receive-only radio astronomy observations and for wireless medical telemetry service ("WMTS"). Radio astronomy involves the reception of radio waves of cosmic origin to facilitate scientific research about the universe. Medical telemetry equipment is used in hospitals and health care facilities to transmit potentially life-critical patient measurement data, such as pulse and respiration rates, to a nearby receiver. Due to the large installed base of Channel 37 devices, we understand that Channel 37 will likely remain in place. Although there is potential for mobile broadband services in adjacent frequencies to interfere with Channel 37 devices – just as there is potential today for adjacent television broadcasts to interfere with Channel 37 – we understand that, under the FCC's rules, Channel 37 licensees are secondary users and thus must accept any interference from transmissions in adjacent frequencies. We also understand that Channel 37 users have multiple alternatives to address interference from nearby transmissions, including, for example, choosing different radio channels within television channel 37 spectrum, and using other channels allocated for WMTS and medical telemetry. The FCC should provide certainty that mobile providers will be permitted full use of any spectrum that is obtained at auction and that is adjacent to Channel 37. Accordingly, another core principle for the band plan framework should be to permit existing operations in television channel 37 to continue, but with no new interference protections from licensed mobile providers that may seek to operate in adjacent frequencies.

4.2. An Illustrative Example Of A Band Plan Framework That Follows The Core Principles.

In this section we present an example developed by AT&T's engineers that illustrates one possible approach to a band plan framework that complies with the core principles set forth above. This approach is summarized in Figure 4.

Figure 4. Illustrative Band Plan Framework.



In this example band plan, there would be 25x25 MHz band of paired spectrum – allocated in 5 MHz blocks – available for auction in every area where clearing, reclaiming of the current white space, and repacking produces at least 72 MHz of spectrum (*i.e.,* the equivalent of 12 television stations) for mobile services. The uplink spectrum would be located in the 673-697 MHz frequency range (formerly occupied by television channels 47-51). There is no need for a guard band between these uplink frequencies and the adjacent 700 MHz A block frequencies (698-704 MHz) because interference is extremely unlikely to occur. The paired downlink spectrum would be located in the 634-658 MHz range, formerly occupied by television channels 41-45. The duplex gap in this example would be 14 MHz in the 659-672 MHz frequency range. There would also be a need for a guard band between the lower edge of the downlink frequencies and the adjacent television station located at Channel 39. The guard band here would be 8 MHz in the 626-633 MHz range (*i.e.,* former television channels 40 and 41). An additional 25 MHz for supplemental downlink could be added below Channel 37 in areas in which at least 114 MHz of spectrum is made available (19 television stations) for mobile services, and more supplemental downlink bands could be added in areas where even more spectrum becomes available.

In areas where the auction yields less than 72 MHz of spectrum for reallocation, this example band plan framework would still make a significant amount of spectrum available for mobile services, although it would not be paired. If at least 42 MHz of spectrum (*i.e.,* eight television channels) is made available for mobile use, the band plan would include the same 25 MHz of downlink spectrum that would be available in areas where 72 MHz or more spectrum is made available. If only 30 to 41 MHz of spectrum is made available, this example band plan would make 10 MHz of spectrum available for auction, which would require its own passband.

This example illustrates how following the core principles described above eliminates or significantly reduces the interference and practical implementation concerns associated with the FCC's proposed band plan framework. There are no television stations in the duplex gap to cause intermodulation interference and adjacent channel interference. There are no mobile uplink blocks assigned to the frequencies below 667 MHz that would cause harmonics that interfere with PCS and BRS/EBS bands. There is geographic uniformity for uplink spectrum, which reduces the potential for co-channel interference.[24] This example plan also reduces the practical implementation challenges associated with the use of low band spectrum, because the paired spectrum is located in the higher frequencies of the 600 MHz band, and the more compressed band plan reduces the overall bandwidth devices seeking to use 600 MHz frequencies must cover. For example, under this example plan, a device would need to cover only 84 MHz to access all of the paired spectrum and the first supplemental downlink spectrum, whereas the FCC's plan would require the same device to cover 132 MHz.

In addition, the example demonstrates how adherence to these core principles can result in more paired spectrum in important scenarios. For example, in areas where 72 MHz of spectrum formerly used for television services are allocated for mobile use, the illustrative band plan presented here produces 25 MHz of paired spectrum, whereas the FCC's proposed band plan would produce only 15 MHz of paired spectrum and would suffer from all of the interference and practical implementation issues discussed above.

Reallocating the spectrum in this manner also demonstrates that the FCC could further minimize the potential for interference through the process of repacking television stations. If the FCC places television stations that are operating at relatively low power next to the guard bands, the potential for adjacent channel interference and intermodulation interference can theoretically be substantially reduced. Such repacking would also permit the use of smaller guard bands than would otherwise be needed, thus freeing additional spectrum for mobile services.

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[24] Co-channel interference might still occur under this approach, but it would be much rarer than under the FCC's proposed band plan framework. Whereas co-channel interference is likely under the FCC's proposed band plan framework in virtually every situation where there are different amounts of clearing in adjacent areas, it could potentially occur under AT&T's plan only where areas with 12 or more stations cleared are adjacent to areas where fewer than 12 are cleared.

This example is merely illustrative of the type of alternative band plan the FCC should consider, and there are additional features that AT&T and other industry participants are examining that could potentially be added to the ultimate band plan framework, depending on whether further investigation confirms their viability. One such feature, which is illustrated in this example, is the use of spectrum in the duplex gap for additional supplemental downlink, which would further increase the efficiency with which 600 MHz spectrum can be allocated for mobile use. Although it is unclear at this stage whether such an approach could be implemented without causing interference to the adjacent uplink and downlink frequencies, the example shows how such an approach might be implemented. In this example, the FCC could make available an additional 10 MHz of unpaired spectrum that could be used for supplemental downlink in the duplex gap.

There are also other potential ways to allocate the cleared spectrum, particularly in those markets in which less than 72 MHz of spectrum becomes available for mobile use. For example, if only 54 MHz of spectrum is made available for mobile use, the band plan could include a single 5 x 5 MHz set of paired spectrum blocks,[25] and if 60 MHz of spectrum becomes available, the band plan could include 10 x 10 MHz of paired spectrum.[26] In these scenarios, however, television stations would exist in the duplex gap, creating potential for harmful intermodulation interference and adjacent channel interference. Such a band plan would also increase the likelihood of co-channel interference where there is an area with 72 MHz or more cleared spectrum that is adjacent to an area with less than 72 MHz (but at least 54 MHz) of cleared spectrum.

Similarly, if further investigation determines that providers can operate with a duplex gap smaller than 14 MHz, the band plan could be designed with a 12 MHz or 10 MHz duplex gap, which would leave room to provide paired spectrum in areas where as little as 48 MHz of

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[25] In particular, where 54 MHz is available, the band plan would include: (1) 5 MHz uplink channel placed from 693-697 MHz (former Channel 51); (2) a 7 MHz guard band from 686-692 MHz; (3) television stations in channels 47-49 (668-686 MHz); (4) a 9 MHz guard band from 559-667 MHz; (4) the same 25 MHz downlink assigned for above-72 MHz scenarios (634-658 MHz), with one block paired with the 5 MHz uplink; and (5) an 8 MHz guard band from 626-633 MHz. Where 60 MHz are available, the band plan would include (1) two 5 MHz uplink channels placed from 688-697 MHz (former Channel 51); (2) an 8 MHz guard band from 680-687 MHz; (3) television stations in channels 47-48 (668-680 MHz); (4) a 9 MHz guard band from 559-667 MHz; (4) the same 25 MHz downlink assigned for above-72 MHz scenarios (634-658 MHz), with two blocks paired with the two 5 MHz uplink blocks; and (5) an 8 MHz guard band from 626-633 MHz.

[26] In particular, the band plan would include: (1) 5 MHz uplink channel placed from 693-698 MHz (former Channel 51); (2) a 7 MHz guard band from 686-692 MHz; (3) television stations in channels 47-49 (668-686 MHz); (4) a 9 MHz guard band from 559-667 MHz; (4) the same 25 MHz downlink assigned for above-72 MHz scenarios (634-658 MHz), with one block paired with the 5 MHz uplink; and (5) an 8 MHz guard band from 626-633 MHz.

spectrum is cleared. The additional spectrum obtained from the smaller duplex gap could also be used to provide guard band protection for Channel 37.

In addition, we understand that the industry is conducting an ongoing feasibility analysis as to whether spectrum below Channel 37 could be used as uplink spectrum (rather than supplemental downlink spectrum) and paired with the 20 MHz of supplemental downlink just above Channel 37 shown in our illustrative example.

5. Auction Issues.

For a successful auction to occur, the FCC must ensure that spectrum is divided into categories, such that characteristics of the spectrum within each category are known, so that prospective bidders may confidently develop bids for spectrum in each category, even if they do not know the precise spectrum that will ultimately be allocated to them. Moreover, to ensure that 600 MHz spectrum can be deployed most efficiently, it is important that 600 MHz spectrum be allocated in a manner that provides for both vertical contiguity (*i.e.,* successful bidders should be allocated blocks of spectrum in adjacent frequencies to the extent possible) and horizontal contiguity (*i.e.* successful bidders should be allocated the same frequencies for adjacent geographic areas).

5.1. Interchangeable Spectrum Within Each Category. The FCC will not know in advance of the auction how much (or which) spectrum will be available for allocation to successful bidders. As a result, it will be critical for the FCC to ensure, to the maximum extent feasible, that the categories of spectrum that are offered at auction are truly interchangeable so that potential bidders can make informed decisions. If bidders believe that certain spectrum in a category will be less useful for the provision of mobile services, then bidders will have to hedge their bids (or choose not to bid) to account for the fact that they may ultimately be allocated this less desirable spectrum. To maximize interchangeability, there are certain issues that the FCC should consider as it continues to develop a 600 MHz band plan framework.

Adjacent Channel Interference. The FCC should minimize the potential for adjacent channel interference. As we explained above, whenever there are broadcasts in channels adjacent to those used to receive mobile services (either at the base station or at the device), there is the potential for the adjacent signal to interfere with mobile service reception, which can reduce the capacity and throughput for the mobile network, and result in lost connections. Adjacent channel interference will adversely affect the frequencies located closer to the edge of a band more than those towards the middle of the band, because the frequencies located closer to the edge of the band are nearer (in frequency) to the interfering signals. Thus, where adjacent channel interference occurs, it will tend to make the spectrum blocks near the edge of the band less valuable than those towards the middle. A real world example of this phenomenon is the lower 700 MHz uplink frequencies, comprised of the A, B, and C blocks. Because the A block is located immediately adjacent to television channel 51, the A block uplink is subject to substantial interference from Channel 51, which makes it less useful for mobile services than the B and C blocks.

To minimize the potential for adjacent channel interference the FCC should focus on two issues. First, as discussed in detail above, the FCC should ensure that the 600 MHz band plan framework includes guard bands between mobile bands and adjacent television broadcasts that are sufficient to minimize adjacent channel interference. Second, to the extent the FCC permits unlicensed use in guard band frequencies, it should ensure that the permissible power levels for such unlicensed use are sufficiently low to avoid adjacent channel interference.

Intermodulation Interference. As we explained above, permitting television stations to operate in the 600 MHz duplex gap(s) or other nearby 600 MHz uplink and downlink frequencies can result in intermodulation products that fall within the 600 MHz downlink frequencies, thus causing harmful interference to these downlink frequencies. When this occurs, the affected downlink blocks will be less valuable than the downlink blocks where no such intermodulation interference is occurring. In this case, to the extent bidders do not know which downlink blocks they will ultimately be allocated, they will likely hedge their bids to account for the fact that the downlink blocks they receive may be subject to intermodulation interference. To make matters worse, the precise location and power levels of the intermodulation products can be very difficult to predict, which would create further uncertainty and increase incentives to hedge bids on spectrum where such interference is possible.

We discussed ways to avoid intermodulation interference above. In particular, the FCC should seek to avoid placing television stations in frequencies where they would likely produce such interference. That is, the FCC should seek to place television stations as far away from mobile uplink bands as possible, and if television stations are placed near mobile uplink bands, the FCC should ensure that there is a guard band that is large enough to at least minimize the potential for intermodulation interference. Furthermore, avoiding placement of TV channels in the duplex gap will make the downlink subject to interference from one side instead of both sides. The FCC could also seek to ensure that television stations operating at relatively low power are placed near guard bands adjacent to the frequencies used for mobile services.

Properly Sized Passbands. The passband size refers to the frequency range that will be covered by a duplexer in a mobile device. The FCC correctly recognizes that there are technological limitations to the maximum (efficient) size of the passband, and that this limitation tends to be in the range of about 4 percent of the center frequency being used. For spectrum in the 600 MHz ranges, this translates into maximum passband sizes of about 25 MHz.

To maximize the efficient use of spectrum, the FCC should adopt passbands that do not exceed these levels. As discussed above, a key feature of any successful band plan will be to maximize the number of uniform downlink bands of the same size that can be used in every geographic area. Increasing the band size will make it more difficult to reach this goal, because it is less likely that the auction process will produce enough spectrum to create larger bands in every geographic area.

Larger band sizes also create significant challenges in areas of the U.S. near the border with Canada and Mexico, which include some very large metropolitan areas. As in the U.S. today, there are numerous televisions stations in Canada and Mexico operating in the 600 MHz

frequencies, and many of these television stations transmit in locations near the U.S. border, including large U.S. cities such as Detroit, San Diego and San Antonio. These Canadian and Mexican television stations are operating in the same frequencies that the FCC is proposing to make available for mobile use in the U.S. There are thus likely to be many areas near the Canadian and Mexican borders, including in highly populated urban areas, where U.S. mobile providers will not be able to use certain spectrum 600 MHz spectrum blocks for mobile services.

The potential for cross-border interference is another reason why the FCC should adopt a framework that accommodates smaller passbands, rather than larger ones. For example, consider a 40 MHz passband in which the top 6 MHz of spectrum are being used by a Canadian television station with a signal that covers Detroit. Even if the device is transmitting and receiving using other frequencies within that passband, the device will still be open to the cross-border television broadcasts and will experience harmful interference. Consequently, all of the spectrum in this passband will be largely unusable in Detroit. But if there were instead two passbands, each with 20 MHz, a device configured with the passband comprising the lower 20 MHz of the original 40 MHz passband would be free from interference in Detroit, and this spectrum could now be used to provide LTE services in Detroit. Devices using this lower 20 MHz could be configured with only this passband, or with both passbands and equipped with a mechanism to turn off the 20 MHz passband that is subject to interference in Detroit.

5.2 Efficient Allocation Of Spectrum. The FCC should also ensure that the ultimate allocation of spectrum to providers permits the spectrum to be used as efficiently as possible. In this respect, the FCC should seek to maximize both "horizontal" and "vertical" contiguity.

Vertical Contiguity. Vertical contiguity refers to the allocation of spectrum blocks in adjacent frequencies. For example, where a bidder wins two 5 MHz blocks of spectrum in a license area within a 20 MHz band, say from 600-620 MHz, adherence to vertical contiguity would allocate the 5 MHz blocks to the bidder either from 600-610 MHz or from 610-620 MHz; it would not allocate one block from 600-605 MHz and another from 615-620 MHz. To maximize the efficiency to which spectrum can be put to use the FCC should seek to ensure that spectrum is ultimately allocated in a manner that ensures vertical contiguity.

One of the most important factors for maximizing spectrum efficiency in LTE deployments is the availability of more spectrum in large contiguous spectrum blocks. LTE supports channel bandwidths of up to 20 MHz. LTE-Advanced will support total channel bandwidth as wide as 100 MHz. LTE uses scalable Orthogonal Frequency Division Multiple Access (OFDMA) that provides larger cell throughput and end user throughput for larger bandwidths. For example, LTE can support a theoretical peak data rate of 300 Mbps in the downlink if the downlink channel bandwidth is 20 MHz; the theoretical peak data rate decreases to 150 Mbps if the channel bandwidth is constrained to 10 MHz (both estimates assume 4 X 4 MIMO). Narrower channel bandwidth is one of the main reasons why current and planned near term LTE deployments cannot realize the full potential of LTE.

A contiguous bandwidth of a certain size is more efficient than two non-contiguous channels that total the same size. The use of contiguous blocks permits the provider to allocate less spectrum to overhead and support. For example, if a provider deploys two separate LTE channels, some overhead – such as synchronization signals, the physical broadcast channel, and system information – would be effectively duplicated on two channels, thus reducing the achievable throughput. Furthermore, only one channel can be assigned to a Release 8 LTE device, limiting the peak throughput available to any given device.

Horizontal Continuity. Horizontal contiguity refers to the allocation of the same spectrum blocks in adjacent geographic areas to the same winning bidder. For example, if a bidder wins a 5 MHz block of spectrum, adherence to geographic contiguity would ensure that the bidder is ultimately allocated this 5 MHz in the same frequency range in adjoining geographic areas. The FCC should seek to maximize geographic contiguity in the auction, because non-geographic contiguity in the allocation of spectrum can significantly degrade the quality of service, resulting in lost connections, lower throughput, and decreased capacity.

For example, it is our understanding that the FCC's rules contain provisions that signals generated by licensed holders do not significantly extend beyond the area covered by the license. The purpose of these rules is to avoid interference to licensees of the same spectrum in adjacent geographic areas. We understand from AT&T's engineers that to comply with these FCC rules, permissible mobile signal levels near the edge of a licensed area must be very low, and at levels that effectively create a "dead zone" – or at least an area where capacity and throughput are severely diminished. These areas can often be more than a mile wide, near the edge of a licensed area. Moreover, these boarders can occur in the middle of densely populated urban areas (Oklahoma City is one example), which effectively leaves large portions of those cities without service, or with very poor service. Permitting providers to obtain spectrum that covers contiguous geographic license areas thus reduces the number and size of these border areas and improves the efficient use of spectrum.

These issues exist even where a provider uses different spectrum in an adjacent area, say 700 MHz spectrum in area "A" and AWS spectrum in adjacent area "B". In the border areas, the 700 MHz and AWS signal levels will still have to be very low to comply with the FCC's rules. As a result, when a device enters these border areas, it may lose service (or experience significantly degraded service) before it is able to switch to the other spectrum band. That is, as the customer reaches the edge of area A, her 700 MHz signal will become very weak or non-existent, and the AWS signal level at the border area B will likewise be very weak or non-existent. It will not be until the consumer travels farther into area B that her device will be able to pick up a strong AWS signal and operate at intended quality levels.

We understand that providers can avoid the FCC's power limitations in border areas by entering into an agreement with the licensee of the same spectrum in the adjacent area. That is, if carriers A and B each own 700 MHz A block spectrum in adjacent areas, they can agree to higher power levels near the border areas. But we also understand from AT&T that it is often not possible to reach agreements with neighboring spectrum holders. For example, in some

instances, the neighboring spectrum holder has not yet deployed a network using the spectrum at issue. In those circumstances, the neighboring spectrum holder has little or no incentive enter into such an agreement, particularly if not doing so impedes their competitor's ability to offer maximum coverage to their customers. And, we have been informed by AT&T that it has indeed been told by neighboring spectrum holders that they will not agree to terms that permit AT&T to avoid the FCC's spectrum limits until such time that they choose to deploy their own networks, which can be years away.

Even when a neighboring spectrum holder is willing to enter into an agreement, we understand from AT&T that it can be very difficult, time consuming, and costly to reach such agreements, because technical disputes inevitably arise, particularly with respect to how the parties will measure and monitor their power levels to minimize interference in border areas. Moreover, even in areas where AT&T is able to reach agreement with neighboring providers, spectrum is still not used as efficiently as would be the case if AT&T owned the same spectrum in both areas. Under these agreements, there are still power limitation requirements near the border areas, which reduces throughput and capacity for AT&T's customers at these border areas.

In addition, allocation of different spectrum blocks to an operator complicates the RF design and increases the potential for interference. When an operator owns the same spectrum block (and hence same carrier frequency) in two adjacent geographic areas, joint RF design across these areas can be carried out to minimize interference. For example, one of the important parameters to be planned in LTE is Physical Cell Identity (PCI) for a given cell (*i.e.*, a sector). Proper PCI planning minimizes interference. If two different operators have the same carrier frequency in adjacent areas, a given PCI may be reused in close-by cells, resulting in interference. In contrast, if an operator is given the same carrier frequency in adjacent areas, the PCI reuse distance can be maximized, minimizing the degree of interference.

Reducing horizontal contiguity also reduces the efficient use of spectrum by increasing the amount of spectrum that must be allocated to overhead for the purpose of managing handoffs between different spectrum bands (say between 700 MHz in area A and AWS in adjacent areas B), rather than to customer bandwidth. For example, a single-receiver LTE device (or User Equipment ("UE")) can be present on only one carrier frequency at a time. To enable a UE to seamlessly move across different carrier frequencies, LTE allows the eNodeB (*i.e.,* the LTE base station) to configure a UE with a measurement pattern that includes a gap during which the UE being served on a carrier frequency, say frequency "fx", can make measurements of a different carrier frequency, say frequency "fy". During such gaps, the UE is absent from the air interface of the serving frequency fx and no uplink or downlink data transfer can occur. The average throughput would thus be lower in such a scenario compared to the intra-frequency scenario that does not need any such measurement gaps. Two measurement patterns are defined in LTE with the same gap of 6 ms but with two different measurement cycles of 40 ms and 120 ms. The overhead would then be 5% or 15% depending upon the configured measurement cycle and throughput would be reduced approximately by these amounts. Since the UE needs to switch between the frequencies, it would consume more processing power. The overall

signaling overhead could also be somewhat higher in the case of inter-frequency handover compared to intra-frequency handover.

ATTACHMENT A

(Professor Reed CV)

Jeffrey H. Reed, Ph.D.

Willis G. Worcester Professor of ECE
The Bradley Department of Electrical and Computer Engineering
Director of Wireless at Virginia Tech
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Vitae

Section I: Experience & Education

Current Position:

Director of Wireless at Virginia Tech (Wireless@VT), 2005-present
Professor of the Bradley Department of Electrical and Computer Engineering, June 2002- Present
Interim Director, The Ted and Karyn Hume Center for National Security and Technolgy, January 2010 – May 2011
CEO and Co-Founder, Power Fingerprinting, Inc. 2011-Present
CTO and Co-Founder, Cognitive Radio Technology, 2007-present
Willis G. Worcester Professor, Bradley Dept. of Electrical and Computer Engineering, 2005-present

Professional Interest:

Research and teaching in signal processing and communication systems

Specific Research Interests	Specific Teaching Interests
Software Radios	Software Radios
Smart Antennas	Digital and Analog Communications
Interference Rejection	Discrete Time and Digital Signal Processing
Wireless Networks	Cellular and Personal Communications
Cognitive Radio	DSP-based Communication System Design
Location Technology	Adaptive Filtering

Education:

Ph.D.
Electrical and Computer Engineering, December 1987, University of California, Davis
Awarded American Electronics Fellowship for Faculty Development
Major: Statistical Signal Processing; Minor: Control Systems and Statistics
Dissertation: *Interference Rejection Using Time-Dependent Adaptive Filters*
Attended part-time at University of Santa Clara, September 1980 through June 1983

M.S.
Electrical and Computer Engineering, June 1980, University of California, Davis
M.S. Project Topic: An EEG Data Acquisition and Analysis System

B.S.
Electrical and Computer Engineering, March 1979, University of California, Davis

Employment:

Professor, Virginia Tech, April 2001-present
Director, MPRG 200-2002
Associate Professor, Virginia Tech, 1997-2001
President and co-founder, Power Fingerprinting, 2011 - present
CTO and co-founder, Cognitive Radio Technologies**,** 2007-present
Co-founder, Dot Mobile, Inc., March 2000-2001
Consultant, Reed Engineering (Self-Employed), 1987-present
Assistant Professor, Virginia Tech, 1992-1997
Research Engineer, University of California, Davis, 1992
Lecturer, University of California, Davis, 1988-1992
Associate Instructor, University of California, Davis, 1985-1987
Teaching Assistant, University of California, Davis, 1984-1985
Member of Technical Staff, Signal Science, Inc., Santa Clara, CA and Hanover, MD, 1980-1985

Professional Affiliations:

Member of **Tau Beta Pi Honor Society**
Member of **Phi Kappa Phi Honor Society**
Member of AFCEA
Fellow of the IEEE

Professional Awards:

Honorary lifetime membership in the Wireless Innovation Forum, 2012
Vehicular Technology Society Distinguished Lecturer 2011
Named Willis G. Worcester Professor of ECE, summer 2005, Fall 2010
Industry Achievement Award, SDR Forum 2004
Institute of Electrical and Electronics Engineers Fellow, Dec. 2004
Virginia Tech College of Engineering Outstanding Researcher Award, 2001

Section II: Funded Research
(Principal Investigator or Co-Principal Investigator)

Paving the Way to Dynamic Spectrum Sharing: Understanding Spectrum Regulatory and enforcement Mechanics, NSF, $466,485

Advanced Wireless Systems Technologies, NRO, $8,128,864, 8/15/12-1/14/2014

Intelligence Community Center of Academic Excellence, DIA, $1,000,000, 9/23/12 to 9/22/14

Sharing and Shaping of 4G Cellular Resources, AMFI, $369,152, 8/10/12 – 5/9/13

Android Security**,** ARO, $64,884, 6/1/12 – 5/31/13

SDR Shield: A Hardware-based Security Solution for Software Defined Radio, NSF, $700,000, 9/1/12 – 8/29/18

Next Generation Secure, DARPA (flow through) 10/15/10 – 1/20/13

Outdoor Cognitive Radio Network Test Bed, DoD, 6/15/12 – 6/14/13

Information Assurance of LTE-Advanced, L-3, $30,000, 6/15/12 – 6/14/14

Enhanced Security Monitoring and Intrusion Detection Using Power Fingerprinting and SDR and CR Wireless Systems, Power Fingerprinting Inc., $50,236.00 7/1/2012 – 12/31/2012

Rural Virginia Testbed Planning, CAER, $169,999.00, 1/1/2012 – 9/30/2012

Wireless Assessment of the Gigapark Sites in the Mid Atlantic Broadband Footprint, Mid-Atlantic Broadband. $54,419.00, 7/1/2011 – 9/1/2011

Cognitive Jammer Detection and Classification. Office of Naval Research (ONR), $100,000.00, 10/1/2011 – 9/30/2013

The Android Tactical Application Analysis & Knowledge Cloud, AROSR/ARO

Mobile Cognitive Radio Testbed, ICTAS, $98,291.00, 7/1/2010 – 6/30/2011

Updated to OSSIE Core Framework to Enhance Compatibility with Open CPI, Mercury Federal Systems, $39,998, 7/1/2011 – 12/31/2011

Mobile Cognitive Radio Nodes Testbed, ARO (DURIP II), 5/13/2010 – 5/12/2011, $213,566

Next Generation Secure, Scalable Communication Network for Smart Grid, Oak Ridge National Laboratory, 12/15/2010 – 09/30/2012 $628,671.00

SDR Technology Development Support, Maryland Procurement Office, 9/30/10 – 9/29/2010

$1,562.300 (expected duration 5 years at $5M)

Mobile Cognitive Radio Testbed, ICTAS, 7/1/10 – 6/30/11 $213,566 (co-PI)

Experimental Development Capability for Software Defined Radio with Agile Hardware, ONR, 1/27/2010 – 1/26/2011 $277,718 (co-PI)

Collaborative Research: Enhancing Access to the Radio Spectrum (EARS) Workshop, NSF 4/15/2010 – 03/31/2011 $21,860.00 (co-PI)

Recommendations for Transitioning Silvus MNM FPGA Core IP, DARPA (Silvus Technologies) 2/18/2010 – 2/17/2011, $39,970.00 (co-PI)

NSWC-TO13-Wireless Distributed Computing: Concept to Reality, Naval Secure Warfare (DARPA) Center 8/16/10 – 8/15/2011 - $498.798.0

Investigating the Relationship of OSSIE to Higher Layers, NSF 8/1/2009 – 2/28/10 $76,040

VT-Cornet: Virginia Tech Cognitive Radio Network, ICTAS, 7/1/08 – 6/30/09 $142,580

Cryptographic API and Subsystem Simulator, SCA Technica, 1/1/09 – 9/26/09 $39,000

Cognitive Radio Network Testbed Instrumentation, Office of Naval Research, 4/15/09 – 4/14/10 $347,979

VT-Cognet: Virginia Tech Cognitive Radio Network Testbed Phase 2, ICTAS 1/12/09 – 1/11/10 $149,959 (co-PI)

CT-ISG: Assuring Security in Spectrum Agile Radio Networks, NSF, 01/01/07 - 12/31/10 $499,997 (co-PI).

Improved Distribution and Error Recovery of the OSSIE Core Framework, SAIC 3/01/2009 – 9/30/2009 $75,000

IC CAE: Emerging Technologies IC CAE, Howard University 9/23/2009 – 9/22/2011 $2.5M

REU Supplement to award #0520418 Nets: Oriwub:An Open Systems Approach for Rapid Proto-typing Waveforms for Software Defined Radio, NSF $41,800

Nets Prowin: An Open Systems Approach for Rapid Prototyping Waveforms for Software Defined Radio, National Science Foundation, 8/1/08 – 7/31/09 $12,000 (asking for additional REU funding)

Enhancements to OSSIE: (Open Source SCA Implementation: Embedded), Science Applications International Corporation, 4/1/07 – 90/07 $75,000

Collaborative Research: CT-T TRIESTE: A Trusted Radio Infrastructure For Enforcing Spectrum Etiquettes, NSF, 10/01/07 – 9/30/10, $150.000 (Reed Co-PI)

Development Design of a Cognitive Engine and Anyalysis of WRAN Cognitive Radio Algorithms, ETRI, 7/01/07 – 12/31/07 $119,999

An Integrated Tool for SCA Waveform Development, Testing, and Debugging and A Tool for Automated Estimation of DSP Resource Statistics for Waveform Components, US-Army-CERDEC Office, 6/12/07 – 6/11/08, $326,125

Software Defined Radio Waveform and Device Development and Component Deployment Using OSSIE, DOD, 7/19/07 – 7/18/10, $975,639 ($184,744 awarded to this point)

Reasoning and Learning in Adapative Wireless Networks, BBN Technologies, 10/1/07 – 12/31/10, $913,196 (co-PI)

US/Ireland International Workshop on Next Generation Open Architectures for Software-Defined Radio, NSF, 9/15/07 – 8/31/08, $35,963

VT-CogNet: Virginia Tech Cognitive Radio Network, ICTAS, 1/1/08 – 6/30/09,$160,170 (Reed, Bose PIs)

Trade Study Of Implementation of SDR: Fundamental Limitations and Future Prospects (DARPA SEED), US Army Aviation & Missile Command, 9/11/07 – 6/30/08 (Reed PI) $115,364

Distributed Computing for Collaborative Software Radio, Office of Naval Research, 02/05/07 - 02/04/10, $533,722 ($108,728 awarded first year)

A Panel of Commercial GSM Experts For Supporting JIEDDO Operations, JIEDDO, 12/18/06 - 2/28/07 $38,275

Cognitive Radio Test-bed, Virginia Space Grant Consortium, 08/16/06 - 08/15/07 $5,000

Emerging Wireless Technologies (EWT) Technology Assessment, Rosettex, 07/03/06 - 12/31/07 $91,000

Development of a Cognitive Engine and Analysis of WRAN Cognitive Radio Algorithms, ETRI, 06/16/06 - 12/31/06 $175,554.

Wireless@Virginia Tech Group Start-up, Institute for Critical Technology and Applied Science – ICTAS, 01/01/06 - 06/30/07 $500,000.

A Low-Cost All-Band/All-Mode Radio for Public Safety, National Department of Justice (Dept. of Justice), 10/01/05 - 09/30/08 $399,816 (Reed Co-PI)

Applying Artificial Intelligence Techniques to the Development of a Cognitive Radio Engine: Assessment, Evaluation, and Implementation, Army Research Office, 10/01/05 - 06/30/06 $49,995.

Analysis of WRAN Algorithms, ETRI, 10/01/05 - 12/31/05 $86,275

NeTS PROWIN: An Open System Approach for Rapid Prototyping Waveforms for Software Defined Radios, 08/15/05 - 08/14/09 $999,995 (Reed Co-PI)

Cognitive Radios, Virginia Space Grant Consortium, 08/10/05 - 08/09/06 $5000

A Software Defined Ultra Wideband Communication System Testbed, Virginia Space Grant Consortium, 08/10/05 - 08/09/06 $5,000

Advanced Wireless Integrated Network: AWINN, Office of Naval Research, 12/20/04 - 06/24/06 $484,200 (Reed portion)

Software Defined Radios: Evolution and Application Areas, Booz Allen Hamilton, 1/1/05 - 3/15/05 $74,497

Ossie and Harriet, SAIC, 08/16/04 - 12/31/05 $300,519

CDMA 2000 System Modeling and Simulation Program, Magnolia Broadband, Inc.**,** 12/15/03 - 12/14/04 $84,500

Policy-based Resource Management in a Vehicular Ad-Hoc Network for First Responders, Naval Postgraduate School, 09/24/03 - 09/30/04 $25,431

System Level Design Approach and Methodologies For Software Defined Radios, National Imagery and Mapping Agency, 7/25/03 - 7/24/06 $189,282

Smart Antennas Research At The MPRG, Army Research Office, 06/01/03-12/31/04 $37,500

Proposal for GDDS Cluster X-SCA-Lite Architecture, General Dynamics, 05/01/03-10/31/03 $85,691

Game Theoretic Analysis Of Radio Resource Management For Ad-Hoc Networks, Office of Naval Research, 04/01/03-03/31/06 $589,411

Game Theory in Radio Resource Management*,* Motorola University Partnership in Research, 09/01/02 - 05/31/04 $60,000

Software Radios and Smart Antennas: Challenges for Creating Seamless Networks, *Samsung Electronics, 04/08/03 - 05/15/04 $520,785*

UWB Propagation Measurements, Modeling, and Communication System Enhancements, DARPA, 08/16/01 - 12/31/03 $688,620

Tactical Communications Architecture and Implementation Plan for the U.S. Customs Service, Naval Surface Warfare Center, Dahlgren, 8/16/01 - 8/15/02 $402,000

ACN Independent Innovative Research Component, Raytheon Systems, 12/1/01 - 11/30/02 $11,250

Foundation Wireless Network for Medical Applications, Carilion Biomedical Institute, 8/6/01 - 8/10/02 $75,000

Interference, Propagation, and Antenna Placement Issues for XM Radio, GM, 3/26/01 - 9/25/02 $583,527

AOL Fellowship in Wireless Home Networking Technologies, AOL, 01/01/01 - 05/15/03 $84,583

Reconfigurable Apertures and Space-Time Processing, Raytheon Systems, 05/00 - 09/02 $841,350

Advanced Wireless Technology for Aerospace Communications, Virginia Space Grant Consortium, 08/00 - 05/03 $15,000

Research and Development for IMT-2000, LG Electronics, 05/15/00 - 09/31/01 $350,000

Motorola University Partnership in Research: Overloaded Array Processing, Motorola, 09/01/00 - 08/31/02 $84,944

Multiuser Detection for Overloaded Antenna Arrays, Raytheon, 05/00 - 05/02 $1,126,194

An Investigation of Base Station Diversity For Cellular Applications - Phase II, Metawave, 02/29/00 - 02/28/01 $104,000

Broadband Channel-Adaptive Radio Modem for NGI Network Extension and Access, Hughes Research Laboratory, 10/01/99 - 11/30/01 $81,412

Research Into Signal Recovery Algorithms in Support of Spectral Spatial Interference Cancellation System (SSICS) – Phase II Research Effort, Raytheon Company, 02/01/00 - 05/15/01 $149,756

Navy Collaborative Integrated Information Technology Initiative (NAVCIITI), Office of Naval Research, 04/00 - 06/04 $9,651,087 (Reed portion $534,089)

Research into Spatial Signal Recovery Algorithms in Support of Spectral Spatial Interference Cancellation System - Phase I (SSICS), Raytheon Company, 080/2/99 - 01/10/00 $97,857

Low Power and Robust Communications Using Hand-Held Smart Antennas for Receiving and Transmitting, Texas Instruments, 07/01/98 - 06/30/00 $331,993

An Investigation of Base Station Diversity for Cellular Applications, Metawave Communications, 03/01/99 - 02/28/01 $179,706

International Wireless Communication Research Program, Virginia Tech Research and Graduate Studies' SEED Program, 01/01/99 to 06/30/00 $7,500

Navy Collaborative Integrated Information Technology Initiative (NAVCIITI), Office of Naval Research, 11/14/98 - 09/30/00 $2,700,000.

Enhancing the Capacity of IMT-2000 Through Turbo Coding and Smart Antennas, LGIC, 10/01/98 - 09/30/99 $122,904

Low Power and Robust Communications Using Hand-Held Smart Antennas for Receiving and Transmitting, Texas Instruments, 07/01/98 - 06/30/99 $132,000

Techniques for Evaluating Location Technologies, Comcast, 05/01/98 - 12/31/98 $112,154

Development of Tools for CDMA Cellular Network Planning, Innovative Global Solutions (IGS), 04/01/98 - 01/31/99 $42,889

Configurable and Robust Wireless Communications Nodes, DARPA, 07/01/97 - 12/30/00 $2,015,431

Support of Telelink System Test, Global-Net, Inc., 09/25/96 - 09/24/97 $50,000

Sprint RFI and Evaluation, Sprint Spectrum L. P., 09/26/96 - 12/31/96 $31,158

Rural MayDay/800 Call-in System Feasibility, I-95 Corridor Coalition/ Virginia Department of Transportation, 02/01/96 - 01/31/97 $299,176 (MPRG share $157,988)

A Study of Reconfigurable Receivers for Cellular and PCS, Texas Instruments, 08/25/95 - 08/25/96 $35,000

CDMA/FM Evaluation Effort, Comdial Corporation/Sigtek, 08/28/95 - 12/31/95 $25,000 (plus $7,500 CWT match)

Measured DECT System Performance in Actual Radio Channels, National Semiconductor, 10/01/94 - 2/15/96 $35,024

Investigation of BMP Impacts on Nonpoint Source Pollution Using System Analysis Procedures, Virginia Water Resource Center/U.S. Dept. of Interior, 04/01/95 - 04/30/96 $9,963

Development and Implementation Of Interference Rejection Techniques for Cellular Communications, SAIC, Center for Wireless Telecommunications (CWT), $50,000 (SAIC, 03/22/95 to 12/31/95) $25,000 (CWT, 07/01/95 to 06/31/96)

Expanded Testing of a High Capacity Adaptive Wireless Receiver, ARPA/AASERT, 08/01/95 - 07/31/98 $125,522

Co-Channel Interference Rejection for FM Mobile Phone Systems, Motorola, 01/16/95 - 09/15/9, $33,000

Curriculum Innovation for Simulation and Design of Wireless Communications Systems, National Science Foundation, 08/16/95 - 07/31/98 $289,291

A High Capacity Wireless Receiver Implemented with A Reconfigurable Computer Architecture, ARPA/WAMIS, 09/94 - 08/30/97, $1,727,230 ($533,250 for the first year, $586,750 second year)

Development of a Low Power High Data Rate Spread-Spectrum Modem**,** Grayson Electronics, Virginia's Center for Innovative Technology (CIT), Center for Wireless Telecommunications (CWT), $29,833 (Grayson, 03/01/94 - 11/30/94), $13,204 (CIT, 03/01/94 - 10/31/94) and $16,000 (CWT matching funds, 04/01/94 - 06/30/95)

Rejection of Interference in AMPS Cellular Communication, ARGO Systems, VA's Center for Innovative Technology (CIT), $25,000 (ARGO Systems, 12/10/93 - 05/10/94) and $12,500 (CIT, 04/01/94 - 07/31/94)

Capacity and Interference Resistance of Spread-Spectrum Automatic Vehicle Monitoring Systems in the 902-928 MHz Band, Southwestern Bell Mobile Systems, 10/01/93 - 08/15/94 $70,007

University Road Connection - A Smart Highway, Virginia Dept. of Transportation, 07/01/94 - 11/01/94 $19,523.79

Development of a Spread Spectrum Transceiver for the DECT System, National Semiconductor, 07/01/94 - 06/30/95 $30,000

Investigation of a Dynamic Range Enhancer for an Electro-optic Interface, Southwestern Bell Technology Resources, Inc., 08/01/93 - 06/01/94 $45,000

IVHS Research Center of Excellence, Federal Highway Administration (FHWA), 1993 - 1998, $1 million/year for 5 years (MPRG total approximately $390,000 over performance period, $330,000 received in 93-94, 94-95, 95-96, 96-97 contract years)

Center for Wireless Communications, Center for Innovative Technology, 09/01/93 - 08/31/98, $300,000 for first year. (Anticipated total funding approximately $1,490,835 plus an additional $357,551 of cost sharing by Virginia Tech)

The Performance and Feasibility of Time-Dependent and Non-Linear Adaptive Filters for Rejecting High-Power Co-Located Co-Channel Interference, US Navy via Systems Research Center, 05/15/93 - 09/01/93, Amount: 1/2 summer session support (value approximately $3,750)

Evaluation of an NTP-Based Protocol for Paging and Advanced Data Services, MobileComm, 07/01/93 - 09/30/93 $39,986

Grants & Gifts:

Ted and Karyn Hume center for National Security and Technology Endowment Fund
January 2010, $5,000,000 (Note that most of this money goes for student fellowships, with $200k provided for center support.)
Total Amount - $5,209.010.00

Intel – Jan. 2010, gift for unrestricted research $50,000.00

Tektronix, reconditioned real time spectrum analyzer and two portable analyzers, ~ $130,000

Tektronix - Dec. 2009, reconditioned Arbitrary Function Generator, 100 Mhz, 2 Channel $5,110.00

Wireless@VT Industrial Affiliates Membership 2006-2009:
Affiliate Funding for the year 2009 – 2010 for Dr. Jeffrey H. Reed is $66,960.
Affiliate Funding for the year 2008 - 2009 for Dr. Jeffrey H. Reed is $40,534

Intel Coporation:: 2009 to support the research in "Cognitive Radio for Minimizing Power Consumption" $44,000

Tektronix*,* 12/2005, cash gift $20,000

Texas Instruments*,* 08/2005, cash gift $27,519

Tektronix, 07/2005, cash gift $20,000

Texas Instruments. 12/2004, cash gift $99,000

Tektronix, spring 2004, cash gift $20,000

CISCO Systems, 08/2003 and 02/2005, cash gift $176,000

Mercury Computer Systems, Inc., 2003, cash gift $50,000

Analog Devices, 2001-2002*,* cash gift $37,500

HRL, ***Smart Antenna Research,*** 2000, cash gift $40,000

Rockwell, Flexible Communications Using Reconfigurable Computing, 1998, $25,000 cash gift

Investigation of CDMA, donation from ITT, 1996, cash gift $100,000

MPRG Industrial Affiliates Membership 1993-2006: Grant total split between the five MPRG faculty (total paid $4,866,500 and an additional $110,000 committed to date). Services provided to sponsors include advanced copies of thesis and dissertations, informal consulting, and special opportunities to employ students.

Intel, 10/2007, $40,000, Support research in "Cognitive Radio for Minimizing Power Consumption," 5/2008, $44,000

Texas Instruments, Evaluation Module Kit, 01/2007, $995

Tektronix, Arbitrary Waveform Generator, 02/2007, $138,000.

Xilinx, Inc., Xilinx System Generator, ChipScope Pro, Xilinx Real-PCI interface, AccelDSP Synthesis Tool with AccelWare DSP IP Toolkits, VLYNQ Interface LogiCORE, ISE Foundation, University Option Embedded Development Kit, 01/2007, $39,615

Tektronix, equipment, $114,000

Texas Instruments, 06/2006, $49,500

Mercury Systems, AdapDEV 1280 Chassis with 900 MHz processor, 08/2003

Spectrum Signal Processing, Inc., Hardware necessary to implement a true software defined radio, 08/2002, $62,329

Grayson Wireless, Cellular test and measurement system, 08/2002, $66,312

Signia-IDT (formerly BAE), RF Front-end valve, 2002, ~$6,000

Altera*,* MAX + Plus II Fixed Node Subscription (FPGA board), $2,000

Texas Instruments, Evaluation Module incl. Code Composer Studio, 06/2001, $19,960

Texas Instruments, ADC-Converter, 03/2001, $99

Analog Devices, Evaluation Boards (5), Visual DSP software (2), In-Circuit Emulators (2), $3,790

Wireless Valley Communications, 2 copies SitePlanner w/LanFielder $49,980, 1 copy SiteSpy on SMT $995, 2005, $50,975

Analog Devices, receiver, processor, and receiver chip set, $645

Texas Instruments, boards, 2001, $2,495

HRL, 2000, Diversity Antenna, $200

Altera, development package, 2000, $995

Altera, (2) MAX+ PLUS II Fixed Node Subscription for PC, (1) design lab package, (1) Micro-Chip; $4,765

Motorola, 56311EVM computer board with DSP and 56311 on it, software, documentation, tutorial, and input/output capabilities, 12/2000, $2000

Texas Instruments, Evaluation software and manuals, 1998, $2,500

Texas Instruments, Evaluation Software, 1997, $1,000

Altera, Development Tools for Programming Configurable Logic Devices, $350

Texas Instruments, DSP Development Systems and Software, 1997, $11,475

Texas Instruments, DSP Hardware and Software, 1997, $27,500

Analog Devices, DSP Development Boards, 1996, $3,200

Altera, Software Materials, 1996, $5,000

SIGTEK, Spread Spectrum Receivers, 1995, $10,000

Section III. Teaching & Advising

Classes Taught:

Graduate Courses

Cellular and Personal Communications (ECE6644)
Software Radios: A Modern Approach to Radio Engineering (ECE5674)
Digital Signal Processing (ECE5624)
Cellular (ECE 5664)

Undergraduate Courses

Implementation of Communication Systems (ECE4654)
Signal Processing (ECE4624)
Communication Systems (ECE3604)

Courses Developed:

Major Revision of ECE course 5664 Cellular Radio and Personal Communications to focus on systems level description and design considerations of cellular standards this will take two more years to complete and result in a textbook.
Implementation of Communication Systems (ECE 4654)
Developed Class in Software Radio (ECE 5664)

Advising: Completed Ph.D. Dissertations:

Yash Vasavada, "An Iterative Confidence Passing Approach for Parameter Estimation and Its Applications to MIMO Systems," May, 2012

Hazem Shatila, "Adaptive Radio Resource Management in Cognitive Radio Communications Using Fuzzy Logic," April 2012

Ashwin Amanna, "Statistical Experimental Design Framework for Cognitive Radio," March 19, 2012

Carlos Aguayo Gonzales, "Power Fingerprinting for Integrity Assessment of Embedded Systems," December 5, 2011

Xueato Chen, "Resource Allocation for Wireless Distributed Computing Networks," (Co-Advised with Dr. Tamal Bose) completed May 2012

An He, " Power Consumption Optimization – A Cognitive Radio Approach," February 2011

Joseph Gaeddert, "Facilitating Wireless Communications through Intelligent Resource Management on Software-Defined Radios in Dynamic Spectrum Environments," January 2011

Lizdabel Moarles Tirando, "An Approach to Using Cognitive in Wireless Networks," December 2009

Kyou Woong Kim, "Exploiting cyclostationarity for radio environmental awareness in cognitive radios," May 2008

Youping Zhao, "Enabling cognitive radios through radio environment maps," May 2007

Rekha Menon, "Interference avoidance based underlay techniques for dynamic spectrum sharing," April 2007 (co-advised with Dr. Michael Buehrer)

Jong-Han Kim, "On the impact of MIMO implementations on cellular networks: An analytical approach from a system perspective," March 2007

Ramesh Chembil Palat, "Performance analysis of cooperative communications for wireless networks," December 2006

Jody Neel, “Analysis and design of cognitive radio networks and distributed radio resource management algorithms,” September 2006

Chris Anderson, “A software defined ultra wideband transceiver testbed for communications, ranging, or imaging.” September 2006

James Hicks, “Novel approaches to overloaded array processing,” August 2003

Raqibul Mostafa, **“**Feasibility of smart antennas for the small wireless terminals,” April 2003

William Newhall, “Radio channel measurements and modeling for smart antenna array systems using a software radio receiver,” April 2003

Pablo Max Robert, “Reduction in coexistent WLAN interference through statistical traffic management,” April 2003

Tom Biedka, “Analysis and development of blind adaptive beamforming algorithms,” August 2001

Srikathyayani Srikanteswara, “Design and implementation of a soft radio architecture for reconfigurable platforms,” July 2001

Rich Ertel, “Antenna array systems: Propagation and performance,” July 1999

Nitin Mangalvedhe, “Development and analysis of adaptive interference rejection techniques for direct sequence code division multiple access systems,” July 1999

Nishith Tripathi, “Generic handoff algorithms using fuzzy logic and neural networks,” November 1997

Paul Petrus, “Novel adaptive array algorithms and their impact on cellular system capacity,” April 1997

Jeff Laster, “Robust GMSK demodulation using demodulator diversity and BER estimation,” January 1997

Rong He, “AMPS co-channel interference rejection techniques and their impact on system capacity, August 1996

Completed M.S. Theses:

Scott Meuleners, “Design and Implementation of a Distributed TDOA-Based Geolocation System using OSSIE and Low Cost USRP Boards,” May 2012

Thomas Cooper, “ Integration of Open-Source Networks,” May, 2012

Shawn Hymel, “Massively Parallel Hidden Markov Models for Wireless Applications,” December 5, 2011

Peter Sahmel, “Eigenspace Approach to Specific Emitter Identification of Orthogonal Frequency Division Multiplexing Signals,” Nov. 2011

Hermie Mendoza, “Distributed Localization for Wireless Distributed Networks in Indoor Environments,” June, 28, 2011

Soumava Bera, “Design and Implementation of a MAC Protocol for Wireless Distributed Computing,” June 11

Hermie Mendoza, “Distributed Localization for Wireless Distributed Networks in Indoor Environments,” May 2011

Matthew Price , “Automatic Modulation Classification Using Grey Relational Analysis,,” April 2011

Ben Hilburn, “Component-Based Design and Service-Oriented Architectures in Software-Defined Radio,” April 2011

Sabares S. Moola, “Rapid Prototyping of Software Defined Radios using Model Based Design for FPGAs,” on July 22, 2010
Nikhil Challa, “ Approaches for Optimizing Software Defined Radio Performance,” on January 31, 2011

Ishtiaq Rouf, “Statistical Analysis of Wireless Communication Systems Using Hidden Markov Models,” July 2009

Matthew Carrick, “Logical representation of FPGA’s & FPGA circuits within the SCA,” July 2009

Patrick Farrell, “Digital hardware designing decisions & trade-offs for software radio systems,” May 2009

Philip Balister, “A software defined radio implemented using the OSSIE core framework deployed on a TI OMAP processor.” December 2008

Jacob DePriest, “A practical approach to rapid prototyping of SCA waveforms,” April 2006

Srinivasan Vasudevan, ”A simulation for analyzing the throughput of IEEE 802.11b wireless LAN systems,” January 2005

Brian Donlan, “Ultra-wideband narrowband interference cancellation and channel modeling for communications,” January 2005

Anil Hebbar, “Empirical approach for rate selection in MIMO OFDM,” December 2004

Seshagiri Krishnamoorthy, “Interference measurements and throughput analysis for 2.4 GHz wireless devices in hospital environments,” April 2003

Yasir Ahmed, “A model-based approach to demodulation of co-channel MSK signals,” December 2002

Ramesh Chembil Palat, “VT-Star – Design and implementation of a test bed for differential space-time block coding and MIMO channel measurements,” October 2002

Jody Neel, “Simulation of an implementation and evaluation of the layered radio architecture,” December 2002

Bing-Leung (Patrick) Cheung, “Simulation of adaptive algorithms for OFDM and adaptive vector OFDM systems,” August 2002

Shakheela H. Marikar, “Resource management in 3G systems employing smart antennas, January 2002

M. Soni, “Computing engine for reconfigurable software radio,” Oct. 2001

Christian Rieser, “Channel sounder for LMDS,” May 2001 (co-advisor)

James Hicks, “Overloaded array processing with spatially reduced search joint detection,” May 2000

Zhong Hu, “Evaluation of joint AOA and DOA estimation algorithms using the antenna array systems,” May 1999

Kim Phillips, “Probability density function estimation for minimum bit error rate equalization,” May 1999

Pablo (Max) Robert, “Simulation tool and metric for evaluating wireless digital video systems,” May 1999

Steven F. Swanchara, “An FPGA-based multiuser receiver employing parallel interference cancellation,” July 1998

Don Breslin, “Adaptive antenna arrays applied to position location,” August 1997

Steve Nicoloso, “Investigation of carrier recovery techniques for PSK modulated signals in CDMA and multipath mobile environments,” May 1997

Brian Fox, “Analysis and dynamic range enhancement of the analog-to-digital interface in multimode radio receivers,” February 1997

Nena Zecevic, “Interference rejection techniques for the mobile unit direct-sequence CDMA receiver, August 1996

Kevin Saldanha, “Performance evaluation of DECT in different radio environments,” August 1996

Milap Majmundar, “Adaptive single-user receivers for direct sequence CDMA systems,” February 1996

Yash Vasavada, “Performance evaluation of a frequency modulated spread spectrum system,” February 1996

Scott Elson, “Simulation and performance analysis of CDPD,” January 1996

Matthew Welborn, “Co-channel interference rejection using model-based demodulator,” January 1996

Francis Dominique, “Design and development of a frequency hopper based on the detection system for the 902-928 MHz ISM band,” December 1995

Nitin Mangalvedhe, “An Eigenstructure technique for direct sequence spread spectrum synchronization,” April 1995

Paul Petrus, “Blind adaptive arrays for mobile communications,” December 1994

Sihano (Raymond) Zheng, “Channel modeling and interference rejection for CDMA automatic vehicle monitoring systems,” November 1994

Fu-Sheng (Frank) Cheng, “A new approach to dynamic range enhancement,” September 1994

Volker Aue, “Optimum linear single user detection in direct-sequence spread-spectrum multiple access systems,” March 1994

Current Ph. D Students:

Eyosias Iman – Ph.D expected completion date December 2013

Dinesh Datla – Ph.D expected completion date July 2012

Karim Said – Ph.D expected completion date May

Abid Ullah – Ph.D expected completion date December 2013

Shravan Garlapati – Ph.D expected completion date May 2013

Matthew Vondall – Ph. D (Co-Advised with Amir Zaghoul) expected completion date Spring, 2013

Stephen Dudley – Ph.D expected completion date May 2014

Matthew Carrick – Ph.D. expected completion date May 2015

Current M.S. Students:

Karim Said - M.S expected completion date June 2012

Thomas Tsou – M.S. expected completion date June 2012

Michael Benonis – M.S. expected completion date December 2012

Sumedha Mohan – M.S. expected completion date May 2013

Section IV. Publications List

Books Authored or Co-Authored:

1. J. H. Reed, ed., An Introduction to Ultrawideband Communications Systems, Prentice Hall, March 2005, ISBN: 0-13-148103-7.

2. J. H. Reed, Software Radio: A Modern Approach to Radio Design, Prentice Hall, May 2002, ISBN: 0-13-081158-0.

3. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, Radio Resource Management in Cellular Systems, Kluwer Academic Publishers, Spring 2001.

Books & Proceedings Edited:

1. W. H. Tranter, B. D. Woerner, J. H. Reed, T. S. Rappaport, and P. M. Robert, Wireless Personal Communications – Bluetooth and Other Technologies, Kluwer Academic Publishers, 2000.

2. W. H. Tranter, B. D. Woerner, T. S. Rappaport, and J. H. Reed, Wireless Personal Communications – Channel Modeling and Systems Engineering, Kluwer Academic Publishers, 1999s.

3. W. H. Tranter, T. S. Rappaport, B. D. Woerner, and J. H. Reed, eds., Wireless Personal Communications: Emerging Technologies for Enhanced Communications, Kluwer Press, 1998.

4. T. S. Rappaport, B. D. Woerner, J. H. Reed, and W. H. Tranter, eds., Wireless Personal Communications: Improving Capacity, Services, and Reliability, Kluwer Press, 1997.

5. J. H. Reed, B. D. Woerner, and T. S. Rappaport, eds., Wireless Personal Communications: Advances in Coverage and Capacity, Kluwer Press, 1997.

6. T. S. Rappaport, B. D. Woerner, and J. H. Reed, eds., Wireless Personal Communications: The Evolution of PCS, Kluwer Press, 1996.

7. B. D. Woerner, T. S. Rappaport, and J. H. Reed, eds., Wireless Personal Communications: Research Developments, Kluwer Press, 1995.

8. T. S. Rappaport, B. D. Woerner, and J. H. Reed, editors, Wireless Personal Communications: Trends and Challenges, Kluwer Press, 1994.

Book Contributions:

1. H. I. Volos, D. Datla, X. Chen, A. He, A. Amanna, T. R. Newman, S.M. Shajedul Hasan, J. H. Reed, and T. Bose, "Green Communications: Realizing Environmentally Friendly, Cost Effective, and Energy Efficient Wireless Systems," in Energy-Aware Systems and Networking for Sustainable Initiatives, IGI Global, June 2012

2. A. He, A. Amanna, X. Chen, D. Datla, J. Gaeddert, S.M. Hasan, H. Volos, "Sustainable Green Computing: Practices, Methodologies and Technologies," edited by Dr. Wen-Chen Hu and Dr. Naima Kaabouch, University of North Dakota, USA IGI Global, 2012

3. "Technical Challenges in Applying Network Neutrality Regulations to Wireless Systems," "Net Neutrality: Contributions to the Debate," Nishith D. Tripathi and Jeffrey H. Reed, Edited by Jorge Perez Martinez, 2011

4. "The Radio Environment Map", (Book Chapter) Cognitive Radio Technology, Dr. Bruce Fette, ed., Y. Zhao, S. Mao, J. Neel, and J.H. Reed2nd edition, 2 April 2009

5. J. Neel. J. Reed, A. MacKenzie, Cognitive Radio Network Performance Analysis in Cognitive Radio Technology, B. Fette, ed., Elsevier, 2nd edition, 2 April 2009.

6. Y. Zhao, S. Mao, J. Neel, and J. H. Reed, "The Radio Environment Map" (Book Chapter) in Cognitive Radio Technology, B. Fette, ed., 2nd ed., Elsevier, April 2009.

7. J. Neel. J. Reed, and A. MacKenzie, "Cognitive Radio Network Performance Analysis" (Book Chapter) in Cognitive Radio Technology, B. Fette, ed., 2nd ed., Elsevier Inc., April 2009.

8. Y. Zhao, B. Le, and J. H. Reed, "Network Support: The Radio Environment Map" (Book Chapter) in *Cognitive Radio Technology*, by B. Fette, Elesvier Inc., pp. 337-363, August 2006, ISBN: 978-0-7506-7952-7.

9. J. O. Neel, J. H. Reed, and A. B. MacKenzie, "Cognitive Radio Performance Analysis" (Book Chapter) in *Cognitive Radio Technology*, by B. Fette, Elesvier Inc., pp. 501-579, August 2006, ISBN: 978-0-7506-7952-7.

10. B. M. Donlan, R. M. Buehrer, and J. H. Reed, "Ultra-wideband Wireless Systems," in the *Encyclopedia of RF and Microwave Engineering*, pp. 5411-5423, Spring 2005, ISBN: 0-471-27053-9.

11. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "Application of a Neurofuzzy System to Handoffs in Cellular Communications" (Book Chapter) in *Neuro-Fuzzy and Fuzzy-Neural Applications in Telecommunications (Signals and Communication Technology)*, by P. Stavroulakis, Springer Publishing, May 2004, ISBN: 3540407596.

12. J. H. Reed and C. J. Rieser, "Software Radio: Technical, Business and Market Implications," in *World Market Series Business Briefing Wireless Technology 2001,* WMRC *PLC – World Markets Research Centre*, pp. 146-150, October 2000, ISBN 1-903140-36-1.

13. P. Petrus and J. H. Reed, "Co-channel Interference in Wireless Communication Systems," in *Encyclopedia of Electrical and Electronics Engineering*, John Wiley & Sons, Inc., February 1999 (invited paper).

14. N. R. Mangalvedhe and J. H. Reed, "Analysis of an Eigenstructure Technique for DSSS Synchronization," in *Wireless Personal Communications: The Evolution of PCS*, Kluwer Press, 1996 (also appears in *Virginia Tech's Sixth Annual Symposium on Wireless Personal Communications*, June 1996), pp. 201-214.

15. J. D. Laster and J. H. Reed, "A Survey of Adaptive Single Channel Interference Rejection Techniques for Wireless Communications," in *Wireless Personal Communications:*

Research Developments, Kluwer Press, 1995 (also appears in *Virginia Tech's Fourth Annual Symposium on Wireless Personal Communications*, June 1994), pp.29-54.

16. I. Howitt, J. H. Reed, V. Vemuri, and T. C. Hsia, "Recent Developments In Applying Neural Nets to Equalization And Interference Rejection," in *Wireless Personal Communications: Trends and Challenges*, Kluwer Press, 1994 (also appears in *Virginia Tech's Third Symposium on Wireless Personal Communications*, June 1993), pp.49-58.

Papers in Refereed Journals:

1. Raqibul Mostafa, Ramesh C. Pallat, Uwe Ringel, Ashok Arman Tikku, and Jeffrey H. Reed, Closed-Loop Transmit Diversity Techniques for Small Wireless Terminals and Their Performance Assessment in a Flat Fading Channel, ETRI Journal, vol.34, no.3, June 2012, pp.319-329.

2. Reed, J. H.; Bernhard, J. T.; Park, J.-M. "Spectrum Access Technologies: The Past, the Present, and the Future," Proceedings of the IEEE , vol.100, no. Special Centennial Issue, pp.1676-1684, May 2012, (invited paper)

3. Ashwin E Amanna, Daniel Ali, Manik Gadhiok, Matthew Price and Jeffrey H Reed, "Cognitive radio engine parametric optimization utilizing Taguchi analysis," EURASIP Journal on Wireless Communications and Networking 2012, 2012:5

4. Xuetao Chen, Tamal Bose, S.M. Hasan and Jeffrey H. Reed, "Efficient detection of primary users in cognitive radio networks," Journal International Journal of Communication Networks and Distributed Systems, Publisher Interscience Enterprises Ltd, Issue Volume 8, Number 3–4/2012, Pages 267-285.

5. Shatila, H., Khedr, M. and Reed, J. H., Opportunistic channel allocation decision making in cognitive radio communications. Int. J. Commun. Syst.. April 2012. DOI: 10.1002/dac.2350

6. Datla, D.; Chen, X.; Tsou, T.; Raghunandan, S.; Hasan, S.M.S.; Reed, J.H.; Dietrich, C.B.; Bose, T.; Fette, B.; Kim, J.; , "Wireless distributed computing: a survey of research challenges," Communications Magazine, IEEE , vol.50, no.1, pp.144-152, January 2012

7. T. Yang, W. Davis, W. Stutzman, J. Nealy, D. Dietrich, S.M. Hasan, J.H. Reed, "Antenna Design Strategy and Demonstration for Software-Defined Radio (SDR)," Analog Integrated Circuits and Signal Processing: Volume 69, Issue 2 (2011), Page 161-171 (update paper from SDR'10 conference)

8. Harpreet S. Dhillon, Jeong-O Jeong, Dinesh Datla, Michael Benonis, R. Michael Buehrer and Jeffrey H. Reed, "A sub-space method to detect multiple wireless microphone signals in TV band white space," Analog Integrated Circuits and Signal Processing, Springer Netherlands, December 2011, Volume 69, Issue 2, pp. 297-306. (update paper from SDR'10 conference)

9. Carlos R. Aguayo González and Jeffrey H. Reed, "Power fingerprinting in SDR integrity assessment for security and regulatory compliance," Analog Integrated Circuits and Signal Processing, Volume 69, Numbers 2-3 (2011), 307-327. (update paper from SDR'10 conference)

10. Dinesh Datla, Haris I. Volos, S. M. Hasan, Jeffrey H. Reed and Tamal Bose, “Task allocation and scheduling in wireless distributed computing networks,” Analog Integrated Circuits and Signal Processing , Volume 69, Numbers 2-3 (2011), 341-353. (update paper from SDR’10 conference)

11. Amanna, K. Thamvichai, M. Carrick, AT. Bose, J. Reed, “Grey Systems Theory Applications to Wireless Communications,” Analog Integrated Circuits and Signal Processing: Volum 69, Issue 2 (2011), Page 259 (update paper from SDR’10 conference)

12. An He, Ashwin Amanna, Thomas Tsou, Xuetao Chen, Dinesh Datla, Joseph Gaeddert, Timothy R Newman, Shajedul Hasan, Haris I Volos, Jeffery H Reed, Tamal Bose, “Green Communications: A Call for Power Efficient Wireless Systems,” Journal of Communications, Vol 6, No 4 (2011), 340-351, Jul 2011

13. A. He, A. Amanna, T. Tsou, X. Chen. D. Datla, J. Gaeddert, T. Newman, S.M. Hasan, H. Volos, J.H. Reed, T. Bose, “Green Communications: A New Paradigm for Power Efficient Wireless Systems,” Journal of Communications Special Issue on Practical Physical Layer Techniques for 4G Systems & Beyond, Vol 6, No. 5. July 2011.

14. D. Datla, H.I. Volos, S.M. Hasan, Jeffrey H. Reed and Tamal Bose, “Wireless Distributed Computing in Cognitive Radio Networks, Ad-Hoc Network (Elsevier,” available online April 15, 2011. (Print copy to be issued)

15. T. Newman, S.M. Hasan, D.Depoy, T. Bose, J.H.Reed, “Designing and Deploying a Building-Wide Cognitive Radio Network Testbed,” *IEEE Communications Magazine,* September 2010

16. A. He, S. Srikantesware, K.K. Bae, T.R. Newman, W. Tranter, M. Verhelst, J. Reed, "Power Consumption Minimization for MIMO Systems- A Cognitive Radio Approach," IEEE JSAC September 2010.

17. A. Amanna, M. Ghadiok, M. Price, J.H. Reed, "Railway Cognitive Radio," IEEE Vehicular Technology Magazine, September 2010, Volume 5, Issue 3, pages 82-89.

18. A. He, S. Srikanteswara, K. K. Bae, J. H. Reed, and W. H. Tranter, "Energy consumption minimization for mobile and wireless devices - a cognitive approach," IEEE Transactions on Consumer Electronics, vol. 56, no. 3, Aug. 2010.

19. A.R. Cormier, Carl B. Dietrich, Jeremy Price, and Jeffrey H. Reed, "Dynamic reconfiguration of software defined radios using standard architectures," Physical Communication, vol. 3, no. 2, June 2010, Pages 73-80 ,doi:10.1016/j.phycom.2009.09.002

20. An He, Kyung Kyoon Bae, T.R. Newman, J. Gaeddert, K. Kim, R. Menon, L. Morales, J. Neel, Y Zhao, J.H. Reed, W.H. Tranter, ”A Survey of Artificial Intelligence for Cognitive Radios”, IEEE Transactions on Vehicular Technology, vol. 59, no. 4, May 2010, pp. 1578-1592.

21. Donglin Hu, Shiwen Mao, Y. Thomas Hou, and Jeffrey H. Reed, "Fine grained scalability video multicast in cognitive radio networks," IEEE Journal on Selected Areas in Communications, Special Issue on Wireless Video Transmission, vol.28, no.3, pp.334--344, April 2010.

22. Carl B. Dietrich, Jeffrey H. Reed, Stephen H. Edwards, Frank E. Kragh, "Experiences From the OSSIE Open Source Software Defined Radio Project," Open Source Business Resource, March, 2010.

23. Menon, R. Macke, A Buehrer M., Reed, J.H. "Interference Avoidance in Networks with Distributed Receivers", IEEE Transactions on Wireless Communications, Vo.57, Issue 10, October 2009, pp. 3078-3091.

24. C. R. Anderson, S. Venkatesh, J. Ibrahim, R. M. Buehrer, and J. H. Reed, "Performance and analysis of a time-interleaved ADC array for a software-defined UWB receiver," Oct. 2009, Volume: 58, Issue: 8, pp. 4046-4063

25. C. R. Aguayo Gonzalez, C. B. Dietrich, F. E. Kragh, S. Sayed, H. I. Volos, J. D. Gaeddert, P. M. Robert, and J. H. Reed, "Open-source SCA-based core framework and rapid development tools enable software-defined radio education and research," *IEEE Commun. Mag.*, October 2009.

26. C. R. Aguayo Gonzalez, C. B. Dietrich, and J. H. Reed, "Understanding the software communications architecture," *IEEE Commun. Mag.*, vol. 47, no. 9, September 2009.

27. Y. Zhao, S. Mao, J.H. Reed, Y Huang, " Utility Function Selection for Streaming Videos with a Cognitive Engine Test Bed", ACM/Springer Mobile Networks and Applications (MONET) at SpringerLink, August 18, 2009.

28. An He, Joseph Gaeddert, Kyung Kyoon Bae, Timothy R. Newman, Jeffrey H. Reed, R. Chembil Palat, A. Annamalai, and J. H. Reed, "Accurate bit error rate analysis of bandlimited cooperative OSTBC networks under time synchronization errors," *IEEE Trans. Veh. Technol.*, vol. 58, no. 5, pp. 2191-2200, June 2009.

29. S. Haykin, D.J. Thomson, J.H. Reed, "Spectrum Sensing for Cognitive Radio," *Proceedings of the IEEE,* Vol. 97, Issue 5, May 2009, pp. 849-877.

30. R. Menon, A. B. MacKenzie, J. Hicks, R. M. Buehrer, and J. H. Reed, "A game-theoretic framework for interference avoidance," *IEEE Trans. Commun.*, vol. 57, no. 4, pp. 1087-1098, April 2009.

31. An He, J. Gaeddert, K. Bae, T. Newman, J. Reed, I. Morales, and C. H. Park, "Development of a case-based reasoning cognitive engine for IEEE 802.22 WRAN Applications," *ACM SIGMOBILE Special Issue on Cognitive Radio Technologies and Systems*, vol. 13, no. 2, pp. 37-48, April 2009.

32. Lizdabel Morales, Chang-Hyun Park, "Development of a Case-Based Reasoning Cognitive Engine for IEEE 802.22 WRAN Applications," ACM Sigmobile Mobile Computing and Communications Review, vol. 13, no.2, pp. 37-48, April 2009.

33. A. B. Mackenzie, J. H. Reed, P. Athanas, C. W. Bostian, R. M. Buehrer, L. A. DaSilve, S. W. Ellingson, Y. T. Hou, M. Hsiao, J. M. Park, C. Patterson, S. Raman, and C. R. C. M. da Silva, "Cognitive radio and networking research at Virginia Tech," *Proceedings of the IEEE*, vol. 97,no. 4, pp. 660-688, April 2009.

34. Y. Zhao, S. Mao, J. O. Neel, and J. H. Reed, “Performance Evaluation of cognitive radios: Metrics, utility functions, and methodology,” *Proceedings of the IEEE*, vol. 97, no. 4, pp. 642-659, April 2009.

35. Seung Min Hur, Shiwen Mao, Y. Thomas Hou, Kwanghee Nam, and Jeffrey H. Reed, "On exploiting location information for concurrent transmission in multi-hop wireless networks," *IEEE Transactions on Vehicular Technology*, vol.58, no.1, pp.314-323, January 2009.

36. R. Menon, R. M. Buehrer, and J. H. Reed, “On the impact of dynamic spectrum sharing techniques on legacy radio systems,” *IEEE Trans. Wireless Commun.*, vol. 7, no. 11, part 1, pp. 4198-4207, November 2008.

37. D.-K. Park, T. Saba, and J. H. Reed, “Technical Standard for unlicensed radio device on DTB band in U.S.A.,” *IEICE Trans. Commun.*, (Japanese Edition), vol. J91-B, no. 11, pp. 1351-1358, November 2008.

38. R. Chen, J.-M. Park, Y. T. Hou, and J. H. Reed, “Toward secure distributed spectrum sensing in cognitive radio networks” (cognitive radio communication and networks), *IEEE J. Select. Areas Commun.*, vol. 46, no. 4, pp. 50-55, April 2008.

39. R. C. Patat, A. Annamalai, and J. H. Reed, “An efficient method for evaluation information outage probability and ergodic capacity of OSTBC systems,” *IEEE Commun. Lett.*, vol. 12, no. 3, pp. 191-193, March 2008.

40. R. Chen, J.-M. Park, and J. H. Reed, “Defense against primary user emulation attacks in cognitive radio networks,” *IEEE J. Select. Areas Commun.*, vol. 16, no. 1, pp. 25-37, January 2008.

41. S. Mao, X. Cheng, Y. T. Hou, H. D. Sherali, and J. H. Reed, “On joint routing and server selection for MD video streaming in ad hoc networks,” *IEEE Trans. Wireless Commun.*, vol. 6, no. 1, pp. 338-347, January 2007.

42. C. A. Gonzalez, F. Portelinha, and J. H. Reed, “Design and implementation of an SCA core framework for a DSP platform,” part 1, *Military Embedded Systems Mag.*, March/April 2007 issue. Part 2 in May/June 2007 issue.

43. J. O. Neal, R. Menon, A. B. MacKenzie, J. H. Reed, and R. P. Gilles, “Interference reducing networks,” *MONET Special Issue - Cognitive Radio Oriented Wireless Networks Commun.*, February 2007.

44. N. Ryu, Y. Yun, S. W. Choi, R. Chembil Palat, and J. H. Reed, “Smart antenna base station open Architecture for SDR networks,” *IEEE Trans. Wireless Commun.*, vol. 13, no. 3, pp. 58-69, June 2006.

45. L. daSilva, G. E. Morgan, C. W. Bostian, S. F. Midkiff, J. H. Reed, C. Thompson, W. G. Newhall, and B. D. Woerner, “The resurgence of push-to-talk technologies,” *IEEE Commun. Mag.*, vol. 44, no. 2, pp. 48-55, January 2006.

46. V. Srivastava, J. Neel, A. Mackenzie, J. Hicks, L. DaSilva, J. H. Reed, and R. P. Gilles, “Using game theory to analyze wireless ad hoc networks,” *IEEE Commun. Surveys Tutorials,* pp. 46-56, December 2005.

47. B. Le, T. W. Rondeau, J. H. Reed, and C. W. Bostian, “Analog-to-digital Converters,” *IEEE Signal Processing Mag.*, pp. 69-77, November 2005.

48. R. Mostafa, R. Gozali, P. M. Robert, R. Chembil Palat, B. D. Woerner, and J. H. Reed, “Design and implementation of a DSP-based MIMO system prototype for real-time demonstration and indoor channel measurements,” *Eurasip J. Applied Signal Processing*, vol. 2005, no. 16, pp. 2673-2685, September 2005.

49. R. Mostafa, A. Annamalai, and J. H. Reed, “Performance evaluation of cellular mobile radio systems with adaptive interference nulling of dominant interferers,” *IEEE Trans. Commun.*, vol. 52, no. 2, pp. 326-335, February 2004.

50. S. Srikanteswara, R. Chembil Palat, J. H. Reed, and P. Athanas, “Overview of configurable Computing machines for software radio handsets,” *IEEE Commun. Mag,*, pp. 134-141, July 2003.

51. J. D. Laster, J. H. Reed, and W. H. Tranter, “Bit error rate estimation using probability density function estimators,” *IEEE Trans. Veh. Technol.*, vVol. 52, no. 1, pp. 260-267, January 2003.

52. P. Petrus, J. H. Reed, and T. S. Rappaport, “Geometrical-based statistical macrocell channel model for mobile environments,” *IEEE Trans. Commun.*, vol. 50, no. 3, pp. 495-502, March 2002.

53. R. Mostafa, F. Alam, K. K. Bae, J. H. Reed, W. H. Tranter, and B. D. Woerner, “3G-around the world and back again,” *RF Design*, February 2002.

54. J. Hicks, S. Bayram, W. H. Tranter, R. J. Boyle, and J. H. Reed, “Overloaded array processing with spatially reduced search joint eetection,” *IEEE J. Select. Areas Commun.*, vol. 19, no. 8, pp. 1584-1593, August 2001.

55. T. Li, Y. M. Vasavada, B. D. Woerner, and J. H. Reed, “A novel direct sequence spread spectrum CDMA system with analog frequency modulation,” *International J. Wireless Inform. Networks*, vol. 7, no.1, pp. 43-53, 2000.

56. M. Majmundar, N. Sandhu, and J. H. Reed, “Adaptive single-user receivers for direct-sequence spread-spectrum CDMA systems,” *IEEE Trans. Veh. Technol.,* vol. 49, no. 2, pp. 379-389, March 2000.

57. T. E. Biedka, W. H. Tranter, and J. H. Reed, “Convergence analysis of the least squares constant modulus algorithm in interference cancellation applications,” *IEEE Trans. Commun.*, vol. 48, no. 3, pp. 491-501, March 2000.

58. S. Srikanteswara, J. H. Reed, P. Athanas, and R. Boyle, “A soft radio architecture for reconfigurable platforms,” *IEEE Commun. Mag.,* pp. 140-147, February 2000.

59. R. B. Ertel and J. H. Reed, "Angle and time of arrival Statistics for circular and elliptical scattering models," *IEEE J. Select. Areas Commun., Wireless Commun. Series*, vol. 17, no. 11, pp. 1829-1840, November 1999.

60. N. Tripathi and J. H. Reed, “Handoffs in cellular systems,” *IEEE Pers. Commun.*, pp. 26-37, December 1998.

61. R. B. Ertel and J. H. Reed, “Generation of two equal power correlated Rayleigh fading envelopes,” *IEEE Commun. Lett.*, vol. 2, no. 10, pp. 276-278, October 1998.

62. P. J. Athanas, J. H. Reed, and W. H. Tranter, “A prototype software radio based on configurable computing,” *Advancing Microelectronics, Special Wireless Issue*, vol. 5, no. 3, pp. 33-38, 1998. (invited paper)

63. J. H. Reed, K. J. Krizman, B. D. Woerner, and T. S. Rappaport, "An overview of the challenges and progress in meeting the E911 requirement for location service," *IEEE Commun. Mag.*, pp. 30-37, April 1998.

64. P. Petrus, R. B. Ertel, and J. H. Reed, “Capacity enhancement using adaptive arrays in an AMPS system,” *IEEE Trans. Veh. Technol.*, vol. 47, no. 3, pp. 717-727, August 1998.

65. P. Petrus, J. H. Reed, and T. S. Rappaport, “Geometrically based statistical macrocell channel model for mobile environments,” *IEEE Trans. Commun.*, accepted for publication.

66. R. B. Ertel, P. Cardieri, K. W. Sowerby, T. S. Rappaport, and J. H. Reed, “Overview of spatial channel models for antenna array communication systems,” *IEEE Pers. Commun.*, pp. 10-22, February 1998. (Also appears in *IEEE Smart Antennas: Adaptive Arrays, Algorithms, Wireless Position Location*, pp. 447-456, 1998.)

67. P. Petrus and J. H. Reed, “Performance analysis of the spectral correlation discriminator array,” *International J. Wireless Pers. Commun. Special Issue*, pp. 337-359, February 1998.

68. Z. Rong, P. Petrus, T. S. Rappaport, and J. H. Reed, “Despread-respread multi-target constant modulus array for CDMA systems,” *IEEE Commun. Lett.*, pp. 114-116, July, 1997.

69. J. Laster and J. H. Reed, “Interference rejection in digital wireless communications,” *IEEE Signal Processing Mag.*, pp. 37-62, May, 1997.

70. P. Petrus, J. H. Reed, and T. S. Rappaport, “Effects of directional antennas at the base station on the doppler spectrum,” *IEEE Commun. Lett.*, pp. 40-42, March 1997. (Also appears in *IEEE Smart Antennas: Adaptive Arrays, Algorithms, Wireless Position Location*, pp. 489-491, 1998.)

71. F. Dominique, J. H. Reed, “Subspace based PN code sequence estimation for direct sequence signals simplified Hebb rule,” *IEEE Electron. Lett.*, vol. 33, pp. 1119-1120, June 1997.

72. F. Dominique and J. H. Reed, “Estimating spectral correlations using the least mean square algorithm,” *IEE Electron. Lett.*, pp. 182-184, January 1997.

73. F. Dominique and J. H. Reed, “A despread data rate update multi-target adaptive array for CDMA signals,” *IEE Electron. Lett.*, pp. 119-121, January 1997.

74. F. Dominique and J. H. Reed, “A simple PN code sequence estimation and synchronization techniques using the constrained Hebbian rule,” *IEE Lett.*, pp. 37-38, January 1997.

75. B. G. Agee, R. J. Kleinman, and J. H. Reed, "Soft synchronization of direct sequence spread spectrum signals," *IEEE Trans. Commun.*, pp. 1527-1536, November, 1996.

76. T. S. Rappaport, J. H. Reed, and B. D. Woerner, "Position location using wireless communications on highways of the future," *IEEE Commun. Mag.*, vol. 34, no. 10, pp. 33-41, October 1996. (invited paper) (Also appears in *IEEE Smart Antennas: Adaptive Arrays, Algorithms, Wireless Position Location*, pp. 393-401, 1998.)

77. N. Mangalvedhe and J. H. Reed, "Evaluation of a soft synchronization technique for DS/SS signals," *IEEE J. Select. Areas Commun.*, vol. 14, no. 8, pp. 1643-1652, October 1996.

78. F. Dominique and J. H. Reed, "A robust frequency hop synchronization algorithm," *IEE Electron. Lett.*, vol. 32, no. 16, pp. 1450-1451, August 1996.

79. P. Petrus and J. H. Reed, "Time dependent adaptive arrays," *IEEE Signal Processing Lett.*, vol. 2, no. 12, pp. 219-222, December 1995.

80. J. H. Reed, N. Yuen, and T. C. Hsia, "An optimal receiver implemented using a time-dependent adaptive filter," *IEEE Trans. Commun.*, vol. 43, no. 2/3/4, pp. 187-190, February-March-April 1995.

81. B. D. Woerner, J. H. Reed, and T. S. Rappaport, "Simulation issues for future wireless modems," *IEEE Commun. Mag.*, vol. 32, no. 7, pp. 42-53, July 1994. (invited paper)

82. R. Mendoza, J. H. Reed, T. C. Hsia, and B. G. Agee, "Interference rejection using the generalized constant modulus algorithm and the hybrid CMA/SCD," *IEEE Trans. Signal Processing,* pp. 2108-2111, vol. 39, no. 9, September 1991.

83. J. H. Reed and T. C. Hsia, "The performance of time-dependent adaptive filters For interference rejection," *IEEE Trans. Acoustics, Speech, Signal Processing,* vol. 38, no. 8, pp. 1373-1385, August 1990.

Conference Papers:

Accepted on the basis of peer review

1. R. Mahajan, R. Mueller, J. Reed, C Williams, T Cambell, N. Ramakrishnan, "Cultivating Emerging and Blacks Swan Technologies," Proceedings of the ASME 2012 International Mechanical Engineering Congress and Exposition, November 9-15, Huston, TX, 2012.

2. C. Dietrich and J.H. Reed, "OSSIE SCA-based Open Source SDR," 2011 IEEE MTT Society's International Microwave Symposium, June 5-10, Baltimore, MD

3. C. Dietrich, E. Wolfe, G. Vanhoy, C. Evans, "Cognitive Radio Testing Using Psychometric Approaches," Wireless Innovation Conference and Product Exposition (SDR'11-WinnCom) November 29-December 2, 2011 in Washington, DCC. Dietrich and J.H. Reed, "OSSIE SCA-based Open Source SDR," 2011 IEEE MTT Society's International Microwave Symposium, June 5-10, Baltimore, MD

4. C. Dietrich, E. Wolfe, G. Vanhoy, C. Evans, “Cognitive Radip Testing Using Psychometric Approaches,” Wireless Innovation Conference and Product Exposition (SDR’11-WinnCom) November 29-December 2, 2011 in Washington, DC.

5. Yaeyoung Yang, William A. Davis, Warren L. Stuzman, S.M. Hasan, Randall Nealy, Carl B. Dietrich and Jeffrey H. Reed; “Antenna Design Strategy and Demonstration for Software-Defined Radio”, SDR’10 November 30th – December 3rd, Washington DC

6. D. Datla, S.M. Hasan, T. Bose, J. Reed, “Computational Accuracy of Distributed Signal Processing in Wireless networks,” SDR’10 November 30th – December 3rd, Washington, DC

7. H, Gaeddertm H, Reedm “Resource Managementwith Real-Time Complexity Monitoring in Software-Defined Radios”, SDR’10 November 30th – December 3rd, Washington, DC

8. C. Gonalez, C. Dietrich, F. Kragh, J. Reed, “SDR Design for Retrofit using Coprocessor and Distributed Architectures,” SDR’10 November 30th – December 3rd, Washington, DC

9. A. Amanna, M.Price, K. Thamavichai, T.Bose, J.H.Reed,”Grey Systems Theory Applications to Wirless Communications”, SDR’10 November 30th – December 3rd, Washington, DC

10. S.Moola, S.M.Hasan, C.Dietrich, J.H.Reed, “Rapid Prototyping of a SDR Based Reconfigurabe MIMO-OFDM Testbed,” SDR’10 November 30th – December 3rd, Washington, DC

11. K.Rele, T.R. Newman, J. Reed, “Security Techniques for Attack Resilient Software Defined Radio,” SDR’10 November 30th – December 3rd, Washington DC

12. Dinesh Datla, S.M. Hasan, Tamal Bose, Jeffrey H. Reed; “Fundamental Issues of Wireless Distributed Computing in SDR Networks,” SDR’10 November 30th – December 3rd, Washington DC.

13. C. Nikhil, J. O-Jeong, C. Dietrich, T.R. Newman, J. Reed, "Evaluation Optimization Techniques for Software Defined Radio Cognitive Radio System Performance", SDR'10 Nov. 30 - Dec 3, 2010 Washington, DC

14. Sabares Moola, S.M. Hasan, Carl B. Dietrich, and Jeffrey H. Reed; “Integration of a SDR Based Reconfigurable MIMO-OFDM Testbed into OSSIE, SDR’10 November 30th – December 3rd, Washington DC.

15. Xueato Chen, S.M. Hasan, Tamal Bose, and Jeffrey H. Reed; “Software Defined Radio Based WirelessGrids” SDR’10 November 30th – December 3rd, Washington DC.

16. C. R. Aguayo Gonzalez and J. H. Reed, “Power Fingerprinting in Unauthorized Software Execution Detection for SDR Regulatory Compliance,” Proceedings of the SDR’10,. Washington DC, December, 2010.

17. T.Newman, C.Clancy, M.McHenry, and Jeffrey H. Reed,”Case Studey:Security Analysis of a Dynamic Spectrum Access Radio System,” IEEE Military Communications Conference MILCOM 2010, Oct. 31-Nov4, 2010 San Jose, CA

18. C. R. Aguayo Gonzalez and J. H. Reed, “Detecting Unauthorized Software Execution in SDR using Power Fingerprinting, IEEE MILCOM 2010. November, 2010.

19. Amanna, M. Price, S. Bera, M. Gadhiok, J.H. Reed, "Cognitive Architecture for Railway Communications", Proceedings of the 2010 ASME Rail Transportation Division Fall Technical Conference, Roanoke, VA, October 2010.

20. Dinesh Datla, Xuetao Chen, Timothy Newman, Jeffrey H. Reed, Tamal Bose, “Power Efficiency in Wireless Network Distributed Communications," IEEE Vehicular Technology Conference, Anchorage, Alaska, September 20-23, 2010

21. Dietrich, C., F. Kragh, S.M. Hasan, J.H. Reed, D. Miller, S.H. Edwards, "Enhancements to Software Defined Radio Design Engineering Education," *ASEE SE Section Annual Conference*, April 18-20, 2010

22. Dietrich, C., F. Kragh, S.M. Hasan, C. Aguayo Gonzalez, A. Adenariwo, H.I. Volos, C. Detrich, D. Miller, J. Snyder, S.H. Edwards, J.H. Reed, "Implementation and Evaluation of Laboratory/Tutorial Exercises for Software Defined Radio Education," ASEE SE Section Annual Conference, April 18-20, 2010.

23. Amanna, M. Gadhiok, M. Price, J.H. Reed, W. Siriwongpairat, T. Himsoon, "Rail-CR: Cognitive Radio for Enhanced Railway Communications", Proceedings of Joint ASME (IEEE) Railway Conference, Urbana, IL, April 2010.

24. Amanna and J. H. Reed, “Survey of Cognitive Radio Architectures”, IEEE Southeastcon 2010 – Energizing Our Future, in Charlotte, NC, March 18 – 21 2010

25. X. Chen, T.R. Newman, D. Datla, T. Bose, J.H. Reed, “ The Impact of Channel Variances on the Wireless Distributed Computing Networks”; *Proceedings of the IEEE Global Communications Conference* Honolulu, HI.; November 30 – December 4, 2009.

26. He, S. Srikanteswara, K. Bae, T. R. Newman, J.H. Reed, W. H. Tranter, M. Sajadieh, and M. Verhelst, “System Power Consumption Minimization for Multichannel Communications Using Cognitive Radio, “ in COMCAS 2009, Tel Aviv, Israel Nov. 9 – 11, 2009.

27. Dinesh Datla, Xuetao Chen, Timothy Newman, Jeffrey Reed, and Tamal Bose,“Power Efficiency in Wireless Network Distributed Computing.” Appeared in the Proceedings of the IEEE VTC-Fall 2009 Conference held September 20-23 in Anchorage, Alaska

28. D. Datla, T. Tsou, T. R. Newman, J. H. Reed, and T. Bose, “Waveform level computational energy management in software defined radios.” *SDR Forum*, December 2009. (won best paper award)

29. J. D. Gaeddert and J. H. Reed, “Leveraging software flexibility for managing power consumption in baseband processing,” *SDR Forum*, December 2009.

30. T. Tsou, J. Reed, “ Software Architecture for Cooperative Applications,” SDR Forum Technical Conference, November 1-4, 2009 in Washington DC.

31. M. Carrick, S. Sayed, C. B. Dietrich, and J. H. Reed, “Integration of FPGAs into SDR via memory-mapped I/O,” *SDR Forum*, December 2009.

32. S. Moola, C. Aguayo Gonzalez, C. B. Dietrich, and J. H. Reed, “Distributed wireless computing with multiple domains.” *SDR Forum*, December 2009.

33. Aguayo Gonzalez and J. H. Reed, “Dynamic power consumption monitoring in SDR regulatory compliance,” *SDR Forum*, December 2009.

34. He, T. R. Newman, J. H. Reed, W. H. Tranter, M. Sajadieh, M. Verhelst, S. Srikanteswara, and K. K. Bae, “Power consumption minimization for MIMO systems using cognitive radio,” *SDR Forum*, December 2009.

35. J. D. Gaeddert and J. H. Reed, “Leveraging software flexibility for managing power consumption in baseband processing.” *SDR Forum*, December 2009.

36. X. Chen, T. R. Newman, D. Datla, T. Bose, and J. H. Reed, “The impact of channel variations on wireless distributed computing networks.” IEEE Global Commun. Conf., (GlobeCom), November-December 2009.

37. He, S. Srikanteswara, K. K. Bae, T. R. Newman, J. H. Reed, W. H. Tranter, M. Sajadieh, and M. Verhelst, “System power consumption minimization for multichannel communications using cognitive radio,” *IEEE International Conf. Microwaves, Commun., Antennas Electronic Syst. (COMCAS)*, November 2009.

38. C.A. Gonzalez, J.H. Reed,” Power Fingerprinting in SDR & CR Integrity Assessment, IEEE MILCOM 2009 in Boston, MA, October 18 – 21, 2009.

39. L. Morales, J.E. Suris, J.H. Reed,” A Hybrid Cognitive Engine for Improving Coverage in 3G Wireless Networks”' *IEEE ICC Joint Workshop on Cognitive Wireless Networks and Systems*, June, 2009.

40. Donglin Hu, Shiwen Mao, and Jeffrey H. Reed, "On video multicast in cognitive radio networks," in *Proc. IEEE INFOCOM 2009*, Rio de Janeiro, Brazil, pp.2222-2230, April 2009.

41. Youping Zhao, Shiwen Mao, Jeffrey H. Reed, and Yingsong Huang, "Experimental study of utility function selection for video over cognitive radio networks," in *Proc. TRIDENTCOM 2009*, Washington D.C., pp.1-10, April 2009.

42. He, S. Srikanteswara, J. H. Reed, X. Chen, W. H. Tranter, K. K. Bae, and M. Sajadieh, “Minimizing energy consumption using cognitive radio,” *IEEE Int. Conf. Performance, Computing Commun., (IPCCC),* December 2008, pp. 372-377.

43. Ramkumar, T. Bose, J. Reed, and M. Radenkovic, “Minimizing energy consumption using cognitive radio: Combined blind equalization and automatic modulation classification for cognitive radios under MIMO environment,” *IEEE DySPAN Symposium*, October 2008.

44. Gonzales, C. Dietrich, and J. H. Reed, “Distributed SDR applications for distance learning,” *IEEE DySPAN Symposium*, October 2008.

45. Dieteich, D. Kumaraswamy, S. Raghunandan, L. Le, and J. H. Reed, “Open space radio: An open source implementation of STRS 1.01,” *IEEE DySPAN Symposium*, October 2008.

46. T. Newman, X. Chen, D. Datla, H. Volos, C. Dietrich, T. Bose, and J. H. Reed, “Cornet” cognitive radio mesh and dynamic spectrum allocation demonstration,” *IEEE DySPAN Symposium*, October 2008.

47. R. Chembil Palat, A. Annamalai, and J. H. Reed, “Log-likelihood-radio based selective decode and forward cooperative communication,” *IEEE Veh. Technol. Conf.*, May 2008 pp. 615-618

48. R. Chembil Palat, A. Annamalai, and J. H. Reed, “Log-likelihood-radio based selective decode and forward cooperative communication,” *IEEE Veh. Technol. Conf.*, May 2008.

49. R. Chembil Palat, A. Annamalai, and J. H. Reed, “Precise error rate analysis of bandlimited BPSK system with timing errors and cochannel interference under generalized fast fading channels,” *IEEE Veh. Technol. Conf.*, May 2008, pp. 1306–1310.

50. M. H. Seung, Mao, K. Nam and J. H. Reed, “On concurrent transmissions in multi-hop wireless networks with shadowing channels,” *IEEE Int. Conf. Commun.*, May 2008, pp. 2662-2666.

51. K. Kim, C. M. Spooner, I. Akbar, and J. H. Reed, “Specific emmitter indentification for cognitive radio with application,” *IEEE Global Commun. Conf.*, Nov.-Dec. 2008, pp. 1–5.

52. S. Mao, J. H. Reed, and Y. Zhao, “Experimental study of utility functions selection for video over IEEE 802.22 wireless regional area networks,” *TRIDENTCOM*, 2009

53. M. Shiwen, J. H. Reed, and H. Donglin, “”On video multicast in cognitive Radio networks, *INFOCOM*, April 2009.

54. R. Chembil Palat, A. Annamalai, and J. H. Reed, “Precise error rate analysis of bandlimited BPSK system with timing synchronization errors and asynchronous cochannel interference under generalized rapid-fading channels,” *IEEE Veh. Technol. Conf. (VTC)*, May 2008.

55. R. Chembil Palat, A. Annanalai, and J. H. Reed, “Efficient computation of information outage probability and ergodic capacity of OSTBC systems,” *IEEE Veh. Technol. Conf. (VTC)*, May 2008, pp. 1428–1432.

56. S. Haykin, J. H. Reed, and D. Thomson, “Spectrum sensing for cognitive radio,” *IEEE Proceedings*, vol. 97, no. 5, pp. 849-877, May 2009.

57. X. Chen, T. Bose, A. He, and J. H. Reed, "A high efficiency outphasing transmitter structure for wireless communications," *IEEE DSP Workshop*, January 2009.

58. S. M. Hur, S. Mao. K. Nam, and J. H. Reed, “On concurrent transmissions in multi-hop wireless networks with shadowing channels,” *IEEE ICC*, May 2008.

59. J. H. Reed, C. Dietrich, D. Miller, and F. Kragh, "Education in software defined radio design engineering", *Proceedings CD*, ASEE, ECD Division Program, February 2008.

60. S. H. Won, H. J. Park, J. O. Neel, and J. H. Reed, "Inter-cell interference coordination/avoidance for frequency reuse by resource scheduling in and OFDM-based cellular system," *66th IEEE Veh. Technol. Conf. (VTC)*, September–October 2007, pp. 1722–1725.

61. Y. Zhao, J. Gaeddert, L. Morales, K. K. Bae, and J. H. Reed, "Development of radio environment map enabled case-and knowledge-base learning algorithms for IEEE 802.22 WRAN cognitive engines," *2nd International Conf. Cognitive Radio Oriented Wireless Networks Commun. (CROWNCOM),* August 2007.

62. J.-H. Kim; K. K. Bae, J. H. Reed, and A. Annamalai, "Capacity and coverage of reverse link DS/CDMA cellular systems with MIMO implementations," *IEEE International Conference Commun. (ICC)*, June 2007, pp. 5897-5902.

63. R. Menon, A. B. Mac Kenzie, R. M. Buehrer, and J. H. Reed, "Joint power control and waveform adaptation for distributed networks," *IEEE Global Commun. Conf. (GlobeCom)*, November 2007, pp. 694-699.

64. R. Aguayo Gonzalez and J. H. Reed, "Validation and verification of modular software for software-defined radios," *Software Defined Radio Conference (SDR Forum)*, November 2007.

65. R. Aguayo Gonzalez and J. H. Reed, "Dynamic spectrum access assessment in cognitive radios," *Software Defined Radio Conference (SDR Forum)*, November 2007.

66. J. Gaeddert, H. I. Volos, D. Cormier, and J. H. Reed, "Multi-rate synchronization of digital receivers in software-defined radios," *Software Defined Radio Conference (SDR Forum)*, November 2007.

67. Y. Zhao, D. Raymond, C. daSilva, J. H. Reed, and S. F. Midkiff, "Performance evaluation of radio environment map-enabled cognitive sharing networks," *IEEE Military Commun. Conf. (MILCOM)*, October 2007, pp. 1-7.

68. J. H. Kim, K. K. Bae, and J. H. Reed, "Capacity and coverage of reverse link DS/CDMA cellular systems with MIMO implementations." *IEEE International Conf. Commun. (ICC)*, June 2007, pp. 5897-5902.

69. J. O. Neel, R. Menon, A. B. MacKenzie, and J. H. Reed, "Interference reducing networks," *CrownCom*, August 2007, pp. 96-104.

70. Y. Zhao, L. Morales, J. Gaeddert, K. K. Bae, J.-S. Um, and J. H. Reed, "Applying radio environment maps to cognitive wireless regional area networks," *DYSPAN Conf.*, April 2007.

71. K. Kim, I. A. Akbar, K. K. Bae, J.-S. Um, and J. H. Reed, "Cyclostationary approaches to signal detection and classification in cognitive radio," *DYSPAN Conf.*, April 2007.

72. R. Menon, A. B. MacKenzie, R. M. Buehrer, and J. H. Reed, "A game-theoretic framework for interference avoidance in ad hoc networks," *IEEE GlobeCom*, November-December 2006.

73. J. O. Neel and J. H. Reed, "Performance of distributed dynamic frequency selection schemes for interference reducing networks," *IEEE MILCOM*, October 2006.

74. Y. Zhao, J. H. Reed, S. Mao, K. K. Bae, "Overhead analysis for radio environment map (REM)-enabled cognitive radio networks," *IEEE Conf. Sensor, Mesh, Ad Hoc Commun. Networks (SECON)*, September 2006.

75. S. Venkatesh, C. R. Anderson, R. M. Buehrer, and J.H. Reed, "On the use of pilot-assisted matched filtering in UWB time-interleaved sampling," *International Conf. Ultra-Wideband (ICUWB)*, September 2006, pp. 119-124.

76. J. O. Neel, M. Robert, and J. H. Reed, "A formal methodology for estimating the feasible processor solution space for a software radio," *Software Defined Radio Forum (SDR Forum)*, November 2005, pp. A117-A122.

77. C. Anderson and J. H. Reed, "Performance analysis of a time-interleaved sampling for a software defined ultra wideband receiver," *Software Defined Radio Forum (SDR Forum)*, November 2005, pp. A75-A80.

78. R. Chembil Palat, A. Annamalai, and J. H. Reed, "Cooperative relaying for ad-hoc ground networks using Swarm UAVS," *IEEE Military Commun. Conf. (MILCOM),* October 2005, pp. 3314-3320.

79. N. Ryu, Y. Yun, S. Choi, and J. H. Reed, "Smart antenna implemented with reconfigurable devices for ADR network," *IEICE Technical Committee Software Radio,* July 2005, pp. 15-22.

80. J.-H. Kim, K. K. Bae, A. Annamalai, and J. H. Reed, "The impact of transmit diversity on the Erlang capacity of reverse link DS/CDMA," *International Symposium Personal Indoor Mobile Radio Commun. (IPMRC)*, September 2005.

81. S. Mao, X. Cheng, Y. T. Hou, H. Sherali, and J. Reed, "Joint routing and server selection for multiple description video streaming in ad hoc networks," *IEEE International Conf. Commun. (ICC)*, May 2005, pp. 2993-2999.

82. Y. T. Hou, Y. Shi, J. H. Reed, and K. Sohraby, "Flow routing for variable bit rate source nodes in energy-constrained wireless sensor networks" *IEEE International Conf. Commun. (ICC)*, May 2005, pp. 3057-3062.

83. K. K. Bae, J.-H. Kim, A. Annamalai, W. H. Tranter, and J. H. Reed, "Impact of transmit diversity at handsets on the reverse link DS/CDMA system capacity," *IEEE Global Commun. Conf. (GLOBECOM)*, November-December 2004, vol. 6, pp. 3700-3704.

84. J. A. Neel, J. H. Reed, and R. P. Gilles, "Game models for cognitive radio algorithm analysis," *Software Defined Radio Forum (SDR Forum)*, November 2004. (Best Paper Award)

85. R. Menon, R. M. Buehrer, J. H. Reed, and A. MacKenzie, "Game theory and interference avoidance in decentralized networks," *Software Defined Radio Forum (SDR Forum)*, November 2004.

86. J. O. Neel, S. Srikanteswara, J. H. Reed, and P. M. Athanas, "A comparative study of the suitability of a custom computing machine and a VLIW DSP for use in 3G applications," *IEEE Workshop Signal Processing Systems (SiPS),* October 2004, pp. 188-193. Alam, B. L. P. Cheung, R. Mostafa, W. G. Newhall, B. D. Woerner, and J. H. Reed, "Sub-band beamforming for OFDM systems in practical channel condition," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2004, vol. 1, pp. 235-239.

87. J.-H. Kim, K. K. Bae, A. Annamalai, W. H. Tranter, and J. H. Reed, "Reverse link Capacity and interference statistics of DS/CDMA with transmit diversity," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2004, vol. 6, pp. 4320-4324.

88. J. A. Neel, J. H. Reed, and R. P. Gilles, "Convergence on cognitive radio networks," *IEEE Wireless Commun. Networking Conf. (WCNC)*, March 2004.

89. D. Murotake, A. Fuchs, A. Martin, B. Fette, J. H. Reed, and P. M. Robert, "A lightweight software communications architecture (SCA) launcher implementation for embedded radios," *Software Defined Radio Technical Conf. Product Exposition (SDR Forum),* November 2003, paper SW3-001.

90. W. G. Newhall, R. Mostafa, C. Dietrich, C. Anderson, K. Dietze, G. Joshi, and J. H. Reed, "Wideband air-to-ground radio channel measurements using an antenna array at 2 GHz for low-altitude operations," *IEEE Military Commun. Conf. (MILCOM),* October 2003, vol. 2, pp. 1422-1427.

91. S. W. Kim, D. S. Ha, and J. H. Reed, "Minimum selection GSC and adaptive low-power rake combining scheme," *IEEE International Symposium Circuits Systems (ISCAS)*, May 2003.

92. M. A. Nizamuddin, P. H. Balister, W. H. Tranter, and J. H. Reed, "Nonlinear tapped delay line digital predistorter for power amplifiers with memory," *IEEE Wireless Commun. Networking Conf.*, March 2003.

93. W. Newhall and J. H. Reed, "A geometric air-to-ground radio channel model," *IEEE Military Commun. Conf. (MILCOM),* October 2002, pp. 632-636.

94. B. Cheung, F. Alam, J. H. Reed, and B. D. Woerner, "New adaptive beamforming algorithm for OFDM systems," *14th International Conf. Wireless Commun. (Wireless)*, July 2002, pp. 71-75. (URSI Best Student Paper Award)

95. J. Hicks, J. Tsai, J. H. Reed, and W. H. Tranter, "Overloaded array processing with MMSE-SIC," *IEEE Veh. Technol. Conf. (VTC – Spring)*, May 2002, pp. 542-546.

96. S. Krishnamoorthy, C. R. Anderson, S. Srikanteswara, P. M. Robert, and J. H. Reed, "Background interference measurements at 2.45GHz in a hospital," *1st Student Research Symposium Virginia Tech Center Biomedical Engineering, Wake Forest University School Medicine*," May 2002.

97. M. C. Valenti, M. Robert, and J. H. Reed, “On the throughput of Bluetooth data transmissions,” *IEEE Wireless Commun. Networking Conf. (WCN)*, March 2002, vol. 1, pp. 119-123.

98. W. Newhall and J. H. Reed, “A geometrically based radio channel model for air-to-ground communications,” *Virginia Space Grant Consortium*, March 2002.

99. S. Srikanteswara, J. Neel, J. H. Reed, and P. Athanas, “Soft radio implementations 3G future high data rate systems,” *IEEE Global Commun. Conf. (GLOBECOM)*, November 2001, vol. 6, pp. 3370-3374.

100. R. Mostafa, A. Hannan, J. H. Reed, and W. H. Tranter, “Narrowband transmit diversity measurements at the handset for an indoor environment,” *ICICS*, accepted, not presented, October 2001.

101. J. Kim, Y. M Vasavada, and J. H. Reed, “Spatio-temporial searcher structure for 3G W-CDMA smart antenna systems,” *IEEE Veh. Technol. Conf. (VTC – Fall)*, October 2001, vol. 3, pp. 1635-1639.

102. J. Kim, K. Zahid, and J. H. Reed, “Performance evaluation of 3G W-CDMA smart antenna systems for rural area multi-path fading environments,” *WPMC,* accepted, not presented, September 2001.

103. R. Gozali, R. Mostafa, R. Chembil Palat, S. Marikar, P. M. Robert, W. G. Newhall, C. Beaudette, S. A. Tsaikkou, B. D. Woerner, and J. H. Reed, “Virginia tech space-time advanced radio,” *IEEE Radio Wireless Symp. (RAWCON)*, August 2001, pp. 227-231.

104. P. Balister, M. Nizamuddin, M. Robert, W. H. Tranter, and J. H. Reed, “Role of signal envelope distribution in predicting the performance of a multicarrier communication system,” *IEEE Radio Wireless Symp. (RAWCON)*, August 2001, pp. 245-248.

105. R. Gozali, S. Bayram, J. Tsai, B. D. Woerner, and J. H. Reed, “Interpolation based data-aided timing recovery scheme for multi-user CDMA receivers,” *Wireless Conf.*, July 2001, pp. 544-548.

106. M. Robert and J. H. Reed, “Software design issues in networks with software-defined-radio nodes,” *WETICE Conf.*, June 2001, pp. 55-59.

107. T. E. Biedka, J. H. Reed, and W. H. Tranter, “Mean convergence rate of a decision directed adaptive beamformer with Gaussian interference,” *IEEE Sensor Array Multichannel Signal Processing Workshop (SAM),* March 2000.

108. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "Pattern classification based handoff using fuzzy logic and neural nets," *IEEE International Conf. Commun. (ICC)*, June 1998, section 48, paper 2.

109. S. K. Yao and J. H. Reed, “GMSK differential detectors with decision feedback in multipath and CCI channels,” *IEEE Global Commun. Conf. (GLOBECOM)*, November 1996, pp. 1830-1834.

110. P. Petrus, T. S. Rappaport, and J. H. Reed, “Geometrically based statistical macrocell channel model for mobile environments,” *IEEE Global Commun. Conf. (GLOBECOM)*, November 1996, pp. 1197-1201.

111. N. Mangalvedhe and J. H. Reed, “An Eigenstructure technique for soft synchronization of spread spectrum,” *IEEE Conf. Acoustics, Speech Signal Processing*, May 1996, pp. 1751-1754.

112. P. Petrus, I. Howitt, and J. H. Reed, “Evaluation of outage probability due to co-channel interference in fading for an AMPS system with an ideal beamformer,” *Wireless Conf.*, July 1996, pp. 29-40.

113. R. He and J. H. Reed, “AMPS interference rejection by exploiting the SAT information,” *IEEE Personal, Indoor, Mobile Radio Commun. (PIMRC)*, September 1995, pp. 597-602.

114. P. Petrus and J. H. Reed, “Co-channel interference rejection for AMPS signals using spectral correlation properties and an adaptive array,” *IEEE Veh. Technl. Conf. (VTC)*, July 1995, pp. 30-34.

115. P. Petrus and J. H. Reed, “Least squares CM adaptive array for co-channel interference rejection for AMPS and IS-54,” *Wireless Conf.*, July 1995, pp. 7.41-7.47.

116. J. Cheng, P. Lemson, J. H. Reed, and I. Jacobs, “A dynamic range enhancement technique for fiber optic microcell radio systems,” *IEEE Veh. Technl. Conf. (VTC)*, July 1995, pp. 774-778.

117. S. P. Neugebauer and J. H. Reed, “Prediction of maximal length pseudorandom sequences using neural networks” *Artificial Neural Networks Engineering (ANNIE)*, November 1994, pp. 675-680.

118. R. J. Holley and J. H. Reed, “Time dependent adaptive filters for interference cancellation in CDMA systems,” *Workshop Cyclostationary Signal Processing*, August 1994.

119. Howitt, R. Vemuri, J. H. Reed, and T. C. Hsia, “Comparison of center estimation methods for RBF networks,” *IMAC Conf.*, July 1994, pp. 1304-1306.

120. Howitt, R. Vemuri, J. H. Reed, and T. C. Hsia, “RBF growing algorithm applied to equalization and co-channel interference rejection problem,” *IEEE World Congress Computational Intelligence/International Conf. Neural Networks*, June-July 1994, pp. 3571-3576.

121. T. Yang, J. H. Reed, and T. C. Hsia, “Spectral correlation Of BPSK and QPSK signals in a nonlinear channel With AM/AM and AM/PM conversions,” *IEEE International Conf. Commun.*, pp. 627-632.

122. J. H. Reed, A. A. Quilici, and T. C. Hsia, “A frequency domain time-dependent adaptive filter for interference rejection,” *IEEE Military Commun. Conf. (MILCOM)*, October 1988, pp. 391-397.

123. J. H. Reed and T. C. Hsia, “A technique for sorting and detecting signals in interference,” *IEEE Military Commun. Conf. (MILCOM)*, October 1988, pp. 425-430.

Accepted on the basis of abstract

1. C. Dietrich and J.H. Reed, “OSSIE SCA-based Open Source SDR,” 2011 IEEE MTT Society’s International Microwave Symposium, June 5-10, Baltimore, MD

2. C. Dietrich, E. Wolfe, G. Vanhoy, C. Evans, “Cognitive Radio Testing Using Psychometric Approaches,” Wireless Innovation Conference and Product Exposition (SDR’11-WinnCom) November 29-December 2, 2011 in Washington, DC

3. M.Gadhiok, A.Amanna, M. Price, J.H. Reed, “Metacognition: Enhancing The Performance of a Cognitive radio,” IEE CogSIMA Conference, Feb 22-24, 2011 Miami Beach, Florida

4. M Khedr, H. Shatila, J. Reed, “Adaptive Reseource Management for Vague Environment Using Cognitive Radio”, ICCST Conference, July 9-11, 2010 Changdu, China

5. H.Shatila, M. Khedr and J. Reed, “Adaptive Modulation and Coding for WiMAX Systmes with Vague Channel State Information using Cognitive Radio”, SOECT 2010, Ottawa, Canada, July 2010

6. Amanna, J. H. Reed, “Survey of Cognitive Radio Architectures”, IEEE Southeast Conference 2010, in Charlotte, NC, March 18-21, 2010.

7. F. Kragh, C. Dietrich, S.M. Hasan, J.H. Reed, D. L. Miller, S. H. Edwards, “ Enhancements to Software Defined Radio Design Engineering Education”, 2010 ASEE Southeast Section Conference, April 18-20, 2010 in Blacksburg, VA.

8. S.M. Hasan, R. Nealy, T. Briseboie, T.R. Newman, T. Bose, J.H. Reed, “Wideband RF Front End Design Considerations for Flexiable White Space Software Defined Radio” [Invited Paper] 2010 Radio and Wireless Symposium (RWS), New Orleans, LA, January 10 – 14, 2010.

9. X. Chen, S.M. Hasan, T. Bose, J.H.Reed, “Cross-Layer Reseource Allocation for Wireless Computing Networks”, 2010 Radio and Wireless Symposium (RWS), New Orleans, LA, January 10 – 14, 2010.

10. S.M. Hasan, R. Nealy, T Brisebois, T.R. Newman, T. Bose, and J.H. Reed, “Wideband RF Front End Design Considerations for a Flexible White Space Software Defined Radio” [invited paper] 2010 Radio and Wireless Symposium (RWS)” in New Orleans, LA, January 10-14, 2010

11. X.Chen, S.M. Hasan, T. Bose, and J.H. Reed, “Cross-Layer Resources Allocation for Wireless Distributed Computing Networks” 2010 Radio and Wireless Symposium (RWS)” in New Orleans, LA, January 10-14, 2010

12. M.Khedr, H. Shatila, J. Reed "Adaptive resource Management for Vague Environment Using Cognitive Radio", ICCSIT conference, July 9-11 in Chengdu, China

13. S. Hazem, K. Mohamed, and J. H. Reed, “Channel estimation for WiMAX systems using fuzzy logic cognitive radio” *WOCN Conf.*, April 2009.

14. C. Gonzales, C. Dietrich, and J. H. Reed, “Distributed SDR applications for distance learning,” *SDR Forum*, October 2008.

15. J. Neel, S. Sayed, M. Carrick, C. Dietrich, and J. H. Reed, "PCET" a tool for rapidly estimating statistics of waveform components implemented on digital signal processors," *SDR Forum*, October 2008.

16. C.Dietrich, D. Kumaraswamy, S. B. Raghundndan, L. Lee, and J. H. Reed, "Open space radio: An open source implementation of STRS 1.01," *SDR Forum*, October 2008.

17. R. Farrell, A. Wyglinski, C. R. Anderson, J. H. Reed, P. Balister, C. Phelps, T. Tous, J. Gaeddert, C. Aguayo, S. Bilen, G. Nychis, J. Chapin, B. Farhang-Boroujeny, N. Pawari, and J. Schiel, "Rationale for clean slate radio architecture," submitted *SDR Forum*, October 2008.

18. J.-H. Kim, K. K. Bae, and J. H. Reed, "Transmit and receiver diversity in the uplink of DS/CDMA cellular systems," *IEEE Veh. Technol. Conf. (VTC Spring 2007*), April 2007.

19. C. A. Gonzalez, F. Portelinha, and J. H. Reed, "Design and implementation of an SCA core framework for a DSP platform," *SDR Forum*, November 2006.

20. C. R. Anderson and J. H. Reed, "Development of and initial performance results for a software defined ultra wideband receiver," *SDR Forum 2006*, November 2006.

21. J. Neel, J. H. Reed, and C. A. Gonzalez, "Automated waveform partitioning and optimization for SCA waveforms," *SDR Forum,* November 2006.

22. S. M. Hasan, P. Balister, K. Lee, J. H. Reed, and S. Ellingson, "A LOW cost MULTI-band/MULTI-mode radio for public safety," *SDR* Forum, November 2006.

23. Y. Zhao, J. Gaeddert, K. K. Bae, and J. H. Reed, "Radio environment map-enabled situation-aware cognitive radio learning algorithms," *SDR* Forum, November 2006.

24. P. Balister, M. Robert, and J. H. Reed, "Impact of the use of COBRA for inter-component communication in SCA based radio," *SDR* Forum, November 2006.

25. R, Menon, R. M. Buehrer, and J. H. Reed, "Impact of exclusion region and spreading spectrum-sharing ad hoc networks," *Workshop Technol. Policy Accessing Spectrum (TAPAS)*, August 2006.

26. R. Chembil Palat, A. Annamalai, and J. H. Reed, "Node density and range improvement in cooperative networks using randomized space-time block coding with time synchronization errors," *4th IEEE Workshop Sensor Array Multichannel Processing (SAM)*, July 2006, pp. 466-470.

27. R. Chembil Palat, A. Annamalai, and J. H. Reed, "Probability of error analysis under arbitrary fading and power allocation for decode and forward cooperative communication," *IEEE Communication Theory Workshop (CTW*), May 2006. (No printed proceedings available.)

28. R. Chembil Palat, J. Kim, J. S. Lee, D. S. Ha, C. Patterson, and J. H. Reed, "Reconfigurable modem architecture for CDMA based 3G handsets," *SDR Forum*, November 2005, pp. B119-B125.

29. R. Menon, R. M. Buehrer, and J. H. Reed, "Outage probability based comparison of underlay and overlay spectrum sharing techniques," *Dynamic Spectrum Access Networks, (DySPAN)*, November 2005, pp. 101-109.

30. Fehske, J. Gaeddert, and J. H. Reed, "A new approach to signal classification using spectrum correlation and neural networks," *Dynamic Spectrum Access Networks, (DySPAN)*, November 2005, pp. 144-150.

31. R. Chembil Palat, A. Annamalai, and J. H. Reed, "Cooperative relaying of ad-hoc ground networks using SWARM UAVS," *IEEE Military Commun. Conf. (MILCOM)*, October 2005. (Page numbers not available.)

32. J. Kim, K. K. Bae, A. Annamalai, and J. H. Reed, "The impact of transmit diversity on the Erlang capacity of reverence link DS/CDMA system," *IEEE International Symposium Personal Indoor Mobile Radio Commun.(PIMRC)*, September 2005. (Proceedings on CD ROM only, no page numbers available.)

33. Y. Zhao, B. G. Agee, and J. H. Reed, "Simulation and measurements of microwave oven leakage for 802.11 WLAN interference managements," *IEEE International Symposium Microwave, Antenna, Propagation, EMC Technologies Wireless Commun. (MAPE),* August 2005, pp. 1580-1583.

34. J. Neel, R. Menon, J. H. Reed, and A. B. MacKenzie, "Using game theory to analyze physical layer cognitive radio algorithms," *Conf. Economics, Technol., Policy Unlicensed Spectrum,* May 2005. (No proceedings available.)

35. R. Mostafa, P. Khanna, W. C. Chung, J. W. Heo, J. H. Reed, and D. S. Ha, "Performance evaluation of 2D rake algorithms for WCDMA-DL applications at the handset," *IEEE Radio Wireless Conf. (RAWCON*), September 2004.

36. C. R. Anderson, S. Krishnamoorthy, C. G. Ranson, T. J. Lemon, W. G. Newhall, T. Kummetz, and J. H. Reed, "Antenna isolation, wideband multipath propagation measurements and interference mitigation for on-frequency repeaters," *IEEE SouthEastCon*, March 2004, pp. 110-114.

37. Y. Ahmed, J. H. Reed, W. H. Tranter, and R. M. Buehrer, "A model-based approach to demodulation of co-channel MSK signals," *IEEE Global Commun. Conf. (GLOBECOM*), December 2003, pp. 2442-2446.

38. J. A. Neel, M. Robert, A. Hebbar, R. Chembil Palat, J. H. Reed, S. Srikanteswara, R. Menon, and R. Kumar, "Critical technology challenges to the commercialization of software radio," *World Wireless Research Forum*, October 2003.

39. S. Krishnamoorthy, J. H. Reed, C. R. Anderson, P. M. Robert, and S. Srikanteswara, "Characterization of the 2.4 GHz ISM band electromagnetic interference in a hospital environment," *25th Annual IEEE Conf. IEEE Engineering Medicine Biology Society*, September 2003.

40. R. Mostafa, K. Dietze, R. B. Ertel, C. Dietrich, J. H. Reed, and W. L. Stutzman, "Wideband characterization of wireless channels for smart antenna Applications," *IEEE Radio Wireless Conf. (RAWCON),* August 2003, pp. 103-106.

41. R. Mostafa, M. Robert, and J. H. Reed, "Reduced complexity MIMO processing for WLAN (IEEE 802.11b) applications," *IEEE Radio Wireless Conf. (RAWCON),* August 2003, pp. 171-174.

42. S. W. Kim, D. S. Ha, and J. H. Reed, "Minimum selection GSC and adaptive low-power rake combining scheme," *International Symposium Circuits Systems (ISCAS)*, May 2003, pp. IV-357—IV-360.

43. F. Alam, R. Mostafa, B. Cheung, B. D. Woerner, and J. H. Reed, "Frequency domain beamforming for OFDM system in practical multipath channel," *ICECE Conf.*, December 2002.

44. S. Srikanteswara, J. Neel, J. H. Reed, and S. Sayed, "Resource allocation in software radios using CCMs based on the SCA," *SDR Forum*, Nov. 2002.

45. J. Neel, J. H. Reed, and R. P. Gilles, "The role of game theory in the analysis of software radio networks," *SDR Forum*, November 2002.

46. R. Gozali, R. Mostafa, R. Chembil Palat, P. M. Robert, W. G. Newhall, B. D. Woerner, and J. H. Reed, "MIMO channel capacity measurements using the Virginia Tech space-time advanced radio (VT-STAR)," *IEEE Veh. Technol. Conf. (VTC Fall)*, September 2002, pp. 884-888.

47. J. E. Hicks, J. Tsai, J. H. Reed, W. H. Tranter, and B. D. Woerner, "The performance of linear space-time processing in overloaded environments," *14th International Conf. Wireless Commun. (Wireless)*, July 2002, pp. 83-89.

48. J. Neel, M. Buehrer, J. H. Reed, and R. P. Gilles, "Game theoretic analysis of a network of cognitive radios," *IEEE Midwest Symposium Circuits Systems*, August 2002, pp. 409-412.

49. M. Robert, L. A. DaSilva, and J. H. Reed, "Statistical back-off method for minimizing interference among distinct net technologies," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2002, pp. 1725-1729.

50. S. Krishnamoorthy, M. Robert, S. Srikanteswara, M. C. Valenti, C. R. Anderson, and J. H. Reed, "Channel frame error rate for Bluetooth in the presence of microwave oven," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2002, pp. 927-931.

51. W.G. Newhall, R. Mostafa, K. Dietze, J. H. Reed, and W. L. Stutzman, "Measurement of multipath signal component amplitude correlation coefficients versus propagation delay," *IEEE Radio Wireless Conf. (RAWCON)*, August 2002, pp. 133-136.

52. S. Srikanteswara, J. Neel, J. H. Reed, and P. Athanas, "Designing soft radios for high-data rate Systems and integrated global services," *35th Asilomar Conf.*, November 2001, vol. 1, pp. 51-55.

53. F. Alam, K. Zahid, B. D. Woerner, and J. H. Reed, "Performance comparison between pilot symbol assisted and blind beamformer-rake receivers at the reverse link of third generation CDMA system," *IEEE Veh. Technol. Conf. (VTC Fall)*, October 2001, vol. 1, pp. 353-357.

54. Y. M Vasavada, J. Kim, and J. H. Reed, "Receiver structure for W-CDMA space-time processing," *IEEE Veh. Technol. Conf. (VTC Fall)*, October 2001, vol. 4, pp. 1965-1969.

55. R. Mostafa, K. Dietze, R. Chembil Palat, W. L. Stutzman, and J. H. Reed, "Demonstration of real-time wideband transmit diversity at the handset in the indoor wireless channel," *IEEE Veh. Technol. Conf. (VTC Fall)*, October 2001, vol. 4, pp. 2072-2076.

56. T. Beidka, J. H. Reed, and W. H. Tranter, "Mean convergence rate of a decision directed adaptive beamformer with Gaussian interference," *Sensor Array Multichannel Signal Processing Workshop, 2002*, pp. 68-72.

57. S. Srikanteswara, J. H. Reed, and P. M. Athanas, "Implementation of a reconfigurable soft radio using the layered radio architecture," *34th Asilomar Conf. Signals, Systems, Computers*, 2000, pp. 360-364.

58. Y. M. Vasavada, T. E. Biedka, and J. H. Reed, "Code gated algorithm: A blind adaptive antenna array beamforming scheme for the wideband CDMA system," *34th Asilomar Conf. Signals, Systems, Computers*, 2000, pp. 1397-1402.

59. T. E. Biedka, J. H. Reed, and W. H. Tranter, "Statistics of blind signature estimators," *34th Asilomar Conf. Signals, Systems, Computers*, 2000, pp. 847-850.

60. S. Bayram, J. Hicks, R. J. Boyle, and J. H. Reed, "Overloaded array processing in wireless airborne communication systems," *IEEE Military Commun. Conf. (MILCOM)*, October 2000. (Proceedings on CD ROM.)

61. S. Bayram, J. Hicks, R. J. Boyle, and J. H. Reed, "Joint maximum likelihood approach in overloaded array processing," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2000, pp. 394-400.

62. S. Srikanteswara, M. Hosemann, J. H. Reed, and P. M. Athanas, "Design and implementation of a completely reconfigurable soft radio," *IEEE Radio Wireless Conf. (RAWCON),* September 2000, pp. 7-11.

63. M. Hosemann, S. Srikanteswara, and J. H. Reed, "A code tracking technique for direct sequence spread spectrum using adaptive filtering," *IEEE Radio Wireless Conf. (RAWCON)*, September 2000, pp. 25-28.

64. W. L. Stutzman, J. H. Reed, C. B. Dietrich, B. Kim, and D. G. Sweeney, "Recent results from smart antenna experiments: Base station and handheld terminals," *IEEE Radio Wireless Conf. (RAWCON)*, September 2000.

65. T. Biedka, C. Dietrich, K. Dietze, R. Ertel, B. Kim, R. Mostafa, W. Newhall, U. Ringel, J. H. Reed, D. Sweeney, W. L. Stutzman, R. J. Boyle, and A. Tikku, "Smart antenna for handsets," *DSPS Fest*, August 2000. (Proceedings not yet published.)

66. R. Mostafa, N. D. Tripathi and J. H. Reed, "DSP Implementation of Communication Systems," *DSPS Fest 2000,* August 2000. (Proceedings not yet published.)

67. S. Bayram, J. Hicks, R. J. Boyle, and J. H. Reed, "Overloaded array processing: Non-linear vs. linear aignal extraction techniques," *12th Annual International Conf. Wireless Commun. (Wireless),* July 2000, vol. 2, pp. 492-498.

68. K. A. Phillips, J. H. Reed, and W. H. Tranter, “Minimum BER adaptive filtering,” *IEEE International Conf. Commun. (ICC),* June 2000, pp. 310-321.

69. B. Kim, W. L. Stutzman, D. G. Sweeney, and J. H. Reed, “Space, polarization, and angle diversity for cellular base stations operating in urban environments,” *IEEE Antennas Propagation International Symposium,* Salt Lake City, UT, July 16-21, 2000, pp. 940-943.

70. B. Kim, W. L. Stutzman, D. G. Sweeney, and J. H. Reed, “Initial results from an experimental cellular base station with space, polarization, and angle diversity operating in urban environments,” *10th Virginia Tech/MPRG Symposium Wireless Pers. Commun.,* Blacksburg, VA, June 14-16, 2000.

71. P. M. Robert, A. Darwish, and J. H. Reed, “Fast bit error generation for the simulation of MPEG-2 transmissions in wireless systems,” *IEEE Wireless Commun. Networking Conf. (WCNC)*, September 1999.

72. P. M. Robert, A. Darwish, and J. H. Reed, "MPEG video quality prediction in a wireless system," *IEEE Veh. Technol. Conf. (VTC)*, May 1999, vol. 2, pp. 1490-1495.

73. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "Fuzzy logic based adaptive handoff algorithms for microcellular systems," *IEEE Veh. Technol. Conf. (VTC),* May 1999, pp. 1419-1424.

74. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "Adaptive handoff algorithms for cellular overlay systems using fuzzy logic," *IEEE Veh. Technol. Conf. (VTC),* May 1999, vol. 2, pp. 1413-1418.

75. R. B. Ertel, Z. Hu, and J. H. Reed, "Antenna array hardware amplitude and phase compensation using baseband antenna array outputs," *IEEE Veh. Technol. Conf. (VTC),* May 1999, pp. 1759-1763.

76. P. M. Robert, A. Darwish, and J. H. Reed, "Effect of error distribution in channel coding failure on MPEG wireless transmission," *Electronic Imaging Conf. (SPIE),* January 1999.

77. S. Srikanteswara, P. Athanas, J. H. Reed, and W. H. Tranter, "Configurable computing for communication systems," *International Microelectronics Packaging Society (IMAPS)*, November 1998.

78. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "Pattern classification based handoff using fuzzy logic and neural nets," *IEEE International Conf. Commun. (ICC)*, June 1998, section 48, paper 2.

79. R. B. Ertel and J. H. Reed, “Impact of path loss on the Doppler spectrum for the geometrically based single bounce vector channel models,” *IEEE Veh. Technol. Conf. (VTC),* May 1998, vol. 1, pp. 586-590.

80. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, “An adaptive direction biased fuzzy handoff algorithm with unified handoff selection criterion,” *IEEE Veh. Technol. Conf. (VTC),* May 1998, vol. 1, pp. 127-131.

81. N. D. Tripathi, J. H. Reed, and H. VanLandingham, “An adaptive handoff algorithm using neural encoded fuzzy logic system,” *Annie Conf.*, November 1997.

82. J. H. Reed, R. Ertel, P. Cardieri, and T. S. Rappaport, “Vector channel models,” *Stanford Workshop Smart Antennas*, July 1997. (Invited presentation.)

83. Z. Rong, T. S. Rappaport, P. Petrus, and J. H. Reed, “Simulation of multi-target adaptive array algorithms for CDMA system,” *IEEE Veh. Technol. Conf. (VTC)*, May 1997. (Also *IEEE Smart Antennas: Adaptive Arrays, Algorithms, Wireless Position Location*, 1998, pp. 321-325).

84. N. Zecevic and J. H. Reed, “Blind adaptation algorithms for direct-sequence spread-spectrum CDMA single-user detection,” *IEEE Veh. Technol. Conf. (VTC)*, May 1997.

85. N. Mangalvedhe and J. H. Reed, “Blind CDMA interference rejection in multipath channels,” *IEEE Veh. Technol. Conf. (VTC)*, May 1997.

86. W. C. Ting and J. H. Reed, “Interference rejection for AMPS using time dependent adaptive filter and model-based demodulation,” *IEEE Veh. Technol. Conf. (VTC)*, May 1997.

87. J. H. Reed, “Cell average carrier to interference coverage improvement by using DSP interference rejection techniques,” *IEEE Veh. Technol. Conf. (VTC)*, May 1997.

88. D. G. Sweeney and J. H. Reed, “License free wireless operation,” *SoutheastCon*, April 1997.

89. T. E. Biedka, B. D. Woerner, and J. H. Reed, “Direction finding methods for CDMA systems,” *Asilomar Conf.*, November 1996, pp. 637-641.

90. T. E. Biedka, W. H. Tranter, and J. H. Reed, “Convergence analysis of the least squares constant modulus algorithm,” *Asilomar Conf.*, November 1996, pp. 541-545.

91. N. R. Mangalvedhe and J. H. Reed, “Analysis of an eigenstructure technique for DSSS Synchronization,” *Virginia Tech’s 6th Annual Symposium Wireless Pers. Commun.*, June 1996. (Also *Wireless Personal Communications: The Evolution of PCS*, Kluwer Press, 1996.)

92. B. Tranter, T. S. Rappaport, B. D. Woerner, J. H. Reed, and D. Krizman, “The role of simulation in teaching of communications,” *Frontiers Education Conf.*, November 1996, paper 7a1.1.

93. T. S. Rappaport, W. H. Tranter, J. H. Reed, B. D. Woerner, and D. M. Krizman, “Curriculum innovation for simulation and design of wireless communications systems,” *American Society Engineering Education Conf.*, June 1996. (CD ROM version only, location 162644ms.pdf.)

94. F. S. Cheng, P. Lemson, J. H. Reed, and I. Jacobs, “The dynamic range enhancement technique applied to an AMPS and CDMA cellular environment,” *IEEE Veh. Technol. Conf. (VTC)*, April 1996, pp. 1057-1059.

95. M. Welborn and J. H. Reed, "Co-channel interference rejection using a model-based demodulator for AMPS and NAMPS," *IEEE Veh. Technol. Conf. (VTC)*, April 1996, pp. 1312-1316.

96. M. Majmundar, J. H. Reed, and P. Petrus, "Interference rejection for IS-54 signals," *IEEE Veh. Technol. Conf. (VTC)*, April 1996, pp. 1321-1325.

97. R. He and J. H. Reed, "A robust co-channel interference rejection technique for current mobile phone system," *IEEE Veh. Technol. Conf. (VTC)*, April 1996, pp. 1007-1011.

98. T. E. Biedka, L. Mili, and J. H. Reed, "Robust estimation of the cyclic correlation in contaminated Gaussian noise," *Asilomar Conf. Signals, Systems Computers*, November 1995, pp. 511-515.

99. R. He and J. H. Reed, "Spectral correlation of AMPS signals and its application to interference rejection," *IEEE Military Commun. Conf. (MILCOM)*, October 1994, pp. 1007–1011 (Invited paper.)

100. V. Aue and J. H. Reed, "An interference robust CDMA demodulator that uses spectral correlation properties," *IEEE Veh. Technol. Conf. (VTC)*, June 1994, pp. 563-567.

101. J. D. Laster and J. H. Reed, "A survey of adaptive single channel interference rejection techniques for wireless communications," *Virginia Tech's Fourth Annual Symposium Wireless Pers. Commun.*, June 1994, pp. 2.1-2.25. (Also *Wireless Personal Communications: Research Developments,* Kluwer Press, 1995.*)*

102. Howitt, J. H. Reed, V. Vemuri, and T. C. Hsia, "Recent developments in applying neural nets to equalization and interference rejection," *Virginia Tech's 3rd Annual Symposium Wireless Pers. Commun.*, June 1993, pp. 1.1-1.12. (Also *Wireless Personal Communications: Trends and Challenges,* Kluwer Press, 1994.)

103. B. G. Agee, K. Cohen, J. H. Reed, and T. C. Hsia, "Simulation performance of a blind adaptive array for a realistic mobile channel," *IEEE Veh. Technol. Conf. (VTC)*, pp. 97-100.

104. J. H. Reed and B.G. Agee, "A technique for instantaneous tracking of frequency agile signals in the presence of spectrally correlated interference," *Asilomar Conf. Signals, Systems, Computers*, 1992, pp. 1065-1071.

105. J. H. Reed and T. C. Hsia, "The theoretical performance of time-dependent adaptive filters for interference rejection," *IEEE Military Commun. Conf. (MILCOM),* pp. 961-965*.*

106. R. Mendoza, J. H. Reed, T. C. Hsia, and B. G. Agee, "Interference rejection using a time-dependent constant modulus algorithm," *Asilomar Conf. Signals, Systems Computers,* 1989, pp. 273-278.

107. J. H. Reed, C. D. Greene, and T. C. Hsia, "Demodulation of a direct sequence spread-spectrum signal using an optimal time-dependent receiver," *IEEE Military Commun. Conf. (MILCOM)*, October 1989, pp. 657-662.

108. C. D. Greene, J. H. Reed, and T. C. Hsia, "An optimal receiver using a time-dependent adaptive filter," *IEEE Military Commun. Conf. (MILCOM),* October 1989, pp. 650-666.

109. R. Mendoza, J. H. Reed, and T. C. Hsia, “Interference rejection using a hybrid constant modulus algorithm and spectral correlation discriminator,” *IEEE Military Commun. Conf. (MILCOM),* October 1989, pp. 491-497.

110. J. H. Reed and T. C. Hsia, “Decision-directed demodulation,” IEEE Conf. Decision Control, 1985, pp. 1286-1287.

111. J. H. Reed and T. C. Hsia, “Application of adaptive short-term correlation algorithms to interference rejection,” Asilomar Conf. Signals, Systems, Computers, 1985, pp. 441-445.

112. J. H. Reed and T. C. Hsia, "A technique for separating short and long-duration signals and its application to interference rejection," 4th Yale Workshop Applications Adaptive System Theory, Yale University, 1985.

Papers, Talks, & Lectures Presented at Professional Meetings:

1. Mid Atlantic Broadband Corp. “Initiatives in Wireless Communications, April 2011

2. 66th Annual Meeting of the ORAU Council of Sponsoring Institutions, “The Hume Center”, Oak Ridge TN, March 2011

3. Under invitation OSTP, “Testbed & Technology Platforms,” White House Conference Center, Truman Room, Washington, DC January, 2011

4. Speaker, Oak Ridge National Laboratory Board of Governors, Oak Ridge, TN May 2010, “The Hume Center for National Security and Technology”

5. Keynote Presentation, “The Future of Cognitive Radio,” Univ of Texas and Austin Technology Incubator. A group of faculty and VCs.

6. Invited Presentation, “The Second Wave of Wireless: A New Wave of Disruptive Technology,” Atlantic Council (DC think-tank) to help inform international decision makers, Oct. 2010.

7. Cognitive Wireless Networking (CoRoNet), Keynote Speaker, Chicago, Illinois, September 20, 2010

8. The Ted & Karyn Hume Center Inauguration Reception and Board Meeting, Arlington, VA August 18, 2010.

9. NSF EARS Workshop, “Workshop on Enhancing Access To The Radio Spectrum’, August 2010, Arlington, VA

10. Invited talk, “Cognitive Radio Research at VT,” ISART, NTIA, July 2010.

11. DoD Technical Exchange Meeting at the Finnish Embassy under the aegis of the Secretary of Defense, Washington D.C. May 2010

12. Speaker, Oak Ridge National Laboratory Board of the Governors, May 2010

13. JASON, an independent group of scientists which advises the United States Governement on matters of science and technology - San Diego, CA May 2010

14. Dr. Jeffrey Reed and Dr. Nishith Tripathi, *Wireless Net Neutrality Regulation: A Response to Afflerbach and DeHaven, March 2010*, submitted to the FCC.

15. Jeffrey H. Reed & Nishith D. Tripathi, *The Application of Network Neutrality Regulations to Wireless Systems: A Mission Infeasible,* submitted to the FCC, Jan. 2010

16. Note the two reports above are *responses to the FCC Notice of Proposed Rule Making on Network Neutrality (a highly controversial subject that poses a major threat to the US wireless industry)*

17. "The Nexus of Security and Technological Leadership, Deemed Export Rule Recommendations and Zero-based Methods to Identify Technologies that Require Deemed Export Control', Submitted to the Security of Commerce by the Emerging Technologies and Research Advisory Committee, A Federal Advisory Committee Appointed by the Secretary of Commerce To examine EARS Regulations. 2009. *Note current EARS regulations currently represent a major challenge to US industry and academia for engaging international personnel in research and this committee addressed this challenge.*

18. Institute for Defense and Government Analysis Conference – Security Issues in Cognitive Radio, 2010.

19. Army Research Lab Seminar, Sept. 2009

20. Lectured VT-MENA in Alexandria, Egypt Nov. 2009

21. Technical seminar at Cairo University, Nov. 2009

22. Presented to NTIA, the telecom regulatory authority in Egypt, Nov. 2009

23. Korean US Communications Technology Symposium, July 2009

24. Finnish Embassy – US Military Collaboration with Finnish Government, March 10-11, 2008

25. Institute for Defense and Government Analysis Conference -- VT's Cognitive Radio and Security Research, March 2009

26. J. H. Reed, IEEE presentation to the IEEE San Diego Section, April 7, 2009 San Diego, CA.

27. J. H. Reed, "Distributed computing in collaborative software radio," presented to the Office of Naval Research, May 1, 2007.

28. J.H. Reed, Keynote Speaker at the *Communications Technology Program Review, Planning Assessment Meeting*, "Distributed computing for collaborative software defined radio," Naval Research Laboratory, May 2007.

29. J. H. Reed, "Issues in cognitive wireless networks," talk presented at the *Intel Research Forum Seminar Series*, Portland, OR, March 28, 2007.

30. J. H. Reed, “Issues in cognitive wireless networks,” talk presented at NIST, March 2, 2007.

31. J. H. Reed, “Understanding the issues in software defined cognitive radios,” seminar presented at the University of Pennsylvania, October 16, 2006.

32. J. H. Reed, “Issues in cognitive wireless networks,” talk presented at the *IEEE Workshop Networking Technologies Software Defined Radio (SDR) Networks*, (held in conjunction with *SECON*), Reston, VA, September 25, 2006.

33. J. H. Reed, “Applications of Markov modeling to cognitive radio,” presented at the *SASDCRT Conf.*, Naval Post Graduate School, Monterey, CA, September 12-13, 2006.

34. J. H. Reed, “Understanding the issues in software defined cognitive radios,” seminar presented at Clemson University, SC, July 21, 2006.

35. J. H. Reed, “Understanding the issues in software defined cognitive radios,” seminar presented at Kyung Hee University, Korea, June 12, 2006.

36. J. H. Reed, “Open architecture bridging the gap in emergency communications,” guest speaker at the *International Wireless Communications Expo – IWCE Conf. Tektronix Symposium,* Las Vegas, NV, May 19, 2006.

37. J. H. Reed, “An introduction to cognitive radio and some research trends in cognitive radios,” talk presented at *ETRI Cognitive Radio Workshop*, Seoul, Korea, April 2006.

38. J. H. Reed, S. Srikanteswara, and J. A. Neel, “Design choices for software radios,” DVD tutorial. Available: http://sdrforum.org/store.html

39. Presentation titled “Software radio: The key for enabling 4G wireless networks,” at the *International Forum - 4th Generation Mobile Commun.*, Centre for Telecommunications Research, May 2003.

40. J. H. Reed, “Key challenges in the design on software radios,” workshop presented at *IDGA Software Radio Conf.*, Alexandria, Va., February 23, 2004.

41. J. H. Reed, “Issues in software radios,” presented at Microsoft, Seattle, WA, March 3, 2003.

42. J. H. Reed, “Wireless convergence paradox,” presented at *Samsung Telecom Forum*, Seoul, Korea, March 16-23, 2003.

43. W. H. Tranter, J. H. Reed, D. S. Ha, D. McKinstry, R. M. Buehrer, and J. Hicks, “High capacity communications using overloaded array,” presented at *COMMTEC*, Chantilly, VA, September 16-20, 2002.

44. R. M. Buehrer and J. H. Reed, “Robust ad-hoc, short-range wireless networks for tracking and monitoring devices,” presented to the Marine Corp., April 2002.

45. J. H. Reed, “Overloaded array processing with spatially reduced search joint detection,” presented at the Dresden University of Technology, September 24, 2001.

46. J. H. Reed, Invited lecture series to several Korean companies, compliments of Samsung Advanced Institute of Technologies. The list of companies included: Samsung, LGIC, and ETRI. Spring 2000.

47. J. H. Reed, "The future of wireless," invited talk, Atlantic City, NJ, November 15, 1999.

48. J. H. Reed, "Software radios," *Motorola Futures Forum*, invited talk to corporate strategists, Pheonix, AZ, November 8, 1999.

49. P. Robert and J. H. Reed, "Digital video transmissions in a wireless system," *9th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

50. M. Hosemann and J. H. Reed, "Synchronization techniques for spread spectrum signals," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

51. S. Srikanteswara and J. H. Reed, "Development of a software radio architecture using reconfigurable computing," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

52. J. Hicks, P. Roy, J. Tilki, L. Beex, J. H. Reed, and W. Farley, "Simulation tool for speech recognition over wireless," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

53. R. Ertel and J. H. Reed, "Optimum SINR antenna array performance analysis," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

54. R. Banerjee, B. D. Woerner and J. H. Reed, "Case studies in software radios," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

55. P. M. Robert, A. M. Darwish, and J. H. Reed, "Fast bit error generation for the simulation of MPEG-2 transmissions in wireless systems," *IEEE Wireless Commun. Networking Conf.*, September 21-24, 1999. (Invited paper; proceedings on CD Rom.)

56. J. H. Reed and S. Srikanteswara, "Software radio architecture for a reconfigurable computing platform," *IEEE Commun. Theory Workshop*, Aptos, CA, May 23-26, 1999.

57. R. Ertel , Z. Hu and J. H. Reed, "Antenna array vector channel modeling and data collection system," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

58. P. M. Robert and J. H. Reed, "Digital video transmissions in a wireless system," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

59. S. Swanchara, S. Srikanteswara, P. Athanas, and J. H. Reed, "Implementation of a multiuser receiver on a recongifugurable computing platform," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

60. Maheshware, et al., "Reconfigurable software radio," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

61. K. Phillips and J. H. Reed, "PDF estimation," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

62. N. Mangalvedhe and J. H. Reed, “Performane of reduced complexity algorithms in adaptive CDMA receivers,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

63. R. Mostafa and J. H. Reed, “Study of smart antenna as an interference rejection technique for the handset,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

64. N. Mangalvedhe and J. H. Reed, “Adapative receivers for multi-rate DS-CDMA systems,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

65. J. H. Reed and B. D. Woerner, "Analog to digital conversion and digital signal synthesis for software radios," half-day tutorial presented at the *IEEE 9th International Symposium Personal, Indoor, Mobile Radio Commun.*, Boston, MA, September 13-16, 1998. (Invited tutorial.)

66. J. H. Reed, “The software radio: Modern radio engineering,” Dresden University of Technology Guest Lecture, Dresden, Germany, November 25, 1997.

67. J. H. Reed, “Adaptive antenna arrays,” Dresden University of Technology Guest Lecture, Dresden, Germany, November 26, 1997.

68. J. H. Reed, “Overview of fundamental wireless systems in today’s telecommunications technology,” *46th Annual International Wire Cable Symposium*, Philadelphia, PA, November 17-20, 1997. (Invited tutorial.)

69. J. H. Reed and R. D. James, “Position location: Overview and business opportunities,” *Wireless Opportunities Workshop*, Roanoke, VA, October 22-23, 1997.

70. R. Ertel and J. H. Reed, “Geometrically based spatial channel models,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

71. A. Hannan and J. H. Reed, “GloMo radio API (application program interface,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

72. S. Swanchara, J. H. Reed, and P. Athanas, “Design and implementation of the GloMo multiuser receiver on a reconfigurable computing platform,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

73. N. D. Tripathi, J. H. Reed, and H. VanLandingham, “High performance handoff algorithms using fuzzy logic and neural networks,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

74. D. Breslin and J. H. Reed, “Multi-sensor testbed hardware development at the mobile and portable radio resesarch group,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

75. N. Mangalvedhe and J. H. Reed, “Blind CDMA interference rejection in multipath channels,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

76. K. Phillips, J. Laster, and J. H. Reed "Adaptive signal processing by bit error rate (BER) estimation," *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

77. T. S. Rappaport, J. H. Reed, and T. E. Biedka, "Position location & E-911: Techniques for wireless systems," *IEEE International Conf. Universal Pers. Commun.*, Cambridge, MA, October 1, 1996. (Invited tutorial.)

78. N. Tripathi and J. H. Reed, "DSP implementation of communications systems: An NSF sponsored curriculum development initiative," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

79. B. Fox, G. Aliftiras, I. Howitt, J. H. Reed, and B. D. Woerner, "Flexible hardware architectures for multimode wireless handsets," *Sixth 6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

80. P. Petrus and J. H. Reed, "Geometrically based statistical single bounce macrocell channel model for mobile environments," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session; also in *IEEE Smart Antennas: Adaptive Arrays, Algorithms, & Wireless Position Location*, 1998, pp. 483-487.)

81. GloMo team, "GloMo adaptive antenna array research," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

82. GloMo team, "GloMo mobile yser research," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

83. J. D. Laster and J. H. Reed, "Improved GMSK demodulation using non-coherent receiver diversity," *Sixth 6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

84. K. Khan, J. H. Reed,and I Howitt, "Interference mitigation in AMPS/NAMPS and CMP using artificial neural networks," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

85. N. Tripathi, J. H. Reed, and H. VanLandingham, "Neural net & fuzzy logic approaches to handoffs in cellular systems," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

86. K. Saldanha and J. H. Reed, "Performance evaluation of an AMPS digital base station with automatic gain control," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

87. R. He and J. H. Reed, "System capacity improvement by ysing DSP interference rejection techniques," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

88. B. D. Woerner, T. S. Rappaport, and J. H. Reed, "Improved spectral efficiency for CDMA systems," *Wireless Technology Conf. Exposition Proceedings*, Stamford, CT, September 1995.

89. P. Petrus and J. H. Reed, "New blind multichannel filtering techniques," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

90. N. Zecevic and J. H. Reed, “Comparative study of adaptive CDMA interference rejection techniques,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

91. M. Majmundar and J. H. Reed, “Interference rejection for IS-54,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

92. D. Bailey and J. H. Reed, “MPRG: Signal processing and communications laboratory,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

93. R. He and J. H. Reed, “Co-channel interference for AMPS and NAMPS signals,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

94. N. Mangalvedhe and J. H. Reed, “An Eigenstructure technique for soft synchronization of DSSS signals,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

95. M. Welborn and J. H. Reed, “Interference rejection using model-based spectral estimation,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

96. A. Amanna, R. James, and J. H. Reed, “Communications on the smart road,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

97. F. Dominique and J. H. Reed, “Development of a frequency hopping system for the 902-928 MHz ISM band,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

98. S. Elson and J. H. Reed, “Modeling CDPD,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.).

99. P. Petrus, F. Dominique, and J. H. Reed, “Spectral redundancy exploitation in narrowband interference rejection for a PN-BPSK system,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

100. F. Cheng and J. H. Reed, “Dynamic range enhancement techniques for RF and fiber optic interface,” *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

101. P. Petrus and J. H. Reed, " Blind adaptive arrays for mobile communications,” *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

102. R. He and J. H. Reed, “Spectral correlation of AMPS signals with applications to interference Rrejection,” *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

103. R. Zheng and J. H. Reed, “System modeling and interference rejection for spread spectrum CDMA automatic vehicle monitoring systems,” *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

104. N. Mangalvedhe and J. H. Reed, "An eigenstructure technique for soft spread spectrum synchronization," *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

105. R. Holley and J. H. Reed, "Time-dependent filters For CDMA interference rejection," *3rd Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1993. (Poster session.)

Technical Reports:

1. Y. Zhao, "Enabling cognitive radios through radio environment maps," MPRG-TR-07- Ph.D. dissertation, May 2007.

2. R. Menon and J. H. Reed, "Interference avoidance based underlay techniques for dynamic spectrum sharing," MPRG-TR-07-, Ph.D. dissertation, April 2007.

3. J.-H. Kim and J. H. Reed, "On the impact of MIMO implementations on cellular networks: An analytical Aapproach from a system perspective," MPRG-TR-07-, Ph.D. dissertation, March 2007.

4. R. Chembil Palat and J. H. Reed, "Performance analysis of cooperative communications for wireless networks," MPRG-TR-06-, Ph.D. dissertation, December 2006.

5. J. O. Neel and J. H. Reed, "Analysis and design of cognitive radio networks and distributed radio resources management in algorithms," MPRG-TR-06-14, Ph.D. Dissertation, September 2006.

6. C. R. Anderson and J. H. Reed, "A software defined ultra wideband transceiver testbed for communications, ranging, and imaging," MPRG-TR-06-13, Ph.D. dissertation, September 2006.

7. C. R. Anderson, S. Venkatesh, D. Agarwal, R. Michael Buehrer, P. Athanas, and J. H. Reed, "Time interleaved sampling of impulse ultra wideband signals: Design challenges, analysis, and results," MPRG-TR-06-12, technical report, August 2006.

8. J.-H. Kim and J. H. Reed, "Efficacy of transmit smart antenna at mobile station in cellular networks," MPRG-TR-06-09, Ph.D. preliminary, May 2006.

9. J. A. DePriest and J. H. Reed, "A practical approach to rapid prototyping of SCA waveforms," MPRG-TR-06-06, M.S. thesis, April 2006.

10. B. M. Donlan, R. M. Buehrer, and J. H. Reed, "Ultra-wideband narrowband interference cancellation and channel modeling for communications," MPRG-TR-05-02, M.S. thesis, January 2005.

11. S. Vasudevan and J. H. Reed, "A simulator for analyzing the throughput of IEEE 802.11b wireless LAN systems," MPRG-TR-05-01, M.S. thesis, January 2005.

12. A. M. Hebbar and J. H. Reed, "Empirical approach for rate selection in MIMO OFDM," MPRG-TR-04-11, M.S. thesis, December 2004.

13. C. R. Anderson, A. M. Orndorff, R. M. Buehrer, and J. H. Reed, “An introduction and overview of an impulse-radio ultrawideband communication system design,” MPRG_TR-04-07, technical report, May 2004.

14. J. Hicks and J. H. Reed, “Novel approaches to overloaded array processing,” MPRG-TR-03-19, Ph.D. dissertation, August 2003.

15. R. Mostafa and J. H. Reed, “Feasibility of smart antennas for the small wireless terminals,” MPRG-TR-03-12, Ph.D. dissertation, April 2003.

16. S. Krishnamoorthya and J. H. Reed, “Interference measurements and throughput analysis for 2.4 GHz wireless devices in hospital environments,” MPRG-TR-03-10, M.S. thesis, April 2003.

17. P. M. Robert and J. H. Reed, “Reduction in coexistent WLAN interference through statistical traffic management, MPRG-TR-03-09, Ph.D. dissertation, April 2003.

18. W. G. Newhall and J. H. Reed, “Radio channel measurements and modeling for smart antenna array systems using a software radio receiver,” MPRG-TR-03-08, Ph.D. dissertation, April 2003.

19. Y. Ahmed and J. H. Reed, “A model-based approach to demodulation of co-channel MSK signals,” MPRG-TR-02-24, M.S. thesis, December 2002.

20. R. Chembil Palat and J. H. Reed, “VT-STAR design and implementation of a test bed space-time block coding and MOMI channel measurements,” MPRG-TR-02-19, M.S. thesis, October 2002.

21. W. Newhall and J. H. Reed, “Radio channel measurements, modeling, and characterization for antenna array Ssystems,” MPRG-TR-02-16, Ph.D. preliminary, August 2002.

22. B.-L. Cheung and J. H. Reed, “Simulation of adaptive array algorithms for OFDM and adaptive vector OFDM systems,” MPRG-TR-02-15, M.S. thesis, September 2002.

23. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, “Navy collaborative integrated information technology initiative,” report #19, MPRG-TR-02-13, technical report, April 2002.

24. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, “Navy collaborative integrated information technology initiative,” report # 17, MPRG-TR-02-05, technical report, January 2002.

25. S. Marikar, L. DaSilva, and J. H. Reed, “Resource management in 3G systems employing smart antennas,” MPRG-TR-02-04, M.S. thesis, January 2002.

26. P. M. Robert and J. H. Reed, “Reduction in coexistent WLAN interference through statistical traffic management,” MPRG-TR-02-01, Ph.D. preliminary, August 2001.

27. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, “Navy collaborative integrated information technology initiative,” report # 16, MPRG-TR-01-17, technical report, October 2001.

28. M. Soni, P. Athanas, and J. H. Reed, “Computing engine for reconfigurable software radio,” MPRG-TR-01-15, M.S. thesis, October 2001.

29. T. E. Biedka and J. H. Reed, “Analysis and development of blind adaptive beamforming algorithms,” MPRG-TR-01-14, Ph.D. dissertation, August 2001.

30. R. Gozali, R. Mostafa, P. M. Robert, R. Chembil Palat, W. Newhall, B. D. Woerner, and J. H. Reed, “Design process of the VT-STAR multiple-input multiple-output (MIMO) test bed,” MPRG-TR-01-12, technical report. August 2001.

31. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, “Navy collaborative integrated information technology initiative,” report # 15, MPRG-TR-01-11, technical report, July 2001.

32. S. Srikanteswara and J. H. Reed, “Design and implementation of a soft radio architecture for reconfigurable platforms,” MPRG-TR-01-10, Ph.D. dissertation, July 2001.

33. R. Mostafa and J. H. Reed, “Feasibility of transmit smart antenna at the handset,” MPRG-TR-01-07, Ph,D. preliminary, December 2000.

34. J. Hicks and J. H. Reed, “Overloaded array processing with spatially reduced search joint detection,” MPRG-TR-00-08, M.S. thesis, May 2000.

35. T. Biedka and J. H. Reed, “A general framework for the analysis and development of blind adaptive algorithms,” MPRG-TR-OO-O5, Ph.D. preliminary, April 2000.

36. S. Srikanteswara and J. H. Reed, “Design and implementation of a soft radio architecture for reconfigurable platforms,” MPRG-TR-00-02, Ph.D. preliminary, November 1999.

37. R. B. Ertel and J. H. Reed, "Antenna array systems: Propagation and performance,” Ph.D. dissertation, July 1999.

38. N. R. Mangalvedhe and J. H. Reed, “Development and analysis of adaptive interference rejection techniques for direct sequence code division multiple access systems,” Ph.D. dissertation, July 1999.

39. K. Phillips and J. H. Reed, “Probability density function estimation for minimum bit error rate equalization,” MPRG-TR-99-04, M.S. thesis, May 1999.

40. Z. Hu and J. H. Reed, “Evaluation of joint AOA and DOA estimation algorithms using the antenna array systems,” MPRG-TR-99-02, M.S. thesis, December 1998.

41. R. B. Ertel and J. H. Reed, "Antenna array systems: Propagation and performance," MPRG-TR-98-12, Ph.D. preliminary, December 1998.

42. N. R. Mangalvedhe and J. H. Reed, "Development and analysis of adaptive interference rejection techniques for direct sequence code division multiple access systems," MPRG-TR-98-13, Ph.D. preliminary, December 1998.

43. P. M. Robert and J. H. Reed, "Simulation tool and metric for evaluating wireless digital video systems," MPRG-TR-98-11, M.S. thesis, September 1998.

44. S. F. Swanchara and J. H. Reed, “An FPGA-based multiuser receiver employing parallel interference cancellation,” MPRG-TR-98-06, M.S. thesis, July 1998.

45. N. Tripathi and J. H. Reed, “Generic handoff algorithms using fuzzy logic and neural networks,” Ph.D. dissertation, MPRG-TR-97-18, November 1997.

46. D. Breslin and J. H. Reed, “Adaptive antenna arrays applied to position location,” MPRG-TR-97-14, M.S. thesis, August 1997.

47. S. Nicoloso and J. H. Reed, “Investigation of carrier recovery techniques for PSK modulated signals in CDMA and multipath mobile environments,” MPRG-TR-97-11, M.S. Thesis, May 1997.

48. N. Tripathi, J. H. Reed, and H. VanLandingham, “An adaptive direction biased fuzzy handoff algorithm with unified handoff candidate selection criterion,” MPRG-TR-97-08, April 1997.

49. N. Tripathi, J. H. Reed, and H. VanLandingham, “An adaptive algorithm using neural encoded fuzzy logic system,” MPRG-TR-97-07, April 1997.

50. N. Tripathi, J. H. Reed, and H. VanLandingham, “A new class of fuzzy logic based adaptive handoff algorithms for enhanced cellular system performance,” MPRG-TR-97-06, April 1997.

51. B. Fox and J. H. Reed, “Analysis and dynamic range enhancement of the analog-to-digital interface in multimode radio receivers,” MPRG-TR-97-02, February 1997.

52. A. Alexander, S. Panchapakesan, D. Breslin, J. H. Reed, T. Pratt, and B. D. Woerner, “The feasibility of performing TDOA based position location on existing cellular infrastructures,” MPRG-TR-96-37, December 20, 1996.

53. N. Tripathi and J. H. Reed, “Handoffs in cellular systems: A tutorial,” MPRG-TR-96-35, November 1996.

54. N. Zecevic and J. H. Reed, “Interference rejection techniques for the mobile unit direct-sequence CDMA receiver,” MPRG-TR-96-27, August 1996.

55. K. J. Saldanha and J. H. Reed, “Performance evaluation of DECT in different radio environments,” MPRG -TR-96-28, August 1996.

56. R. He and J. H. Reed, “AMPS co-channel interference rejection techniques and their impact on system capacity,” MPRG-TR-96-25, July 1996.

57. N. Zecevic and J. H. Reed, “Techniques and adaptation algorithms for direct sequence spread spectrum capacity,” MPRG-TR-96-27, July 1996.

58. M. K. Khan, J. H. Reed, and I. Howitt, “Interference mitigation in AMPS/NAMPS and GSM using artificial neural networks,” MPRG-TR-96-24, June 1996.

59. J. H. Reed, T. S. Rappaport, and B. D. Woerner, “What you should know before returning to school,” *RF Design*, pp. 67-69, March 1996.

60. T. Biedka and J. H. Reed, “Direction finding methods for CDMA mobile wireless systems,” MPRG-TR-96-20, June 1996.

61. Y. M. Vasavada and J. H. Reed, “Performance evaluation of a frequency modulated spread-spectrum system,” MPRG-TR-96-13, February 1996.

62. M. V. Majmundar and J. H. Reed, “Adaptive single-user receivers for direct sequence CDMA systems,” MPRG-TR-96-12, January 1996.

63. R. He and J. H. Reed, “Co-channel interference rejection techniques for AMPS signals using spectral correlation characteristics,” MPRG-TR-96-11, January 1996.

64. J. S. Elson and J. H. Reed, “Simulation and performance analysis of cellular digital packet data,” MPRG-TR-96-08, February 1996.

65. J. D. Laster and J. H. Reed, “Improved GMSK demodulation emphasizing single channel interference rejection techniques,” MPRG-TR-96-05, February 1996.

66. M. Welborn and J. H. Reed, “Co-channel interference rejection using model-based demodulator” MPRG-TR-96-04, January 1996.

67. F. Dominique and J. H. Reed, “Design and development of a frequency hopper based on the DECT system for the 902-928 MHz ISM band,” MPRG-TR-96-02, January 1996.

68. P. Athanas, I. Howitt, T. S. Rappaport, J. H. Reed, and B. D. Woerner, “A high capacity adaptive wireless receiver implemented with a reconfigurable computer architecture,” MPRG-TR-18, November 1995.

69. N. Mangalvedhe and J. H. Reed, “An eigenstructure technique for direct sequence spread spectrum synchronization,” MPRG-TR-95-04, April 1995.

70. Y. M. Kim, N. Mangalvedhe, B. D. Woerner, and J. H. Reed, “Development of a low power high data rate spread-spectrum modem,” MPRG-PPR-95-01, February 1995.

71. Y. M. Kim, N. R. Mangalvedhe, B. D. Woerner, and J. H. Reed, “Development of a low power high data rate spread-spectrum modem,” MPRG-PPR-95-02, June 1995.

72. P. Petrus and J. H. Reed, “Blind adaptive antenna arrays for mobile communications,” MPRG-TR-95-01, December 1994.

73. S. Yao and J. H. Reed, “Differential detection of GMSK signals,” MPRG-TR-94-27, October 1994.

74. R. Zheng, J. Tsai, R. Cameron, L. Beisgen, B. D. Woerner, and J. H. Reed, “Capacity and interference resistance of spread-spectrum automatic vehicle monitoring systems in the 902-928 MHz ISM Band,” MPRG-TR-94-26, final report to Southwestern Bell Mobile Systems, October 1994.

75. F.-S. Cheng and J. H. Reed, “A new approach to dynamic range enhancement,” MPRG-TR-94-25, October 1994.

76. R. S. Zheng and J. H. Reed, “Channel modeling and interference rejection for CDMA automatic vehicle monitoring systems,” MPRG-TR-94-21, November 1994.

77. R. He and J. H. Reed, “AMPS interference rejection: Blind time-dependent adaptive filtering - Volume I,” final report to ARGO Systems Inc., MPRG-TR-94-19, July 1994.

78. T. H. Qazi and J. H. Reed, “Model-based demodulation of FM signals - Volume II,” MPRG-TR-94-17, final report to ARGO Systems, August 1994.

79. M. Subramanian and J. H. Reed, “Noncoherent spread-spectrum communication systems,” MPRG-TR-94-14, August 1994.

80. F. Cheng, A. Kelkar, I. Jacobs, and J. H. Reed, “Performance evaluation for the dynamic range enhancement technique (DRET),” MPRG-TR-94-10, final report to Southwestern Bell Technology Resources, September 1994.

81. V. Aue and J. H. Reed, “Optimum linear single user detection in direct-sequence spread-spectrum multiple access systems,” MPRG-TR-94-03, March 1994.

82. R. Holley and J. H. Reed, “Time dependent adaptive filters for interference cancellation in CDMA systems,” MPRG-TR-93-15, September 1993.

Other Papers & Reports:

1. P. M. Robert and J. H. Reed, “Va. Tech finds soft radio’s missing link,” *EE Times*, August 2004.

2. J. H. Reed, T. C. Hsia, and H. Etemad, “Differential demodulation of BPSK using time dependent adaptive filtering,” final report to California MICRO Program, 1992.

3. J. H. Reed, “Adaptive filters and their application to interference rejection,” *Defense Electronics*, pp. 85-86 and 89-90, May 1989.

4. W. Gardner, B. G. Agee, W. A. Brown, C. K. Chen, J. H. Reed, and R. S. Roberts, “A comparison of Fourier transformation and model fitting methods of spectral analysis,” Signal and Image Processing Lab Report No. SIPL-86-4, Department of Electrical and Computer Engineering, University of California, Davis, 1986. (Also in *Statistical Spectral Analysis — A Non Probabilistic Theory*, Prentice-Hall.)

Selected Corporate Report Topics:

* A DSP-Based Receiver for the New North American Digital Cellular Standard
* Spread Spectrum Detection Techniques
* Cyclic Spectral Analysis of Modulated Signals
* Projection of Future High-Volume Digital Communication Systems
* A High Speed Digital Filter for Sample Rate Conversion
* A Least-Squares System Identification Method
* Cyclic Adaptive Filtering for Interference Rejection
* Implementation Issues of Adaptive Interference Rejection Techniques
* Investigation of Modern Spectral Analysis Techniques
* The Performance of Time-Dependent Adaptive Filtering of Real Data
* A Maximum-Likelihood Estimator for Tracking and Detecting Frequency Hopping Signals

* Digital Signal Processing Algorithms for Squelch Control
* A Low-Cost Whitening Filter for Jammer Applications
* Time-Dependent Single Channel and Multi-Channel Interference Rejection Algorithms

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Section V. Public Service / Outreach

Industrial Affiliate / Outside Agency Contacts:

Companies and Government Agencies visited in 2009 - 2012 to promote Wireless@ VT and the Hume Center:

Apple Computer
Booz Allan Hamilton
DARPA
Army Research Lab
ZETA
SAIC
DRT
Laboratory of Telecommunications Science
John Hopkins Applied Physics Lab
NRO
NSA
CRT
Defense Spectrum Office
NIST
NRL
Northrup Grumman
ISI
RINCOM
CERDEC
Award Solution
ONR
Applied Signal Technologies
DSO
GE
MBC
LTS
Nokia
IDA
Motorola
NSA
MA-COMM
Intel
NSF
FCC
FBI
Samsung
Aerospace Corporation
CIA
US Army
Thales Communications
Textronix
ONR
SPAWAR
ATT
Ventura Solutions
Syracuse Research Corp
SPAWAR
I-APRA
L-3
DRS
CAER
Lockheed Martin

Funding Agency Reviewer:

NSF
University of California, MICRO
Kansas 2000
Qtar Science Foundation
ARO
Canadian Foundation for Innovation

Sponsored Visiting Researchers:

Ahmed Darwish from Cairo University, June-September 1999
Yeongjee Chung from Korea, January-August 1999
Shinichi Miyamoto from Kobe, Japan, April 2001-March 2002
Young-Soo Kim from Seoul, Korea, February 2002-February 2003
Friedrich Jondral from Karlsruhe, Germany, April-June 2004
Francisco Portelinha from Brazil, October 2004-February 2006
Seuck Ho Won from Korea, February 2005-January 2006
Duk Kyu Park from Seoul South Korea, January 2007-February 2008
Marojevic Vuk from Spain, September 2007-January 2008
Francisco Martins Portelinha from Brazil, February 2008-March 2008
Jeong Ho Kim from South Korea, July 2008 – February 2010
Stefan Werner Nagel from Germany, August 2009 - October 2009
Arthur Herzog from Darmstadt, Germany April 2010 – June 2010

Conference Organization & Technical Reviewing:

Editorial Board Member for the Proceedings of the IEEE
IEEE Fellows Selection Committee for Computer Society
Organizing Committee for Globecom 2010
Technical Program Committee for IEEE Dyspan 2009/2010
Technical Program Committee for Globecomm 2009
Technical Program Committee for VTC 2009
Technical Program Committee for COMCAS 2009 (and session chair)
Associate Editor for Proceedings of the IEEE, Issue on Cognitive Radio, April & May 2009
Associate Editor for IEEE Journal on Select Area of Communications, Issue on Cognitive Radio
Technical Program Committee for IEEE Conference on Communications
Technical Program Committee for CrownCom
Reviewer

IEEE Transactions on Antennas and Propagation
IEEE Transactions on Wireless Communications
IEEE Transactions on Communications
IEEE Transactions on Signal Processing
IEEE Transactions on Aerospace and Electronics Systems
IEEE Transactions on Selected Areas of Communications
IEEE Signal Processing Letters
IEEE Communications Magazine
IEEE Communications Letters
International Journal of Electronics

Session Chair for the SDR Forum 2007, Denver, CO, November 5 – 9, 2007
Advisory Board, *IEEE International Conf. Ultrawideband (ICU)*, September 2005.
Moderator for the paper session "Ultrawideband Design Approaches," at the *Communications Design Conf.*, March - April 2004.
Moderator for the panel, "UWB Panel on Communication Systems Design," at the *Communications System Design Conf.*, October 2003.
Chair of session titled, "Mobile Computing and Software Defined Radios," at the *International Conf. Engineering Reconfigurable Systems Algorithms (ERSA)*, June 2003.
Co-technical program chairman for the *SDR Forum Conf.*, November 2002.

General Chair for the *UWBST Conf.*, November 2003.
Technical program chairman for the *SDR Forum/MPRG Workshop Smart Antennas*, June 2003.

Federal & State:

President's Council of Advisors in Science and Technology working group on transitioning federal spectrum for commercial use and economic growth, 2011-2012

Army Research Office Board of Visitors, 2012- present

Idaho National Labs Advisory Board, 2012 - present

IEEE Fellows Evaluation Committee for Computer Science, 2012

National Science Foundation workshop co-organizer, *Enhancing Access to the Radio Spectrum*, August, 2010. Goal was to develop a major research program to support spectrum research for the National Broadband Plan. Participants include Secretary of Commerce, a Commissioner of the FCC, interim head of NSF, multiple NSF Division Directors, Whitehouse and Capitol Hill staffers.

US Dept. of Commerce Committee on EARS Regulations 2008-2009. A Federal Advisory Committee Appointed by the Secretary of Commerce To examine EARS Regulations. 2009. *Note current EARS regulations currently represent a major challenge to US industry and academia for engaging international personnel in research and this committee addressed this challenge.* 2007.

Co-Leader for the SDR Forum and Object Management Group of Smart Antenna API standardization efforts 2008-2009

Co-Leader for NSF workshop on SDR held in Ireland on May 12 – 16, 2008.

Virginia Broadband Task Force (headed by now Senator Warner and US CTO Anish Chopra) to examine steps for bridging the digital divide.

DARPA panel member to identify and create new programs for DARPA to support NSA. This activity is expected to result in $60M – $80M in new DARPA programs. 2007

Workshop help DARPA define a new program in bio-mimesis, the imitation of living organisms through electronics and mechanics.

Assisted the Army Research Office in developing their five year research plan forcommunications.

University Professional Service Current & Past:

Distinguished Lecturer for the IEEE Vehicular Technology
Director Wireless @ Virginia Tech
Interim Director, Ted and Karyn Hume Center
Participation within the Center for Wireless Telecommunications (CWT)
Department Computing Committee
Faculty Advisor to the Honor System

Faculty Advisory Committee, Information Technology for VT
EE Graduate Administrative Committee (Grad AdCom)
Communications Area Committee
US Student Recruitment Strategy Task Force
Course supervisor of ECPE 5674 and ECPE 4654
ECE Department Head Search Committee
ECE Executive Committee
ECE Resource Committee
Deputy Director, MPRG
ECE Recruiting Committee

Section VI. Industrial Experience

Industrial Employment:

Allied Communications, co-founder, 2011- present
Power Fingerpring, Inc. President and Co-Founder, 2011-Present
Cognitive Radio Technology, LLC. CTO and co-founder, 2007- Present
Co-founded Dot Mobile, Inc. March 2000-2001
(Company specializes in mobile data applications including wireless-internet based applications.)

Past Clients

ACM Systems	Grass Valley Group
Analog Devices	BRTRC
DIGCOM	E-Systems
F&S	General Dynamics
Gray Cary	Harris Broadband
Honeywell	HRL
IWT	Jones Day
NORCOMM	SAIC
Labarge	IDA
SRC	Weil
Samsung	MITRE
Shafer	SCA Technica
IIT	Navsys
US Navy	Tantivy
Arnold Porter	Sidley Austin

Founded Reed Engineering, March 1986 – Present
(Company performs consulting, expert witnessing and training in wireless communications and signal processing.)

Member, Technical Staff Signal Science, Inc., Santa Clara, CA, 1980-1985

Areas of Specialization:

- Spread spectrum detection
- Foreign technology analysis
- Computer systems administration

Past and Current Advisory Board Positions:

TechContinuum
Samsung Telecommunications
Spyrock
Totus Lighting
Airbee
FAWNA
Wayve Tech

Selected past industry projects:

- Technical Evaluation of AT&T and T-Mobile Merger
- Comments on FCC NPR making
- Expert Witness Wireless Email
- Software Architecture for Radios
- Company acquisition evaluation
- Expert witness in wireless location systems (multiple times)
- Evaluation of a wireless high-speed internet access system
- Evaluation of wireless/signal processing companies for acquisition
- Tutorials on software radio issues
- Tutorials on trends in wireless communications
- Adaptive interference rejection techniques
- Spread spectrum signal detection
- Expert witness for wireless power sources
- Study Panelist for NSA/DARPA programs via Schafer Corp.
- Advising on Trends in Communications: SAIC
- Provide Survey of Low Power Communications Trends: Mitre Corporation

ATTACHMENT B

(Professor Tripathi CV)

Nishith D. Tripathi, Ph. D.
419 Stonebridge Circle, Allen, TX 75013
Tel.: 214-477-3516 and E-mail: ntripathi123@att.net

AREAS OF EXPERTISE

LTE (E-UTRAN and EPC), LTE-Advanced, IMS, WiMAX, 1xEV-DO (Rev. 0 and Rev. A), UMTS R99, HSDPA, HSUPA, HSPA+, CDMA2000 1xRTT, IS-95, CDMA, OFDM, OFDMA, Advanced Antenna Technologies, IP-related Technologies

PUBLICATIONS

- Author of an upcoming **book** (with Jeffrey H. Reed), "Cellular Communications: A Comprehensive and Practical Guide," ***Accepted for Publication by IEEE/Wiley***, 2013. (**Book Contents**: Introduction to Cellular Communications, Elements of a Digital Communication System, Radio Propagation, IP Fundamentals, GSM, GPRS, EDGE, IS-95, CDMA2000 1xRTT, R99 UMTS/WCDMA, 1xEV-DO Rev. 0, HSDPA, 1xEV-DO Rev. A, HSUPA, HSPA+, IMS, Emerging 4G Technologies)
- Author of a **book** (with Jeffrey H. Reed and Hugh F. VanLandingham), "Radio Resource Management in Cellular Systems," Kluwer Academic Publishers, 2001.
- Contributor (With Jeffrey H. Reed) to the article, "Technical Challenges in Applying Network Neutrality Regulations to Wireless Systems," in the **book** titled "Net Neutrality: Contributions to the Debate," Edited by Jorge Perez Martinez, 2011.
- Author of one chapter in the **book**, "Neuro-Fuzzy and Fuzzy-Neural Applications in Telecommunications," Editor- Peter Stavroulakis, Springer, April 2004.

EXPERIENCE

AWARD SOLUTIONS *March '04 to Present*

Director and Principal Consultant

- Successfully launched a new program to ensure and develop SME (Subject Matter Expert) expertise in the areas of LTE RAN and Ethernet-based Backhaul. Developed processes and plans to facilitate SME certification. Devised expertise development plans, on-line tests, and defense tests. Directed the oral defense meetings for the final stage of SME certification.
- Managed and led SMEs for following course development projects: LTE Bootcamp-Phase II (**Topics**: End-to-end Data Sessions in LTE-EPC, PCC: QoS and Charging Architecture for LTE, Voice over LTE (VoLTE) using IMS, Voice services using CSFB and SRVCC, LTE and eHRPD Interworking, LTE and GSM/UMTS interworking, and LTE-Advanced), and LTE Radio Network Planning and Design.
- Mentored SMEs to prepare them to teach technologies such as LTE, WiMAX, OFDM, and Advanced Antennas.
- Developed courses on LTE-Advanced and TD-LTE.
- Developed two sessions, TD-LTE and Self Organizing Network (SON), as part of LTE Bootcamp- Phase II for an infrastructure vendor.
- Enhanced the LTE Radio Network Planning and Design course to reflect configurations of commercial deployments using LTE log-files and to adhere to customer-specific RF design guidelines.
- Continued to teach a variety of LTE and HSPA+ courses (e.g., VoIP, IMS, and IPv6 for LTE and HSPA+ Signaling) at new and existing clients.
- Delivered several web-based sessions of LTE Bootcamp- Phase II.

Lead SME

- Taught *first-time offerings* of courses at various clients to acquire new training business.
- Managed and guided SMEs for timely and quality-controlled completion of following course development projects: LTE/1xEV-DO Interworking, EPC Overview, HSPA+

Overview, Fundamentals of RF Engineering, IP Convergence Overview, and Advanced Antenna Techniques.

- Devised and implemented strategies to maximize the quality of project deliverables and to accelerate the completion of the deliverables.

SME- Course Development

- Developed an in-depth LTE Bootcamp Series for an infrastructure vendor (**Topics**: EPS Network Architecture, OFDMA/SC-FDMA, Radio Channels, System Acquisition & Call Setup, DL & UL Traffic Operations, Handover, and Antenna Techniques).
- Developed numerous instructor-led and web-based training courses by working in a team environment (**Examples**: Interworking of LTE with 1xEV-DO & 1xRTT, LTE Air Interface, WiMAX Essentials, WiMAX Network Planning, UMB, 1xEV-DO, HSUPA, Multiple Antenna Techniques, and IP Convergence).
- **Example Course Contents**: Network architecture, air interface features, DL & UL data transmission, call setup, handover/handoff, resource management, and interworking.
- Designed outlines for several new courses.

Senior Consultant- Training

- Taught *in-person* and *web-based* (via WebEx and LiveMeeting) courses at major chip-set manufacturers, infrastructure & device vendors, service operators, and test-tool vendors.
- Delivered an in-depth LTE bootcamp multiple times for a major LTE infrastructure vendor.
- **Area Expertise**: LTE Radio Network Planning & Design (including Certification), Interworking of LTE with (1xEV-DO, 1xRTT, UMTS, and GERAN), LTE Protocols & Signaling, LTE Air Interface, WiMAX Networks and Signaling, 1xEV-DO Optimization, 1xEV-DO Rev. 0 and Rev. A, IP Fundamentals, HSDPA/HSUPA/HSPA+, UMTS R4/R5 Core Networks, UMTS Network Planning and Design
- Strived to make the training experience full of *relevant* knowledge and to maximize the value of training to students.

VIRGINIA TECH *Spring 2010 to Present*

Adjunct Assistant Professor

- Co-taught the cellular communications class.
- Developed and presented the lecture material. Designed and graded quizzes.
- Helped educate the NSF about LTE and LTE-Advanced.

HUAWEI TECHNOLOGIES *October '01 to March '04*

Product Manager and Senior Systems Engineer

- Worked with engineers to resolve numerous **field trial issues** for **CDMA2000** systems.
- Defined test procedures for various features to evaluate performance of the CDMA2000 product.
- Designed advanced RL MAC and Power Control algorithms for a 1xEV-DO System.
- Designed various high-performance radio resource management (RRM) algorithms for the **CDMA2000** base station and base station controller. Major designed features include adaptive forward link and reverse link call admission control algorithms, dynamic F-SCH rate and burst duration assignment algorithms, R-SCH rate assignment algorithm, F-SCH burst extension and termination mechanisms, schedulers, forward link and reverse link overload detection and control algorithms, SCH soft handoff algorithm, F-SCH power control parameter assignment mechanism, adaptive radio configuration assignment algorithm, load balancing algorithm, and cell-breathing algorithm.
- Worked on the design of an RRM simulator to evaluate the performance of call admission control, load control, and scheduling algorithms for a **CDMA2000** system.
- Designed system level and network level simulators to evaluate the capacity gain of the smart antenna-based **UMTS** systems employing multiple beams.

- Reviewed **UMTS** RRM design and proposed enhancements related to call admission control, cell breathing, load balancing, soft capacity control, potential user control, and AMR control.
- Educated engineers through presentations to facilitate development of the **1xEV-DO** product.
- Led a team of engineers to define a comprehensive **simulation tool-set** consisting of link level simulator, system level simulator, and network level simulator to evaluate performance of CDMA systems including **IS-95**, **IS-2000**, **1xEV-DO**, **1xEV-DV**, and **UMTS**.
- Managed a group of engineers, prepared project plans, and established efficient processes to meet the requirements of the **CDMA2000** BSC product line.

NORTEL NETWORKS *September '97 to September '01*

Senior Engineer

Radio Resource Management, July '99 to Sept. '01

- Developed a comprehensive RRM simulator that models data traffic and major features of the MAC layer and physical layer. Analyzed various aspects of the RRM for several test cases. The performance results such as capacity and throughput were used in educating the service providers on the RRM for IS-2000 systems.
- Proposed a generic call admission control algorithm and filed a patent with the U.S. Patent Office.

Management of Supplemental Channels, June '00 to Sept. '01

- Designed and analyzed supplemental channel management for enhanced data performance and filed a patent with the U.S. Patent Office.

Data Traffic Modeling, Jan. '99 to Sept. '01

- Prepared a common framework for data traffic models for analysis of systems carrying data (e.g., 1xRTT and UMTS). Types of analysis include RF capacity, end-to-end performance, and provisioning. The data models for telnet, WWW, ftp, e-mail, FAX, and WAP services are considered.

Multi-Carrier Traffic Allocation, June '99 to Sept. '01

- Provided MCTA capacity improvements (compared to non-MCTA systems) that proved to be identical to the ones observed during the field-testing. Developed a method to estimate the MCTA capacity using the field data. This method was used in estimating MCTA capacity gains by RF engineering teams.

SmartRate and Related Vocoder Designs (e.g., SMV), June '99 to Sept. '01

- Provided estimates of SmartRate capacity improvements that were found to be close to the observed capacity gains in the field tests.

CDMA Based Fixed Wireless Access Systems, Sept. '97 to Dec. '98

- **Capacity Estimates**. Determined the system capacity for a variety of configurations using an IS-95 based simulator. These configurations include different rates such as 9.6 kbps and 13 kbps, different deployment scenarios such as 2-tier embedded sector and border sector, and different diversity techniques such as switch antenna diversity and phase sweeping transmit diversity. These capacity estimates were used for various project bids. The simulator utilizes propagation channel models extracted from the actual field measurements.
- **Handoff and Power Control Algorithms**. Analyzed existing handoff and power control mechanisms for fixed wireless systems and proposed new approaches.
- **Bridge between the Simulator and a Deployed System**. Developed a procedure to estimate the loading level for the simulator so that the capacity estimate from the simulator is close to the achieved capacity in real systems.
- **Switch Antenna Diversity Schemes**. Proposed three algorithms to exploit mobile switch antenna diversity. These schemes provide a low-cost solution that significantly enhances RF capacity.
- **Combined Overhead Power and Handoff Management**. Proposed a method of combined management of overhead channel power and handoff to improve capacity.

Educator

- Made presentations on topics such as data modeling, fixed wireless systems, and AI tools.
- Taught "Introduction to Wireless" class at Nortel.
- Prepared tutorials on the standards such as 1xRTT, 1xEV-DO, and UMTS.

VIRGINIA TECH *January '93 to August '97*

Research/Teaching Assistant, Mobile & Portable Radio Research Group (MPRG), Electrical Engineering

- Developed adaptive intelligent handoff algorithms to preserve and enhance the capacity and the Quality of Service of cellular systems.
- Helped *develop* and *teach* a new wireless communications course **(DSP Implementation of Communication Systems**) as part of an **NSF** sponsored curriculum innovations program. Implemented different subsystems of a communication system (e.g., a digital transmitter, a carrier recovery system, a code synchronizer, and a symbol timing recovery system) using the **Texas Instruments** TMS320C30 DSP development system.
- Refined the class material for undergraduate and graduate signal processing classes.
- Investigated different aspects involved in dual-mode adaptive reconfigurable receivers as part of a project sponsored by **Texas Instruments**.

PATENTS/DRAFTS (AUTHOR/CO-AUTHOR)

- Enhanced Power Control Algorithms for CDMA-Based Fixed Wireless Systems, Patent Number 6,587,442, Filed Date: October 28, 1999.
- Method and apparatus for managing a CDMA supplemental channel, Patent Number 6,862,268, Filed Date: December 29, 2000.
- Dynamic Power Partitioning Based Radio Resource Management Algorithm, Patent Disclosure No.: 11942RR, Filed Date: August 23, 2000.
- Switch Antenna Diversity Techniques at the Terminal to Enhance Capacity of CDMA Systems, Patent Disclosure No. RR2544, Filed Date: June 19, 1998.
- Adaptive Radio Configuration Assignment for a CDMA System, October 2003.
- Multi-carrier Load Balancing for Mixed Voice and Data Services, October 2003.
- Methodology for Hierarchical and Selective Overload Control on Forward and Reverse Links in a CDMA System, October 2003.
- A New Predictive Multi-user Scheduling Scheme for CDMA Systems, November 2003.
- A New Method for Solving ACK Compression Problem by Generating TCK ACKs based on RLP ACKs on the Reverse Link, October 2003.

ACTIVITIES

Member of **IEEE**. Reviewed research papers for the *IEEE Transactions on Vehicular Technology*, *IEE Electronics Letters* and the *IEEE Control Systems Magazine*.

EDUCATION

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY **Blacksburg, VA**
Ph.D., Wireless Communications, August 1997, Overall GPA: 3.8/4.0
Dissertation: Generic adaptive handoff algorithms using fuzzy logic and neural networks

M.S., Electrical Engineering, November 1994, Overall GPA: 3.8/4.0

GUJARAT UNIVERSITY **Ahmedabad, India**
B.S., Electrical Engineering, September 1992
Graduated among the top 2% of the class.

EXHIBIT B

Design of the FCC Incentive Auctions*

Yeon-Koo Che Phil Haile Michael Kearns

January 25, 2013

*Che is the Kelvin J. Lancaster Professor of Economic Theory, Department of Economics, Columbia University. Haile is the Ford Foundation Professor of Economics, Department of Economics, Yale University. Kearns is Professor and National Center Chair, Department of Computer and Information Science at the University of Pennsylvania. The analysis and comments here are provided by the authors on behalf of AT&T. We thank Eric Maskin (Harvard University) for helpful comments.

Contents

I Executive Summary **1**

1 Overview **1**

2 Strengths of the Proposal **5**

3 Concerns **7**
3.1 Forward Auction 7
3.2 Reverse Auction 10
3.3 Closing Rules 13

4 Key Proposals **14**
4.1 Forward Auction 14
4.2 Reverse Auction 16
4.3 Closing Rules 19

5 Conclusion **20**

II Forward Auction **21**

6 The NPRM and MALS Proposals **21**
6.1 Clock Auction 21
6.2 SMR Auction 22

7 Primary Concerns **23**
7.1 Exposure Risk 23
7.2 Frequency Contiguity 26
7.3 The Overflow Problem 28
7.4 Other Sources of Inefficiency 31

8 Clock Package Auction **34**
8.1 Objects for Sale 36
8.2 Hierarchical Structure 37
8.3 Overview of the Clock Package Auction 39
8.4 Feasible Supply and Feasible Allocations 40
8.5 Total Demand, Excess Demand 42
8.6 Price Clocks 43
8.7 Examples 44
8.8 Properties of the CPA 49

9 Supplementary Bidding **54**

10 Improved Assignment Phase **57**
10.1 Random Priority with Enriched Preferences 58
10.2 Assignment Auction 62

11 Other Concerns and Recommendations **63**
11.1 Generic Licenses 63
11.2 Bidding Credits 64
11.3 Activity Rule 65

III Reverse Auction **67**

12 The NPRM and MALS Proposals **67**
12.1 Descending Clock Auction 68
12.2 Other Reverse Auction Designs 70

13 Primary Concerns **70**
13.1 Computational Complexity 70
13.2 Delay and Uncertainty Due to Target Failures 71

14 Single-Pass Reverse Auction **71**
14.1 Single-Pass: Baseline 72
14.2 Single-Pass with Proxy Bidding 74

15 Addressing Algorithmic Issues **75**
15.1 Background and Context 77
15.2 Computational Complexity in a Descending Clock Auction 80
15.3 Computational Complexity in Sealed-Bid Auctions 87
15.4 Empirical Evaluations of Reverse Auction Mechanisms 89
15.5 Specific Requests for Repacking Constraint Data 93

IV Closing Rules **95**

16 The NPRM and MALS Proposals **95**

17 Primary Concerns with the One-Sided Closing Trial **96**

18 Two-Sided Closing Trial **97**
18.1 Baseline Proposal 97
18.2 Closing Trial with Proxy Bidding 100
18.3 Avoiding Overshooting 101

Appendix A Clock Package Auction Simulations **103**
A.1 Simulation Design 103
A.2 Results: Baseline Specification 108
A.3 Sensitivity Analysis 114

Appendix B Other Concerns with CCA Supplementary Bidding **118**

Appendix C Proof of Theorem 4 **120**

Appendix D Reverse Auction Simulations **122**

Part I

Executive Summary

1 Overview

The FCC's September 2012 Notice of Proposed Rulemaking ("NPRM") proposes an ambitious plan to create a marketplace in which spectrum currently licensed for broadcast television can be repurposed for more highly valued mobile wireless use. This "Incentive Auctions" proposal involves using auctions to determine which users value the spectrum most highly, license spectrum to these users, and compensate current licensees who relinquish spectrum rights. The FCC has conducted many spectrum auctions in the past. But this is the first time an auction to sell spectrum rights is to be combined with an auction to purchase spectrum rights from existing licensees. Designing such a marketplace is complicated not only by incumbent claims on the spectrum, but also by technological constraints for mobile wireless and broadcast television uses.

Broadly speaking, there are two components of the proposed auction design: (1) a *reverse auction* in which current broadcast television licensees can offer to sell their licenses; and (2) a *forward auction* in which mobile wireless carriers may offer to purchase licenses. The quantities of spectrum transferred from broadcast television licensees to wireless carriers in each geographic area will be determined through a sequence of trials, starting with high *target* quantities that subsequently decline as necessary. Payments and spectrum reallocations take place only when a target quantity is identified at which wireless carriers are willing to buy at prices generating revenues that exceed the total cost of purchasing from broadcast television licensees. Indeed, because remaining broadcast television licensees must be "repacked" into another region of the frequency spectrum in order to create a viable wireless

spectrum band plan, buyers will be required to pay prices sufficient not only to compensate sellers, but also to cover repacking costs and costs of administering the auction itself.

The need to repack TV licensees without creating interference introduces significant complications to the design of a reverse auction. Repacking constraints are "global," in the sense that placing a broadcaster in one market in a particular frequency can affect the feasibility of placing broadcasters in the same or nearby frequencies in other markets. For example, Washington, D.C. and Philadelphia, PA are sufficiently proximate that use of a UHF channel in one may preclude use of the same channel in the other market. For the same reason, decisions regarding channel usage in Philadelphia are also likely to affect New York City, which then may affect Bridgeport, CT, and then Boston, MA. Similarly, a Washington D.C. assignment may affect feasible assignments in Baltimore, MD and possibly Richmond, VA. Thus, channel usage can have a "daisy-chain" effect that can link major metropolitan areas—as well as smaller communities—that are hundreds of miles apart.

There is considerable variation across markets in the density of broadcast television licensees, as well as within-market variation in stations' "contours"—geographic coverage areas, which must be substantially maintained after repacking. Further, cross-market variation in the willingness of TV licensees to go off the air creates challenges to designing a viable nationwide band plan, and introduces the likelihood that the prices required to clear a given quantity of spectrum will vary substantially across markets.

The main auction design proposal was developed in Milgrom, Ausubel, Levin, and Segal (2012) ("MALS"). The authors are prominent economists with extensive experience in market design, including the design of prior FCC spectrum auctions. They propose the use of "clock" auctions in both the forward and reverse auctions. In a clock auction, prices are offered by the FCC. Bidders respond by indicating the trades they would like to make at those prices. Prices are then adjusted (e.g., upward in the forward auction), and the process continues until the trades desired by all bidders match the trades that are available.

The term "clock" refers to the fact that price offers are made by the "auctioneer" (here, the FCC), not by bidders. Bidders' choices in the auction are limited to expressions of quantities that would be demanded or supplied at the current price offers. Relative to other types of auction designs, including the Simultaneous Multi-Round (SMR) auction used in prior FCC spectrum auctions, a clock auction offers a number of advantages, including simplification of bidding and assurance that the auction keeps moving toward a final allocation.

The reverse auction would begin with provisional target quantities of spectrum to be cleared in each market. Although there would be a single nationwide reverse auction, it will utilize different clocks for each market and each *relinquishment option*—e.g., go off the air, share with another station, or move to a lower band. The option to "remain in the current band" (i.e., to be repacked) is always available as well. Bidders who do not participate in the auction are automatically assigned to this option. Participation in the auction is strictly voluntary. Clock prices may differ across bidders within a market and may move at different speeds, due to differences in coverage areas, in the feasibility of each option, in the costs of repacking, or in the effect of repacking one station on the ease of repacking others.

The auction clocks begin with high initial ("reserve") prices chosen by the FCC for each feasible relinquishment option in each market. Each bidder selects the option he[1] finds most attractive at these prices. Roughly speaking, prices are then lowered, bidders again express their preferences, and the process iterates until prices reach a level just low enough that the quantity of spectrum offered in each market equals the target quantity.

Complicating this simple description is the fact that feasibility considerations will limit repacking options. Each clearing target determines the amount of spectrum available for repacking bidders who choose to stay on the air. Before prices are adjusted during the auction, the feasibility of repacking each remaining bidder (i.e., the feasibility of adding that bidder to the set to be repacked) must first be checked. If it becomes infeasible for a given

[1] For clarity we use "he" to refer to bidders despite the fact that bidders are firms.

bidder to be repacked, his current relinquishment offer will be provisionally accepted at the current clock price for that option. The feasibility checking iterates until it is the case that each remaining bidder could feasibly be repacked. Only at this point do clock prices decline for these remaining bidders.

In the proposed forward clock auction, the FCC would simultaneously offer licenses in every market. Here the proposed notion of a market is an Economic Area ("EA") as defined by the Bureau of Economic Analysis. There will typically be more than one class of license available in each market; e.g., licenses for 10MHz of "paired" spectrum (5 MHz for wireless uplink, 5MHz for downlink), and licenses for 5MHz of unpaired (downlink only) spectrum. Licenses for different combinations of EA and class are treated as distinct *objects* and will have different clocks. Multiple *units* of each object, corresponding to specific frequencies, will typically be available. However, all units of the same object are treated as generic. At the beginning of the auction, all objects are given low initial (reserve) prices by the FCC. Potential buyers respond to these prices by specifying the number of units of each object that they would wish to purchase at these prices. Prices for objects with excess demand (demand that exceeds the available supply) then rise, and bidders indicate their demands at these new prices. This process continues until the quantity of spectrum demanded in each market is no larger than the associated target quantity. Thus, the forward auction stops at prices just high enough to eliminate excess demand relative to the target quantities.

At this point, the total revenue that would be generated nationwide by selling the target quantities at the forward auction prices are compared to the total cost of purchasing the same quantities at the provisional reverse auction prices. The difference between the total nationwide revenue and total nationwide cost is the *net revenue* that would be generated at the current clearing target. If this net revenue is sufficient to cover the expected nationwide repacking costs, the "grand auction" ends, licenses are reallocated, and all payments are made. If the net revenue is insufficient, there is a provision for continuing the forward

auction to determine whether there are higher prices that forward auction bidders are willing to accept and which would close the gap. If this *closing trial* fails, the clearing targets are reduced. The reverse auction then resumes, pushing prices lower until supply is equated to the new target. Symmetrically, the forward auction resumes, with prices rising until demand is equated to the new targets. Net revenue is checked and the grand auction either terminates or resumes with still lower clearing targets.

2 Strengths of the Proposal

The proposed design has a number of significant virtues.

Simplicity A clock auction keeps the decisions for a bidder as simple as possible: a bidder need only choose the trades he would like to make at the prices currently offered. In the reverse auction, this means choosing one from a short list of relinquishment options, including the option to remain on the air in one's current band. For the forward auction, this means choosing the types and quantities of licenses the bidder would wish to purchase if the current clock prices turn out to be the final prices. The use of generic licenses provides additional simplicity by avoiding artificial distinctions between substantially identical licenses.

Simplicity is one of the dimensions in which the proposed design appears to be a significant improvement on the SMR design used in the previous ("forward") FCC auctions. We discuss the SMR auction in more detail below. Simplicity is also a substantial advantage of the clock design relative to the theoretically attractive but highly opaque Vickrey-Clark-Groves (VCG) auction. In a VCG auction it can be difficult for bidders to understand how their actions translate to outcomes during the auction.

Success The clock auction design ensures that the auctions will proceed to termination in reasonable time and will terminate at a feasible allocation.[2] Some alternative auction designs can stall or proceed only very slowly.

Transparency Identical licenses will trade at identical prices. No bidder will discover that he was excluded despite offering a price more favorable than that at which a similarly situated bidder was allowed to trade. These properties need not hold in a VCG or SMR auction.

Price Discovery In the forward auction, many licenses are offered simultaneously. A bidder's valuation of a particular license may depend on which complementary licenses he is also able to acquire. Further, the desirability of one combination of licenses will depend on the prices at which alternative combinations are available. In a multi-object clock auction, clock prices provide valuable feedback along the way about where all prices are likely to end up. This facilitation of "price discovery" can enable bidders to focus on the most relevant sets of licenses and to reoptimize their spectrum aggregation strategies as the auction proceeds.

Competition The auction design allows bidders on both sides (forward and reverse) to compete on even footing for the most valuable use of the spectrum. No particular type of bidder is treated more favorably than another. And no spectrum is set aside for either use: bids determine the quantity of spectrum allocated to mobile wireless vs. broadcast television. Combined with the use of generic licenses in the forward auction, which avoids artificial thinning of competition, these features will encourage efficiency of the final spectrum allocation.

[2] This assertion is subject to potential computational challenges, disccussed below, that are associated with determining the feasibility of repacking each television licensee that has not already dropped out of the auction.

Limited Scope for Manipulation We see little scope for manipulation that could undermine the efficiency of the allocation or limit revenues generated. This contrasts, for example, with the SMR design, which is susceptible to collusion, signaling, and entry by speculators who can harm both revenues and efficiency.

3 Concerns

We see many favorable features of the MALS proposal and believe it is the best starting point from which to design the details of the incentive auctions. Nonetheless, there are several features that give us concern. Below we discuss a few of the most important issues. In the subsequent section we summarize several proposed modifications that we believe can address these concerns.

3.1 Forward Auction

Exposure Risk Our most serious concern with the proposed forward auction design is its treatment of complementarities between licenses. Such complementarities will exist for many (perhaps the vast majority of) forward auction bidders: any bidder who will wish to assemble coverage over regions larger than a single EA. The clock auction design allows bidders to pursue packages of licenses, but only by offering to buy each individual license that is part of the desired package. Such a strategy becomes problematic when the value of one license is highly dependent on whether other licenses in the package are also acquired.

Consider, for example, a bidder seeking to obtain a coverage footprint in the Philadelphia Major Economic Area ("MEA"), which is comprised of three EAs. Under the MALS auction design, such a bidder would have two options. One is to aggressively pursue all three EA licenses, offering to buy all of them as long as the total cost stays below the value these licenses have to him as a whole. This can be a very risky strategy. It is possible that the

clock stops for one of the EA licenses while prices for the other two rise to levels that make the package unprofitable. A bidder following the aggressive strategy would be stuck: he would be forced to make good on his offer to purchase the first license. This license alone might not allow a viable service offering, but the bidder would be forced pay a price that he agreed to under the assumption that he would be able to offer coverage throughout the Philadelphia MEA. The risk of this highly unprofitable outcome is known as "exposure risk" or the "exposure problem."[3] It is a serious problem for firms seeking to offer service in any area larger than a single EA.

The other option for such a bidder is to bid conservatively, avoiding the exposure risk. This is also undesirable. It can lead to inefficient allocations (if the most valuable use of the spectrum is as part of a package) and to reduced revenues (even if the most valuable use is not in packages). Revenues are of particular importance here due to the interaction between the forward and reverse auctions. Unlike prior FCC auctions, here revenues and efficiency cannot be separated.

Frequency Contiguity A second major concern is that the NPRM and MALS proposals do not make adequate provisions for bidders to obtain contiguous blocks of spectrum. Two types of frequency contiguity are important. First, within a geographic area, wireless service providers seeking to offer LTE or LTE-Advanced services desire significant blocks of spectrum in adjacent frequencies. We understand that such *vertical contiguity* is essential to optimal performance of these technologies. Second, bidders seeking coverage areas encompassing multiple EAs desire licenses in identical frequencies in each EA. We understand that such *horizontal contiguity* minimizes interference at boundaries and allows use of more efficient network deployment.

The current proposals for assigning individual licenses to winners of generic licenses in

[3] See, for example, the extensive discussion of the exposure problem in the edited volume of Cramton, Shoham, and Steinberg (2010).

each EA may address the need for vertical contiguity within a single EA. But they would not allow bidders to express their broader needs for frequency contiguity. For example, the proposed random assignment of specific frequencies to winners in each EA virtually guarantees a lack of horizontal contiguity. The result would be a reduction in bidders' willingness to pay, inefficiently low quantities of spectrum cleared, and inefficient allocation of the spectrum that is cleared.

Other Sources of Misallocation: The Overflow Problem We have already discussed potential misallocation arising from the exposure problem and the needs for frequency contiguity. In some cases misallocation may take the form of *undersell*—failure to sell some units. Misallocation can also arise from other sources. Some, like the possibility that market clearing prices do not exist—are inherent to any allocation mechanism with anonymous prices. However, at least one additional source of misallocation is particular to the MALS design, which provides no language for bidders to express whether their demand for a particular license is driven by interest in a larger bundle of licenses. Without such language, bidders seeking small groups of licenses can face rising prices even when their own demands are not a source of scarcity.

An example will illustrate the problem. Consider the Boston MEA, which includes the Bangor, Portland, and Boston EAs. Suppose that six 10MHz paired licenses are available in Bangor and Portland, but only five in the Boston EA. This implies that at most five bidders could obtain MEA-wide coverage. Suppose that at some point in the auction "regional bidders" seeking MEA-wide coverage (or coverage in a larger area that includes the MEA) are demanding seven licenses, while there is only one Portland EA license demanded by a firm seeking coverage in Portland alone. Suppose the regional bidders have an all-or-nothing strategy in this MEA: they are not interested in any strict subset of the 3 EAs. In such a situation, we would like the auction to "hold on" to the offer of the Portland-only bidder: we

know that only five units of demand from the regional bidders can be satisfied. So selling all licenses requires allocating to the Portland-only bidder. However, under the MALS design, the auction will count eight units of demand for the Portland license, conclude that this license is in excess demand, and raise its price. This will force the Portland-only bidder to either pay a higher price or exit, even though his demand is not a source of scarcity. This will tend to force such a bidder out of the market unnecessarily.

We term this phenomenon the *overflow problem*. With a richer bidding language, the auction design could account for feasibility constraints and limit the extent to which demand for large packages "flows down" to be counted as demand for the smaller packages and individual licenses nested in the larger package. Without such a language, too much demand flows down. This creates artificial competition for smaller bidders. This bias against smaller bidders will lead to undersell and/or inefficient allocations of licenses.

3.2 Reverse Auction

Computational Complexity Fully optimal clearing of a given target quantity of spectrum would minimize the total costs of clearing and of repacking television broadcasters who remain on the air. Reaching this fully optimal solution is certainly infeasible. An immediate problem is that the reservation values of broadcast TV licensees are unknown. Licensees must volunteer to sell and will not oblige if asked to reveal their true reservation values so that the efficient quantity of spectrum could be cleared at the lowest possible cost. This *incentive compatibility* constraint alone makes it impossible to pay each cleared television licensee the lowest price he would accept for his license. A second problem is the computational complexity involved in finding a cost-minimizing allocation. This complexity arises from the effect of repacking one station on the feasibility (or cost) of repacking others. Even if bidders' reservation values were known to the FCC, the cost minimization problem is an integer programming problem of a type known to be computationally hard in general.

The unique challenge in the reverse auction design is to handle adequately both incentive compatibility and computational feasibility while also keeping the rules sufficiently simple and transparent. Here, issues of auction design and computational considerations are intertwined in a way that has not previously been well explored in the theory or practice of auction design.

The clock auction proposed by MALS offers one possible approach. Taking bidding strategies as given, it replaces minimization of total cost with minimization of payments to cleared licensees, subject to sequential verification of repacking feasibility. As long as more bidders than necessary are volunteering to be cleared, prices fall, leading to repacking of bidders with the highest reservation values. In the simplest form of the proposed design, repacking constraints would enter only through verification that it is feasible to repack a bidder before he is offered a new set of prices. This approach puts priority on the cost of clearing relative to the cost of repacking. Only when it is infeasible for a bidder to be repacked would the auction allow repacking costs to affect the choice of which broadcasters are to be cleared. Possible variations include using repacking constraints to adjust relative clock speeds or to score bidders' offers. This would allow repacking costs to play a larger role, but repacking would still be done sequentially, possibly leading to suboptimal choices. The degree of suboptimality may depend heavily on the nature of the repacking constraints, about which the FCC has thus far released little information.

Further, the MALS clock auction does not avoid significant computational challenge. Formally, feasibility checking takes the form of a "graph coloring problem," which is known to be computationally hard in the worst case. Without knowing the fine details of repacking constraints, it is impossible to determine whether the feasibility checking required by the MALS proposal is itself computationally feasible.

The NPRM also entertains other types of reverse auction designs, where full optimization over bids and repacking costs might play a more prominent role. Few details are provided,

making a careful analysis of such options difficult. However the discussion in the NPRM suggests the possibility of a tradeoff between computational complexity and optimality of alternative auction designs. Whether there is such a tradeoff—and where particular proposals lie on (or inside) the frontier—is unclear however, again because the NPRM is vague about the nature of the repacking constraints and imprecise about the amenability of this type of constrained optimization problem to solution using standard algorithms or specialized algorithms adapted to the features of the repacking problem.

Without details of the repacking constraints, it is impossible to evaluate the computational complexity of alternative auction designs, or to evaluate their performance in terms of expenditure, quantity of spectrum cleared, and efficiency.

Real-Time Feasibility Checking A potentially significant drawback of the proposed reverse clock auction is its requirement of real-time feasibility checking. As already noted, feasibility checking is likely be computationally challenging. Requiring that this be done in real time as the auction proceeds may be especially demanding. Because the feasibility of repacking must be checked for each bidder every time clock prices are to be decremented, there will be many opportunities for the auction to stall or even fail altogether, due to computational delay or failure. This may lead to the use of approximate solutions, harming efficiency.

Delay and Uncertainty Due to Target Failures. Because the FCC seeks to find the maximum quantity of spectrum that should be reallocated, the initial clearing targets will almost certainly be too high. It is likely that several clearing targets will need to be tried before reaching one that satisfies the closing conditions for the grand auction.

Under the current rules, each time the target is reduced, the forward auction must pause while reverse auction bidders are reconvened in order to obtain new "supply" prices for the reduced target quantities. In addition to the burden this creates for bidders, this feature of

the auction design will delay completion of the grand auction. It may also introduce uncertainty for reverse auction bidders, since truthful bidding would require some broadcasters to take actions that commit them to assignments days or weeks ahead of other bidders.

3.3 Closing Rules

The MALS proposal recognizes that the forward and reverse auctions could stop at prices that lead to failure of the net revenue requirement even when some bidders would be willing to improve their offers enough for the revenue requirement to be met. Some inefficiency of this type is unavoidable, due to incentive compatibility constraints (Myerson and Satterthwaite (1983)). However, separation of the forward and reverse auctions leads to greater inefficiency than necessary. Although the purpose of the incentive auctions is to allocate scarce spectrum competitively, a clock auction in the forward market induces competition only between mobile wireless carriers. Forward auction bidders compete to be among the provisional winners, but do not compete directly with sellers for final ownership of spectrum. Likewise, a reverse clock auction creates competition only between current broadcast television licensees. Reverse auction bidders compete to be provisional sellers, but the two sides never compete directly to determine how much spectrum should be transferred from potential sellers to potential buyers. The result is that both the forward and reverse auction will tend to stop too soon, i.e., at prices that are unnecessarily low in the forward auction and unnecessarily high in the reverse auction.

This is recognized in the MALS proposal and underlies their suggestion that, when net revenue falls short, the forward auction would continue—prices would continue rising until either the revenue target is reached or total demand falls. This *closing trial* would allow provisional winners in the forward auction to express their willingness to offer better prices when necessary to ensure that they are allocated the licenses they seek. This is an important addition to the design. However there is no such provision for the supply side: reverse

auction bidders lack the corresponding opportunity to improve their price offers to ensure that profitable sales take place. Even if there are reverse auction bidders who would like to offer prices substantially below those set by the reverse auction (recall that these prices are the maximum prices that clear the fixed target), those bidders will have no opportunity to express this. The result will be unnecessary inefficiency. Some trades that both buyers and sellers would like to make will not take place. The total quantity of spectrum shifted from broadcast television to mobile wireless will be inefficiently (and unnecessarily) low.

4 Key Proposals

We offer a number of specific proposals aimed at addressing the concerns described above, as well as others discussed in more detail below. Here we describe the most important of these proposals.

4.1 Forward Auction

Clock Package Auction To address several concerns, including those relating to exposure, horizontal contiguity, and the overflow problem, we propose a variation of the MALS forward auction in which prices are offered not only for EA licenses, but also for a prespecified set of packages. For example, the "objects" offered in the auction might be licenses for each EA, for each Major Economic Area (MEA), for each Regional Economic Area Group (REAG), and for the entire United States. Within the fifty states there are 172 EAs, which lie in 48 MEAs, and 8 REAGs. Thus, relative to the original design, the number of objects for sale would expand only marginally.

As with the MALS proposal, clock prices would start low, with bidders expressing their demands at each set of prices. Prices rise on objects with excess demand until reaching a level at which demand no longer exceeds supply. When possible, prices of packages will equal

the sum of the prices of the package components. However, when feasibility constraints and strong demand for packages necessitate, the package price may exceed the sum of component prices. This ensures that package bidders have no advantage or disadvantage relative to bidders seeking individual licenses and encourages straightforward bidding.

We call this proposed design the Clock Package Action ("CPA").[4] It departs only modestly from the original MALS design, but addresses several of our most important concerns. Important to our proposal is that packages are specified as consisting of horizontally frequency-contiguous spectrum.[5] By allowing bidders to make offers for horizontally contiguous packages, the CPA provides a way for bidders to express the substantial complementarities between individual licenses that may be dependent on horizontal frequency contiguity.

To the extent that the offered packages cover the packages of interest to bidders, the CPA also addresses the problem of bidder exposure arising from geographic complementarities. A bidder interested in a package can bid on the package without risk: if the price climbs to a level that exceeds his valuation of the package, he will be free to stop demanding the package and redirect his interest elsewhere. The CPA also avoids the overflow problem by enriching the bidding language in a way that permits accounting for all feasibility constraints when calculating excess demand. Although there is no strict dominance relation between the CPA and the MALS forward auction design in terms of efficiency or revenue, a simulation study suggests that substantial efficiency and revenue gains from using the CPA may be likely.

Re-Offer Unsold Licenses Whatever the design of the forward auction, there is a significant possibility that some cleared licenses will remain unsold. MALS refers to such unsold licenses as "residue." We give several examples in the text below. An important question is

[4] This is distinct from what has sometimes been called the "Package Clock Auction," a version of what we call "Combinatorial Clock Auction" below.

[5] We discuss possible relaxations in the body of our report.

whether unsold licenses should be re-offered by the FCC. This question is less simple than it may initially seem. On one hand, unused licenses are an obvious source of inefficiency, and selling them also generates additional revenues. On the other hand, anticipation of an opportunity to bid for unsold licenses could distort bidding behavior in the primary auction.

Short of using a VCG mechanism for the forward auction (which we do not recommend), we see no way to completely avoid these opposing concerns. However, we believe the scope for distortion of incentives will be limited when only unsold licenses are to be re-offered after the primary clock auction. Incentives for manipulation may be further reduced if the decision whether to re-offer licenses is left to the discretion of the FCC. We therefore recommend that the FCC preserve the option to re-offer unsold licenses. Revenues generated by such sale should be included in the determination of closing conditions.

We recommend use of another clock auction if unsold licenses are re-offered. As long as the Clock Package Auction is used in the primary auction, we believe this will adequately address issues of exposure risk and needs for frequency contiguity. We therefore believe that the supplemental auction could be implemented using the original MALS forward clock auction design.

4.2 Reverse Auction

Single-Pass Reverse Auction An alternative to the sequence of reverse auctions (at declining targets) proposed by MALS is reverse auction conducted in a single pass. The simple idea is that instead of stopping the auction when prices clearing the first provisional clearing target are reached, the auction would continue and trace out the "supply curve" over the range of potential clearing targets.

In our baseline single-pass proposal, the mechanics of the reverse auction would be identical to that of a single reverse auction in the original design. Suppose that the FCC believes that the feasible range of cleared channels per market is between 8 and 16. The auction

would begin at prices sufficient to ensure that 16 channels were cleared, and continue until only 8 licenses per market were being offered by current TV licensees. The FCC would record bidders' choices at every round of the auction, including intra-round bids, for later use. The interaction between forward and reverse auction would be exactly as originally proposed by MALS. The forward auction would begin with an attempt to satisfy the closing conditions for a quantity Q_1 (say, $16 \times 6\text{MHz} = 96\text{MHz}$ in every market, less whatever is set aside for guard bands or other use). Revenues from the forward auction would be compared to the total costs of clearing Q_1, obtained from the reverse auction. If the net revenues fell short, the target would be reduced to Q_2. However, rather than reconvening the reverse auction to establish the (lower) prices for clearing target Q_2, these new prices would simply be taken from the supply curve obtained from the single-pass reverse auction.

From a bidder's perspective, the single-pass auction is nearly identical to one of the reverse auctions under the MALS proposal. Just as with the MALS proposal, a bidder would need to come prepared with one number (a reservation value) for each possible relinquishment option. A bidder's options during the auction would be identical to those under the original proposal, and the rules determining prices paid to bidders for each relinquishment option would be no different. Just as in the original proposal, bidders' choices between relinquishment options would be binding offers.

The single pass option offers several advantages. One is elimination of the need for a new reverse auction each time a clearing target fails. This would simplify participation in the reverse auction. It would also avoid delay: rather than pausing the forward auction to reconvene reverse auction bidders each time the clearing target is adjusted, the forward auction could proceed without interruption.

The single-pass design also simplifies participation of reverse auction bidders in a "two-sided closing trial" and would further allow the FCC to minimize the likelihood of "overshooting" during a closing trial (see below). This could lead to more cleared spectrum.

Another advantage is that bidders would be assured that all broadcaster offers were chosen the same day; unlike the MALS design, here a bidder need not worry that the final offers of different TV stations might be made days or weeks apart.

A slight variation on our proposal is to conduct the single-pass auction using proxy bidding. This idea was suggested in the NPRM and might offer additional benefits. With proxy bidding, each bidder would report his minimum acceptable price for each relinquishment option to a proxy agent (software). The proxy agent would then bid on his behalf in the clock auction, selecting the profit maximizing option for the bidder at each new set of prices. This would be similar to the proxy bidding system on eBay. A potentially important advantage of proxy bidding is that verification of repacking feasibility (and any other underlying optimization subject to repacking constraints) could be performed offline rather than in real time. Depending on the complexity of the feasibility checking problem, offline feasibility checking may allow more complete solutions of this problem, assuring that maximal spectrum is cleared at the lowest possible cost.

Problem-Specific Constrained Optimization The discussion of computational and algorithmic issues in the NPRM lacks critical detail. The most general lesson one should take from research and practical experience with challenging constrained optimization problems is that good solutions are often problem-specific. It is difficult—often impossible—to prescribe efficient algorithms for solutions for very general classes of problems (e.g., integer linear programming problems). However, specific instances of such problems often have special structure that allow known algorithms to perform well, or that permit the design of new algorithms that perform well by tailoring to this special structure. In some cases this can be shown theoretically, while in others this can be demonstrated convincingly through simulation. Because details on the nature of the actual repacking constraints have not been provided, it is impossible to make specific recommendations, or to draw clear lines between

which proposals under consideration present computational problems, and which do not. We recommend that such information be provided so that industry experts can assist in the evaluation of algorithmic issues and their interaction with the design of the reverse auction rules.

4.3 Closing Rules

Two-Sided Closing Trial We propose an alternative that departs modestly from the MALS "one-sided closing trial" proposal but offers potential for substantial improvement in efficiency. The main idea is that all competitors participate when a closing trial is triggered. This would allow all potential owners of spectrum rights to compete, expressing their willingness to improve upon the provisional prices in the forward and reverse clock auctions when necessary to ensure that their desired trades are consummated.

In the baseline version of our proposal, no change to the main forward or reverse auction is needed. However, if the forward auction reaches a point where excess demand is zero but the nationwide net revenue condition fails, all parties would be told that the clearing conditions have failed. Prices would then be raised in the forward auction while lowered in the reverse auction. For example, in a sequence of rounds, prices in the forward auction could rise by a percentage ρ while those in the reverse auction fall at the same rate. Bidders on each side would express demand/supply at the clock prices, just as in the original forward and reverse auctions. Prices would continue to adjust until either the net revenue condition is satisfied or prices reach a point at which demand falls short of supply.

The advantage of this approach is that it provides both forward and reverse auction bidders the opportunity to express their willingness to accept less favorable prices to ensure that their trades are executed. This can lead to more efficient allocation of spectrum and to outcomes that are preferred by participants in both the forward and reverse markets.

The use of the single-pass reverse auction would allow significant additional efficiency

gains in a two-sided closing trial. This is because a remaining source of potential inefficiency is the miscoordination of the forward and reverse price clocks, which could lead to *overshooting* on one side of the market during a closing trial. The spirit of including reverse auction bidders in the closing trial is that both sides may have some "slack" in the sense that they are willing to accept somewhat less favorable prices if necessary. But it is impossible for the FCC to know which side (or more generally, which bidders) has more slack and, therefore, how quickly to adjust one price relative to another. This leads to the possibility that the clock overshoots valuations on one side before allowing bidders on the opposite side to express their full willingness to adjust the provisional prices. In some cases this could cause a two-sided closing trial to fail when a one-sided trial would have succeeded. With the single-pass reverse auction, much of this inefficiency can be avoided, since the FCC would know the prices at which the clocks would overshoot the valuations of reverse auction bidders. Overshooting on the supply side can be avoided completely, and further adjustments (discussed below) can minimize overshooting on the demand side as well.

5 Conclusion

The FCC and their advisors have developed an ambitious proposal making substantial progress toward design of the incentive auctions. We believe this proposal is an excellent starting point for discussion. Although we see several significant shortcomings, we believe these can be addressed through relatively modest alterations to the MALS design. We have sketched our concerns and proposals above. Below we provide a more extensive discussion of these ideas and others.

Part II

Forward Auction

The purpose of the forward auction is twofold. First, it provides a way for mobile wireless providers to reveal the value they place on spectrum currently allocated for broadcast television use. This is important for assessing how much spectrum has its highest value use in broadcast television vs. mobile wireless service. Second, the forward auction provides a method of determining allocations among mobile wireless providers, and the payments they will make to the FCC. Although the FCC has conducted auctions of spectrum in the past, those auctions served only the second purpose. The interaction between potential buyers (in the forward market) and potential sellers (in the reverse market) is new. In addition, the FCC and its experts seek to take advantage of experience in prior auctions and recent developments in market design.

6 The NPRM and MALS Proposals

6.1 Clock Auction

In the forward clock auction proposed by MALS, the FCC would simultaneously offer licenses in each EA. There will typically be more than one class of license available in each market; e.g., licenses for 10MHz of "paired" spectrum (5 MHz for wireless uplink, 5MHz for downlink), and licenses for 5MHz of unpaired (downlink only) spectrum.[6] Licenses for different combinations of EA and class are treated as distinct *objects* and will have different clocks. Multiple *units* of each object, corresponding to specific frequencies, will typically be

[6] The proposed building block for the forward auction licenses is a 5MHz license. This contrasts with the 6MHz licenses for broadcast television that will be obtained from the reverse auction.

available. However, all units of the same object are treated as generic. At the beginning of the auction, all objects are given low initial (reserve) prices by the FCC. Potential buyers respond to these prices by specifying the number of units of each object that they would wish to purchase at these prices. Prices for objects with excess demand (demand that exceeds the available supply) then rise, and bidders indicate their demands at these new prices. This process continues until the quantity of spectrum demanded in each market is no larger than the associated target quantity. Thus, the forward auction stops at prices just high enough to eliminate excess demand relative to the target quantities.

6.2 SMR Auction

As an alternative, the NPRM mentions the possibility of a Simultaneous Multiround (SMR) ascending auction. The SMR has been used in prior FCC spectrum auctions. In an SMR auction, the FCC would separately identify each license by geography and frequency (there is no generic treatment of licenses). Bidders make price bids on any subset of these specific licenses they desire. The auction proceeds in a sequence of rounds, with prices constrained to move only higher. After each round, the FCC declares a provisional winner for every license. Bidding for all licenses remains open as long as there is bidding activity on any license. The provisional winners become final winners only when bidding activity ceases on all licenses. This feature facilitates aggregation of licenses, but does so most effectively when the bidders regard alternative licenses as substitutes rather than complements.

Although the SMR has a number of virtues, it has a number of significant limitations as well. In an SMR auction bidders must choose which particular license to bid on and how much to raise the current standing bids. This introduces many possible strategies for achieving the same goal, as well as ambiguity in interpreting the behavior of competitors. This inhibits price discovery. Indeed, in early rounds bidders may intentionally "park" their demand on licenses they do not want in order to hide their intentions and inhibit price

discovery. The SMR is also inadequate for guaranteeing efficient aggregation when bidders regard alternative licenses as complements, as will be the case whenever a bidder seeks to assemble a group of licenses covering a region larger than a single EA. Because the bidders make offers for specific frequency blocks in the SMR, a hold out problem can arise: a small bidder can easily win a license that makes it impossible for another bidder to obtain multiple licenses with frequency contiguity. Even worse, a speculator may target such a license for the purpose of reselling for a high price in the resale market (e.g., Pagnozzi (2010)). In this sense, SMR does little to guarantee efficient aggregation and vertical contiguity. Bidders may also attempt to signal or coordinate through bids. Further, the fact that provisional winning bids are identified in each round makes this auction format susceptible to collusion. By contrast, the proposed clock auction eliminates the problem of holdout and enables the FCC to guarantee within-region contiguity. The clock design appears to be less susceptible to collusion.

In what follows we focus on the clock auction proposed by MALS. We believe this is a superior starting point for the forward auction design.

7 Primary Concerns

7.1 Exposure Risk

Our most serious concern with the proposed forward auction design is its treatment of complementarities between licenses. Such complementarities will exist for any bidder who will wish to assemble coverage over regions larger than a single EA. This may be the vast majority of forward auction bidders. The clock auction design allows bidders to pursue packages of licenses, but only by offering to buy each individual license that is part of the desired package. This introduces a substantial exposure risk for bidders.

This risk is especially severe if, as the auction proceeds, each bidder is permitted to

reduce his quantity demanded only for objects whose prices have risen. We believe this is the intended policy in the MALS proposal.[7] However, this rule creates severe exposure risk for bidders whose valuations exhibit complementarities. This point has been emphasized, for example, by Ausubel, Cramton, and Milgrom (2006). We view the proposed rules as creating unacceptable exposure risk to forward auction bidders. This will inhibit efficient aggregation of licenses and lead to conservative bidding, inefficient spectrum allocations, and low revenues. The revenue implications are especially problematic here, due to the role of the net revenue requirement. Unlike prior FCC auctions, issues of revenue and efficiency cannot be separated: low revenues will lead to inefficiently low quantities of spectrum cleared. Further, even ignoring the role of revenues, both large bidders and small bidders (those not themselves subject to exposure risk) can be harmed by the exposure problem. An example illustrates.

Example 1. *Suppose there are 2 licenses, A and B, and three bidders. Bidders' valuations*

$$\begin{aligned} v_1 &= (6, 0, 6) \\ v_2 &= (0, 10, 10) \\ v_3 &= (5, 5, 10 + \beta) \end{aligned}$$

where, for example, bidder 1*'s valuation vector* v_1 *indicates a value of* 6 *for license A alone,* 0 *for license B alone, and* 6 *for the pair. Bidder 3 places positive value on both license, and obtains a complementarity "bonus" of* $\beta > 0$ *if he obtains both, so that his valuation of the pair is* $5 + 5 + \beta$*. Begin with* $\beta = 5$*. In this case the efficient allocation gives license A*

[7] An alternative would be to permit a bidder to reduce his quantity demanded on any license as long as the price rises for some licenses he previously demanded. In the absence of concerns for frequency contiguity (see section 7.2 below), this alternative would avoid the exposure risk arising from geographic complementarities: a bidder interested in a package of licenses could exit the auction if that package becomes expensive, even if that is due to an increase in the price of only one component EA license. However this alternative rule would weaken incentives for straightforward bidding and could lead to substantial undersell.

to bidder 1 and license B to bidder 2. Suppose that bidders use ***straightforward bidding*** *strategies, i.e., at every set of clock prices, each bidder chooses the demand that would yield him the largest profit if the current clock prices turned out to be the final prices. In this case the auction would proceed as follows*[8]

p_A	p_B	*demand*
1	1	A,B,A+B
2	2	"
⋮	⋮	"
6	6	0,B,A+B
6	7	"
⋮	⋮	"
6	10	0,0,A+B

Note that once p_B reaches 9, bidder 3 would like to exit the auction altogether. However, because the auction rules forbid this (only the price of B is rising), the combination A+B is the most profitable demand he is permitted to express. The resulting outcome is bad from all bidders' perspectives: bidder 3 makes a loss; bidders 1 and 2, who should have obtained licenses, obtain nothing.

We might expect bidder 3 to avoid the exposure risk by bidding more conservatively. Suppose he follows a ***conservative straightforward bidding*** *strategy: he uses a straightforward bidding strategy except that he refuses to demand any good whose price exceeds his stand-alone valuation for the good. With such a strategy, the value of β becomes irrelevant to the auction*

[8] In our examples we assume arbitrarily small bid increments, denoted by ϵ when necessary. We show only key "rounds" of the clock auction, listing prices in that round and the demands expressed at those prices. The list of demands in each row of the "demand" column show the objects demanded, with commas separating the demands of each bidder. We write "A+B" to indicate demand for a unit of A and a unit of B.

outcome. The auction will proceeds as follows,

p_A	p_B	*demand*
1	*1*	*A,B,A+B*
2	*2*	*"*
$\vdots$	$\vdots$	*"*
5	*5*	*A,B,0*

Now bidder 3 avoids the exposure problem. Revenues are substantially lower, which may lead to failure of the net revenue requirement. Otherwise, whether the auction allocation is efficient depends on whether efficiency is helped or harmed by eliminating bidder 3 from competition. For small β this is efficient; for $\beta > 6$ it is not.

7.2 Frequency Contiguity

A second major concern is that the NPRM and MALS proposals do not make adequate provisions for bidders to obtain contiguous blocks of spectrum. Two types of frequency contiguity are important. First, within a geographic area, wireless service providers seeking to offer LTE or LTE-Advanced services desire significant blocks of spectrum in adjacent frequencies. We understand that such *vertical contiguity* is essential to optimal performance of these technologies. Second, bidders seeking coverage areas encompassing multiple EAs desire licenses in identical frequencies in each EA. We understand that such *horizontal contiguity* minimizes interference at boundaries and allows use of more efficient network deployment.

The current proposals for assigning individual licenses to winners of generic licenses in each EA may address the need for vertical contiguity within a single EA. But they would not allow bidders to express their broader needs for frequency contiguity.

The MALS proposal suggests the use of a random priority rule for assigning particular

frequencies to winners of the clock auction. The NPRM mentions the possible use of a bidding mechanism for assignment. The currently envisioned version of the random priority rule is problematic if bidders care about horizontal contiguity. Assuming that the generic auction is held for each EA, a random priority rule would work as follows: 1) Each winner rank-orders all possible sets of frequency blocks that equal to the number of licenses he won in the clock auction. 2) The FCC randomly orders all the winners. 3) The winner first on the list is assigned his most preferred blocks; the second on the list is assigned his most preferred block of those remaining, and so on. This procedure will generate inefficient allocations when bidders value horizontal contiguity. This can be illustrated by a simple example.

Example 2. *Suppose there are two EAs, EA_1 and EA_2, and suppose each EA_i has three frequency blocks: A_i, B_i, C_i for $i = 1, 2$. Assume that in the reverse auction all three blocks are cleared in EA_1. In EA_2, only two of them are cleared. Suppose there are three bidders, 1, 2, 3 in the forward auction. Bidder 1 and bidder 2 each won 1 license in each EA, whereas bidder 3 won only one license in EA_1 in the forward generic auction. Suppose 1 and 2 rank: $A_i - B_i - C_i$ in that order in each EA_i, for $i = 1, 2$. And suppose 3 ranks: $C_1 - B_1 - A_1$. Then, bidder 3 gets C_1 in EA_1, but 1 and 2 get (A_1A_2, B_1B_2), (A_1B_2, B_1A_2), (B_1A_2, A_1B_2), (B_1B_2, A_1A_2) with equal probability, 1/4. If it is more valuable for a bidder to win the same frequency block across the EAs, this outcome is inefficient.*

Further, there is no dominant strategy for bidders in the random assignment phase. To illustrate, return to the example and suppose winning A_1A_2 is not much more valuable than winning B_1B_2. It is an equilibrium for 1 to rank $A_i - B_i - C_i$ in each EA $i = 1, 2$ and for 2 to rank $B_i - A_i - C_i$ in each EA_i, $i = 1, 2$. This leads to an efficient assignment of (A_1A_2, B_1B_2, C_1) for bidders 1, 2, and 3, with probability one. While this may suggest that bidders may be able to coordinate on an efficient outcome in equilibrium, in practice such coordination may be difficult to achieve. The lack of strategy-proofness is a drawback. Of

course, if both 1 and 2 value A_1A_2 sufficiently more than B_1B_2, then the above inefficient allocation will be the unique equilibrium.

7.3 The Overflow Problem

The MALS forward auction provides no language for bidders to express whether their demand for a particular license is driven by interest in a larger group of licenses. Without such language, bidders seeking small groups of licenses can face rising prices even when their own demands are not a source of scarcity, leading to bias against small bidders and inefficient allocations.

An example will illustrate the problem. Consider the Boston MEA, which includes the Bangor, Portland, and Boston EAs. Suppose that six 10MHz paired licenses are available in Bangor and Portland, but only five in the Boston EA. This implies that at most five bidders could obtain MEA-wide coverage. Suppose that at some point in the auction "regional bidders" seeking MEA-wide coverage (or coverage in a larger area that includes the MEA) are demanding seven licenses, while there is only one Portland EA license demanded by a firm seeking coverage in Portland alone. Suppose the regional bidders have an all-or-nothing strategy in this MEA: they are not interested in any strict subset of the 3 EAs. In such a situation, we would like the auction to "hold on" to the offer of the Portland-only bidder: we know that only five units of demand from the regional bidders can be satisfied. So selling all licenses requires allocating to the Portland-only bidder. However, under the MALS design, the auction will count eight units of demand for the Portland license, conclude that this license is in excess demand, and raise its price. This will force the Portland-only bidder to either pay a higher price or exit, even though his demand is not a source of scarcity. This will tend to force such a bidder out of the market unnecessarily.

We term this phenomenon the *overflow problem*. With a richer bidding language, the auction design could account for feasibility constraints and limit the extent to which demand

for large packages "flows down" to be counted as demand for the smaller packages and individual licenses nested in the larger package. Without such a language, too much demand flows down. This creates artificial competition for smaller bidders. This bias against smaller bidders will lead to undersell and/or inefficient allocations of licenses.

Within the simple clock auction design proposed by MALS, we see no easy fix. Indeed there is a tension between avoiding the inefficiency introduced by the exposure problem and avoiding those introduced by the overflow problem. The following example illustrates.

Example 3. *Suppose there are two markets, with two licenses available in market A but only one license in market B. Suppose there are six bidders with valuations for A, B, and the pair A+B given by*

$$\begin{aligned} v_1 &= (1,0,1) \\ v_2 &= (3,0,3) \\ v_3 &= (0,6,6) \\ v_4 &= (0,8,8) \\ v_5 &= (2,3,7) \\ v_6 &= (3,5,12). \end{aligned}$$

This type of configuration is highly plausible: markets in which less spectrum can be cleared will tend to be those where licenses are more valuable. The unequal clearing across markets limits the feasible supply of the "package" AB desired by bidders 5 and 6 to one unit. The efficient allocation involves assigning 1 unit of each object to bidder 6, and the remaining unit of object A to bidder 2.

Under the MALS proposal we may expect bidders 5 and 6 to bid cautiously to avoid the

exposure problem. If bidders use conservative straightforward bidding strategies, the auction will proceed as follows:

p_A	p_B	*demand*
1	1	0,A,B,B,A+B,A+B
2	2	0,A,B,B,A+B,A+B
2+ϵ	2+ϵ	0,A,B,B,B,A+B
2+ϵ	3	0,A,B,B,0,A+B
$\vdots$	$\vdots$	$\vdots$
2+ϵ	5+ϵ	0,A,B,B,0,A
2+ϵ	6	0,A,0,B,0,A

The allocation is inefficient. Further, the magnitude of this inefficiency can be made arbitrarily large by changing bidder 6's package valuation.

We might hope that package bidders would bid less cautiously, so that the implications of exposure risk are not so dire. If they do, this will introduce the overflow problem. Supposing that all bidders follow straightforward bidding strategies, the auction will proceed as follows:

p_A	p_B	*demand*
1	1	0,A,B,B,A+B,A+B
2	2	0,A,B,B,A+B,A+B
3	3	0,0,B,B,A+B,A+B
3	4	0,0,B,B,A,A+B
3	5	"
3	6	0,0,0,B,A,A+B
3	7	"
3	8	0,0,0,0,A,A+B

Revenue is higher but the allocation is still inefficient. This time the inefficiency is due to the overflow problem. Although only one A+B pair is feasible, bids by the package bidders drive bidder 2 out of the market, leading to misallocation of one of the market A licenses. This is undesirable, but the MALS auction design does not allow for any distinction between demand for A alone and demand for A as part of the AB package. In addition to the misallocation, bidder 5 falls prey to the exposure risk he ignored and is forced to pay more than his valuation for the license he wins.

7.4 Other Sources of Inefficiency

Nonexistence of Market Clearing Prices

As pointed out by Ausubel and Milgrom (2002), market clearing prices need not exist when some licenses are complements. Suppose for example that there are two licenses (A and B) available and two bidders with valuations

$$\begin{aligned} v_1 &= (4, 5, 15) \\ v_2 &= (7, 9, 9)\,. \end{aligned}$$

Here bidder 1 obtains a significant complementarity when obtaining both licenses, whereas bidder 2 does not. The efficient allocation gives both licenses to bidder 1. For a pair of prices (p_A, p_B) to yield no demand from bidder 2 requires $p_A \geq 7$, $p_B \geq 9$. But at such prices bidder 1 demands no licenses. In the MALS auction, with conservative straightforward

bidding, the auction will proceed as follows:[9]

p_A	p_B	demand
1	1	A+B,B
1	1+ϵ	A+B,B
$\vdots$	$\vdots$	$\vdots$
1	3	A+B,A
1+ϵ	3	A+B,B
1+ϵ	3+ϵ	A+B,A
$\vdots$	$\vdots$	"
3	5	A+B,A
3+ϵ	5	A+B,B
3+ϵ	5+ϵ	A,A
3+2ϵ	5+ϵ	A,B

The allocation is inefficient, and revenues are low relative to the surplus available. With straightforward bidding, the allocation would be worse, with one of the two licenses failing to sell.

We emphasize that the potential lack of market clearing prices is a limitation not just of a clock auction, but of any mechanism in which the same prices are offered to all potential buyers. Anonymity of prices is an attractive feature and may be essential if bidders are to view the auction as fair. However, this feature may lead to some inefficiency, sometimes in the form of undersell.

[9] We assume bidders resolve indifferences between licenses by choosing A. This has no effect on the final allocation and an arbitrarily small effect on revenue.

Miscoordination of Price Clocks

Synchronization of price clocks can be important in any clock auction. A simple example illustrates.

Example 4. *Suppose there are two licenses available, A and B. There three bidders with valuations*

$$\begin{aligned} v_1 &= (5, 0, 5) \\ v_2 &= (0, 9, 9) \\ v_3 &= (3, 6, 12) \end{aligned}$$

where, for example, bidder 3 places value 3 on license A alone, 6 on license B alone, and 12 on the "package" AB. Here the efficient allocation excludes bidder 3. Depending on the synchronization of clocks, the MALS auction could proceed as follows under straightforward bidding:

p_A	p_B	*demand*
1	1	A,B,A+B
⋮	⋮	″
5	5	0,B,A+B
5	⋮	0,B,A+B
5	7	0,B,A+B
5	8	0,B,A+B
5	9	0,B,A

The allocation is inefficient (and bidder 3 faces a loss).[10]

[10]Note that bidder 3 would like to exit the auction entirely at the prices (5,7) but is not permitted to, since only p_B is rising at this point. The most profitable option available to bidder 3 at this point is to continue demanding A+B.

However, if the clocks moved at different speeds (that for B moving twice as fast), efficiency could be achieved with straightforward bidding:

p_A	p_B	*demand*
1	*2*	*A,B,A+B*
2	*4*	*"*
3	*6*	*"*
4	*8*	*A,B,0*

This gives the efficient allocation.[11]

Of course, optimal coordination of clocks depends on the realized valuations and the strategies used by bidders. Perfect synchronization is therefore infeasible. Inefficiency may arise no matter how the price clocks are controlled. However, there may be general principles for synchronization of clocks that can enhance efficiency. For example, clock speeds might be calibrated based on expected final prices, perhaps based on prices in prior FCC spectrum auctions. This issue should be investigated further.

8 Clock Package Auction

MALS mentions the possibility of adding packages to the forward auction. Two ideas are suggested: holding a full Combinatorial Clock Auction ("CCA") as explored in Ausubel, Cramton, and Milgrom (2006), or adding a limited number of packages to the clock auction. We prefer the latter.

The key elements of the CCA are a clock phase used for price discovery, followed by a sealed bid phase that determines winners. We refer readers to Ausubel, Cramton, and

[11] With conservative straightforward bidding, both clock speeds yield the efficient allocation.

Milgrom (2006) and Cramton (2012) for details. Although the CCA has a number of attractive features, it has several others we view as problematic for the FCC forward auction. One concern is the fact that all licenses remain "up for grabs" at the end of the clock auction, with winners not determined until after a sealed bid phase. A second is that the "VCG-nearest core" pricing rule used for the critical sealed-bid phase is opaque, making it difficult for bidders to understand the strategic environment they face. Finally, we are uncertain what effect the sealed bid phase might have on bidding behavior in the clock phase of the auction, particularly given the substantial complementarities between licenses. In the worst case this might lead to poor price discovery, substantial uncertainty for bidders, low revenues, and inefficiently low quantities of spectrum cleared.

We believe that substantial gains can be obtained following the simpler option of adding packages to the clock auction. Here we provide a detailed proposal for doing so, using a simple hierarchical structure to define the set of packages offered. We propose offering packages that cover each Major Economic Area (MEA), each Regional Economic Area Group (REAG), as well as the entire nation. This particular choice is not essential, and our formal description below incorporates the possibility of other "multi-tree" structures. But the EA-MEA-REAG-nationwide structure is natural, and we believe it would capture most of the significant geographical complementarities between licenses.

The introduction of packages to the clock auction is motivated by the issues of exposure risk, need for horizontal contiguity, and the overflow problem, all discussed above. Each is a problem that, if left unaddressed, could lead to inefficient allocations of cleared spectrum, low revenue, and inefficient reduction in the quantity of spectrum traded in the combined forward and reverse auctions. The inclusion of packages in the forward clock auction can address all three issues.

Before proceeding with the details, we emphasize that our proposal

- involves a very modest change to the original proposal;
- does not introduce significant complexity to the auction from the perspective of bidders or the FCC;
- does not set aside any spectrum for packages;
- does not require equalized clearing of spectrum across markets;
- results in no thinning of competition for any license;
- creates no advantage (or disadvantage) for package bidders;
- will not lead to violation of the property that identical licenses sell for identical prices, except when feasibility constraints and excess demand for packages requires superadditive package prices;
- does not appear to introduce new opportunities for undesirable strategic bidding behavior.

8.1 Objects for Sale

As with the original MALS clock auction, the auction is a multi-*unit* multi-*object* auction. An *object* is class of generic license covering a particular geographic area. Typically there will be more than one license of each such class, i.e., more than one *unit* of each object.

For simplicity we assume here that all licenses covering a particular geography are generic. Our proposal easily extends to allow multiple mutually exclusive classes of licenses (e.g., paired vs. unpaired) that are generic within each class. Objects are then defined by their geographic coverage. The elementary geographic building block is the EA. A package object

is a collection of single-EA objects; for example, an MEA license for Philadelphia consists of one EA license in each of the three EAs comprising this MEA .

Let $\mathcal{E}$ denote the set of EAs and $\mathcal{S}$ the set of packages offered. Then

$$\mathcal{O} = \mathcal{E} \cup \mathcal{S}$$

represents the set of objects for sale. Complexity considerations dictate that $\mathcal{O}$ not include all possible subsets of $\mathcal{E}$. Rather, $\mathcal{S}$ should include the packages of greatest importance to bidders. We will assume that $\mathcal{S}$ is chosen so that $\mathcal{O}$ can be placed in a hierarchical structure defined below.

A notion of (sufficient) horizontal contiguity is defined in advance. All objects are specified as consisting of horizontally contiguous allocations of spectrum.[12] No spectrum is set aside for package licenses. Competition in the auction (and feasibility constraints) will determine how much spectrum, if any, is to be allocated to package licenses.

8.2 Hierarchical Structure

For objects k and j in $\mathcal{O}$, we write $k \subset j$ (equivalently, $j \supset k$) if the set of EAs included in object k is a strict subset of those included in j. When $k \subset j$ we will say that j *contains* k. We will say that object j is a *parent* of object k (equivalently, k is a *child* of j) if both (i) $k \subset j$ and (ii) $\nexists \ell \in \mathcal{O}$ such that $k \subset \ell \subset j$. An object may have no parent, one parent, or multiple parents. Let π_j denote the set of j's parents and let χ_j denote the set of j's children.

We represent the parent-child relationships with a directed graph Γ containing one vertex for each object $j \in \mathcal{O}$. For $j, k \in \mathcal{O}$, Γ has a directed edge from j to k if j is a parent of k.

[12] Alternatively, smaller packages (say, MEAs and REAGs) could be specified with a guarantee of horizontal contiguity, with larger packages (say, a national package) coming only with the promise of contiguity when possible.

Figure 1 illustrates with a simple example in which seven objects are for sale: one for each of four EAs, one for each of two MEAs, and one for the "nation" as a whole.

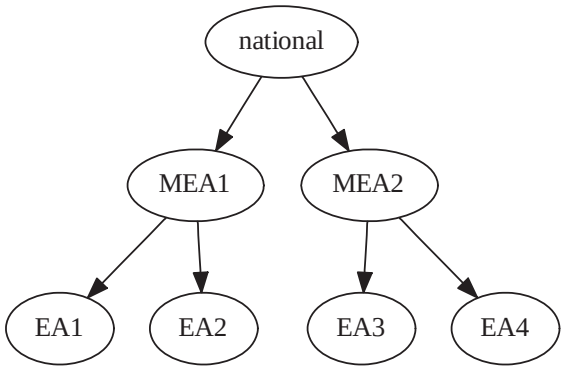


Figure 1: A simple multitree structure.

Because the parent-child relationship is defined based on strict subsets, there can be no directed cycles in Γ. We will further require that Γ be a *multitree,* i.e., that there be at most one undirected path between any two vertices in Γ.[13] The structure in Figure 1 satisfies this restriction. Another example is given in Figure 2, where Regional Economic Area Groups (REAGs) are included as well. Both examples generate a *tree* structure for Γ, which is a special case of a multitree. Another possible multitree structure is one identical

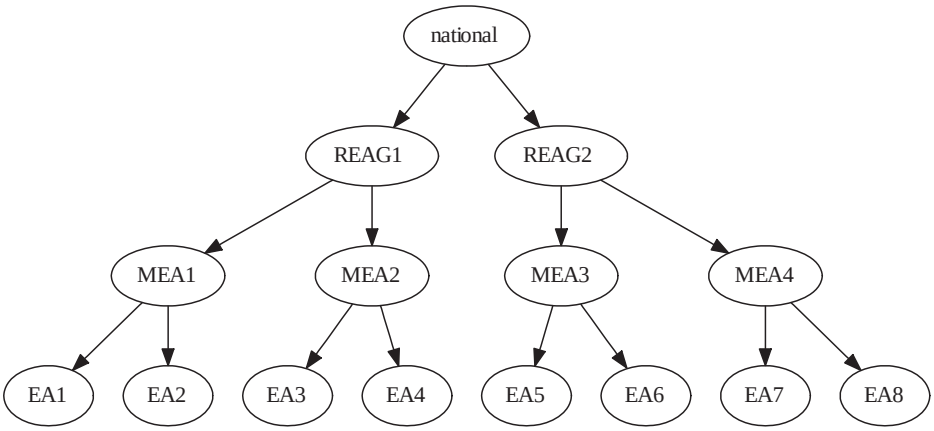


Figure 2: A larger multitree structure.

[13]Equivalently, the set of vertices reachable from any given vertex forms a tree.

to that in Figure 2, but without the national license. For the forward auction, the multitree structure is likely to cover the types of packages needed. As shown below, a key feature of the multitree structure is a lack of ambiguity about which objects are in excess demand.[14]

Each object can be assigned to a unique *tier* in Γ. This assignment can be constructed iteratively as follows: objects which are single-EA licenses are assigned to tier 1; parents of tier-1 objects are assigned to tier 2; parents of tier-2 objects to tier 3; etc. Let $\tau^{\max}$ denote the maximum non-empty tier. In the prior examples the assignments to tiers are simple: for example, tier 1 corresponds to the EA objects, with tier $\tau^{\max}$ corresponding to the national object.

8.3 Overview of the Clock Package Auction

The auction includes price clocks for each object. Initial (reserve) prices $p_k^{\min}$ are set for each EA license. Reserve prices for packages are additive:

$$p_j^{\min} = \sum_{\substack{k \in \mathcal{E}: \\ k \subset j}} p_k^{\min}. \tag{1}$$

The auction begins at these prices and proceeds through multiple rounds with progressively higher prices. In each round, bidders express nonnegative integer quantities demanded for each object at the current clock prices. Bidders' expressed demands are binding offers. A bidder expressing positive demand for multiple objects is agreeing to purchase all of those objects if the auction ends at the current prices. Prices continue to rise until there is no excess demand (defined below) for any object, at which point the auction terminates. As

[14] It may be useful to consider an example of a structure that violates the multitree restriction. Let there be three EAs: A,B, and C, and suppose the packages offered are AB,BC, and ABC. The graph of this structure is not a multitree because there are two directed paths from ABC to B. This could be accommodated (imperfectly) in our design by defining only one of the packages AB or BC to be a child of ABC, yielding a modified graph that is a multitree. The choice of the child would be arbitrary and could affect the outcome of the auction. Further, the CPA avoids the overflow problem entirely when Γ is a multitree, but only partially when Γ must be modified to obtain a multitree.

suggested in the MALS proposal, intra-round bidding can be used to minimize overshooting due to discrete price increments.

8.4 Feasible Supply and Feasible Allocations

For each $j \in \mathcal{O}$, let q_j^f denote the *feasible supply* of object j. This is the maximum number of units of the object that could be allocated. For objects consisting of a single EA license, this is just the number of available licenses in that EA. Because every package object is a collection of smaller objects, the feasible supply of a package object will be limited by the minimum feasible supply among its components (i.e., its children). In particular, for any object j such that $\chi_j \neq \emptyset$,

$$q_j^f \leq \min_{k \in \chi_j} q_k^f.$$

With package licenses specified as horizontally contiguous, the feasibility of horizontal contiguity might further constrain the feasible supply, yielding a strict inequality.

The set of quantities $\{q_j\}_{j \in \mathcal{O}}$ is a *feasible allocation* if for all $k \in \mathcal{O}$,

$$q_k + \sum_{\ell \supset k} q_\ell \leq q_k^f. \tag{2}$$

Typically the set $\left\{q_j^f\right\}_{j \in \mathcal{O}}$ will not be a feasible allocation.

Example 5. *Suppose there are 4 EAs, labeled A,B, C, and D. Let $\mathcal{O}$ be comprised of the singleton EA objects, two regional objects AB, CD, and a national object ABCD. Suppose sufficient spectrum has been cleared to allow allocation of up to 3 licenses in EAs A,B, and*

C but only 2 licenses in EA D. If there are no other feasibility constraints, we have

$$\begin{aligned} q_A^f &= 3 \\ q_B^f &= 3 \\ q_C^f &= 3 \\ q_D^f &= 2 \\ q_{AB}^f &= 3 \\ q_{CD}^f &= 2 \\ q_{ABCD}^f &= 2 \end{aligned}$$

An example of a feasible allocation is

$$\begin{aligned} q_A &= 1 \\ q_B &= 1 \\ q_C &= 2 \\ q_D &= 1 \\ q_{AB} &= 1 \\ q_{CD} &= 0 \\ q_{ABCD} &= 1. \end{aligned}$$

This feasible allocation also utilizes all the available licenses.

To avoid incentives for manipulation, we require that the expressed demand of a bidder at any price be a feasible allocation.[15] This constraint is easily imposed: if quantities $\left\{q_{ij}^d\right\}_{j\in\mathcal{O}}$

[15] Demands for infeasible allocations cannot be filled. Thus, attempts to distort the outcome of the auction with such bids have no cost. The same concern would arise in the MALS auction, where ruling out demands for infeasible allocations is also simple.

are demanded by a bidder i, the auction interface can verify that

$$q_{ij}^d + \sum_{k \supset j} q_{ik}^d \leq q_j^f \quad \forall j \tag{3}$$

before entering the bid, asking the bidder for a corrected demand vector if (3) is violated.

8.5 Total Demand, Excess Demand

Critical to the forward clock auction is the determination of which objects are in excess demand at a given set of prices. Without packages this is simple: the total number of units of an object demanded is compared to the total number of units available. With packages, we must account for the fact that demand for a package implies demand for the objects contained in the package. With the multitree structure this is straightforward. Further, because bidders express demand for package objects separately from demand for smaller objects, we can now avoid the overflow problem (see section 7.3).

Begin by defining the *first-order demand* for object j to be the quantity demanded of the object alone at the current prices. For example, first-order demand for an EA license is the quantity of this license demanded alone (not as part of a package object). Let $d_j^1(p)$ denote the first-order demand for object j.

Object j's *second-order demand,* denoted $d_j^2(p)$, and *total demand*, denoted $d_j^T(p)$ are then defined iteratively. Second-order demand for an object j represents the demand for j embedded in the feasible demand for objects that include j. Total demand for j is simply the sum of the first-order and second-order demand. The iterative definition starts from the top (tier $\tau^{\max}$) of the graph Γ and proceeds down. For each object j in tier $\tau^{\max}$ let

$d_j^T(p) = d_j^1(p)$. We then proceed to tier $\tau^{\max} - 1$. For each object j in this tier, let

$$d_j^2(p) = \sum_{k \in \pi_j} \min\left\{q_k^f, d_k^T(p)\right\} \tag{4}$$

$$d_j^T(p) = d_j^1(p) + d_j^2(p). \tag{5}$$

We take the minimum of q_k^f and $d_k^T(p)$ in (4) to account for the fact that in some cases not all demand for a parent can flow to its children, due to feasibility constraints. For example, in Example 5 above, at most two units of demand for the package CD would ever be counted as demand for C.[16] This process continues through tier 1, applying equations (4) and (5) at each tier.

Finally, object j has *excess demand* at prices p if total demand for j exceeds its feasible supply, i.e., if

$$d_j^T(p) > q_j^f.$$

8.6 Price Clocks

If no object has excess demand at the current clock prices, the clock auction terminates. Otherwise prices rise for all objects that (i) have excess demand or (ii) contain objects with excess demand. For specificity only, we assume bid increments are specified as a constant percentage increase.

Whereas the determination of total demand works from the top down in the graph Γ, determination of new clock prices works from the bottom up. Let p_j denote the current price of an object j; the new price p_j' is to be determined. For each tier-1 object j such that $d_j^T(p) > q_j^f$, the price will be incremented to $p_j' = (1+\delta)\, p_j$. Moving then to tier 2, the price of an object j in this tier will be incremented if either

[16] One way to represent this is to assign capacities to the edges in the graph Γ. The edge from j to any child $k \in \chi_j$ would have capacity q_j^f. The maximum demand that can flow down from parent to child is determined by the capacity of the relevant edge.

(a) the price of some object $k \in \chi_j$ has already been incremented; or

(b) $d_j^T(p) > q_j^f$.

If condition (a) holds,

$$p'_j = \max\left\{p_j, \sum_{k \in \chi_j} p'_k\right\}$$

regardless of whether condition (b) also holds.[17] If only condition (b) applies—i.e., if $p'_k = p_k$ for all $k \in \chi_j$, but there is excess demand for j—the new price is $p'_j = (1+\delta)\, p_j$. Only in this latter case is the price of a package *not* additive in the prices of its components (children).

This process continues through each of the higher tiers until all price adjustments have been determined. The new prices are then offered to bidders in the next round. As in the MALS proposal, bidders would be allowed to reduce the quantity they demand only for objects whose prices have risen.

8.7 Examples

Example 6 (Elimination of Exposure Risk). *Our first example illustrates the elimination of the exposure problem when the clock package auction is used and $\mathcal{O}$ includes all packages relevant to bidders. Let there be two markets, A and B, with two identical licenses*

[17] Alternatively, the price increment could be made larger if both conditions hold. Whether this aids efficiency is ambiguous in general under straightforward bidding (recall our discussion of clock synchronization). However, we believe that minimizing deviations from additive package price is desirable for encouraging straightforward bidding, as a bidder will know that he cannot slow down the rise in a package price by withholding demand for the package until later rounds and bidding instead on its components in early rounds.

available in each. There are five bidders with valuations

$$\begin{aligned} v_1 &= (5,0,5) \\ v_2 &= (4,0,4) \\ v_3 &= (0,5,5) \\ v_4 &= (0,4,4) \\ v_5 &= (3,3,11). \end{aligned}$$

Here the CPA proceeds under straightforward bidding as follows:

p_A	p_B	p_{AB}	*demand*
1	*1*	*2*	*A,A,B,B,AB*
2	*2*	*4*	*"*
3	*3*	*6*	*"*
4	*4*	*8*	*A,0,B,0,AB*

This yields the efficient allocation. Compare this to what may arise without including packages in the auction. Suppose the clock auction proposed by MALS were held. If bidder 4 avoids the exposure problem by adopting a conservative straightforward bidding strategy, that auction would proceed as follows:

p_A	p_B	*demand*
1	*1*	*A,A,B,B,A+B*
2	*2*	*"*
$\vdots$	$\vdots$	*"*
$3+\epsilon$	$3+\epsilon$	*A,A,B,B,0*

All units sell, but the exposure problem leads to inefficiency and low revenue: total revenue is 25 percent lower and total surplus (ignoring the potential adverse effect of revenue losses on closing conditions) is 14 percent lower.

Example 7 (Elimination of the Overflow Problem). *Return now to Example 3 (page 29). Previously we saw that the MALS auction design leads to inefficiency and/or undersell and there was a tension between addressing the needs of large bidders (facing the exposure problem) and those of small bidders (facing the overflow problem). Adding package clocks to the auction eliminates both problems. With the same setup considered in Example 3, the CPA would proceed as follows:*

p_A	p_B	p_{AB}	*demand*
1	1	2	0,A,B,B,AB,AB
1	2	3	"
⋮	⋮	⋮	"
1	5+ϵ	6+ϵ	0,A,B,B,A,AB
1+ϵ	5+2ϵ	6+3ϵ	"
2-ϵ	6	8-ϵ	0,A,0,B,A,AB
2	6+ϵ	8+ϵ	0,A,0,B,0,AB
2	7	9	"
2	8	10	0,A,0,0,0,AB

This yields the efficient allocation. Notice that the price of object A pauses once the sum of its first-order demand and the feasible second-order demand falls to 2 units (in the first

round displayed). At this point

$$\begin{aligned} d_A^T &= d_A^1 + \min\left\{q_{AB}^f, d_{AB}^T\right\} \\ &= 1 + \min\{1, 2\} \\ &= 2 \\ &= q_A^f. \end{aligned}$$

The total demand equals the feasible supply; thus, there is no excess demand for A. This illustrates how the CPA allows the excess demand calculation to distinguish between demand for A alone and demand for A that is embedded in demand for a package. This distinction is impossible in the simple (MALS) clock auction, but is essential if we are to obtain efficiency. Stopping the price at 1 allows the auction to "hold on" to the demand of bidder 2 while still raising the price to the package bidders. Of course, if one of the package bidders later drops its demand for the package and instead demands a unit of A, p_A will rise again. This occurs in the example when p_B reaches $5+\epsilon$ and bidder 5 finds license A more profitable than the package.

Example 8 (Superadditive Package Prices). *Let there be two markets, A and B, with two identical licenses available in each. However, interference constraints limit the number*

of feasible horizontally contiguous AB packages to 1. There are six bidders with valuations

$$\begin{aligned} v_1 &= (5,0,5) \\ v_2 &= (6,0,6) \\ v_3 &= (0,5,5) \\ v_4 &= (0,6,6) \\ v_5 &= (3,3,11) \\ v_6 &= (4,4,14)\,. \end{aligned}$$

Complementarities in the two package bidders' valuations are contingent on horizontal contiguity. With straightforward bidding, the CPA would proceed as follows:

p_A	p_B	p_{AB}	*demand*
1	*1*	*2*	*A,A,B,B,AB,AB*
⋮	⋮	⋮	*″*
5	*5*	*10*	*0,A,0,B,AB,AB*
5	*5*	*11*	*0,A,0,B,0,AB*

The price clocks for the single-market licenses stop at 5, even though three units of each are demanded. This is because only 1 of the 2 package units demanded can be part of a final allocation. For example

$$\begin{aligned} d_A^T &= d_A^1 + \min\left\{q_{AB}^f, d_{AB}^T\right\} \\ &= 1 + \min\{1,2\} \\ &= 2 = q_A^f. \end{aligned}$$

However, there is excess demand for the package at this point, so the package price p_{AB} continues to rise. This yields a package price that exceeds the sum of the component prices p_A and p_B. Note that the degree of superadditivity, the total revenues, and the total surplus could be made arbitrarily high in this example by driving up the package valuations of bidders 5 and 6. With the original MALS proposal and conservative straightforward bidding, the exposure problem (this time the exposure of obtaining packages that lack horizontal contiguity) leads to a worse outcome

p_A	p_B	*demand*
1	1	A,A,B,B,A+B,A+B
⋮	⋮	"
3+ϵ	3+ϵ	A,A,B,B,0,A+B
4+ϵ	4+ϵ	A,A,B,B,0,0

Revenue is nearly 25 percent lower, while total surplus is 15 percent lower. Both losses can be made arbitrarily large by driving up the complementarities in the two package bidders' valuations.

8.8 Properties of the CPA

Success

The CPA is guaranteed to "succeed" in the sense that it will terminate at a feasible allocation. We show this with the following two results.

Theorem 1. *If the clock package auction terminates at price vector p^*, the implied allocation $\left\{d_j^1\left(p^*\right)\right\}_{j\in\mathcal{O}}$ is feasible.*

Proof. Since the auction terminates when there is no excess demand

$$d_j^T(p^*) \leq q_j^f \quad \forall j \in \mathcal{O}. \tag{6}$$

Recall that for all objects j in tier $\tau^{\max}$, $d_j^T(p^*) = d_j^1(p^*)$. Now consider an object j in tier-$(\tau^{\max} - 1)$. Any object $k \supset j$ must be in a higher tier. So by (4), (5), and (6), $d_j^T(p^*) = d_j^1(p^*) + \sum_{k \supset j} d_k^1(p^*)$. Continuing this iteration through tier 1, we obtain

$$d_j^T(p^*) = d_j^1(p^*) + \sum_{k \supset j} d_k^1(p^*) \quad \forall j \in \mathcal{O}.$$

By (6) this implies

$$d_j^1(p^*) + \sum_{k \supset j} d_k^1(p^*) \leq q_j^f \quad \forall j \in \mathcal{O}$$

i.e., $\left\{d_j^1(p^*)\right\}_{j \in \mathcal{O}}$ is a feasible allocation. □

Theorem 2. *Suppose that (i) the bid increment is bounded from below by $\delta > 0$, (ii) bidder valuations are finite, and (iii) there exists $L < \infty$ such that no bidder expresses demand which, if accepted, would yield the bidder a loss greater than L. Then the clock package auction will terminate in a finite number of rounds.*

Proof. Suppose to the contrary that for every round $r = 1, 2, \ldots, \infty$ there is excess demand. This requires that there be at least one object j that is in is excess demand in an infinite number of rounds. Because the bid increment is bounded from below by δ, the price of j (and any object containing j) must diverge to infinity. Because valuations are finite, this requires that there be some bidder demanding units of j (or an object containing j) who would face an arbitrarily large loss if his demand were accepted. This contradicts part (iii) of the hypothesis. □

No Exposure Problem

As long as the set $\mathcal{S}$ includes all of the types of packages desired by bidders (i.e., all those involving complementarities or the need for horizontal contiguity), the exposure problem is absent.

No Overflow Problem

As illustrated in the examples, the overflow problem and its bias against small bidders is eliminated. A bidder's price rises only when his own demand is a source of scarcity.

Simplicity for the FCC

The form and complexity of the proposed clock auction is essentially the same as that in the MALS proposal. We have added a relatively small number of package licenses to the auction: if there are K EAs and L packages, the number of objects in the auction is $K + L$ vs. K in the original proposal. Operation of the auction involves only the calculation of excess demand and adjustment of price clocks. Our description of these calculations translate directly to an algorithm for controlling the price clocks. The complexity of this algorithm is linear in the total number of objects for sale.

Simplicity for Bidders

The addition of packages to the ascending clock auction leaves the fundamental decisions for bidders unchanged. As in the original MALS proposal, a bidder merely indicates its most preferred purchases at each round of prices. The price of a package license is never less than the sum of prices for each component EA license. This keeps bidders' decisions simple (there are no tempting arbitrage opportunities that involve exposure risk) and aids price discovery. With the restriction to bids that are themselves feasible allocations, we see

no new opportunities for strategic bidding behavior created by the addition of packages to the clock auction.

Fairness

The clock package auction as we have described it creates no advantages or disadvantages for large bidders (e.g., those bidding for packages) or small bidders (e.g., those bidding for individual licenses). The allocation of spectrum to package vs. single licenses is not preset but is determined by prices. A package bidder has no advantage because it must always pay a price at least as large as the sum of the component prices for the elements of its package. It is not disadvantaged either: although package prices may be superadditive, this happens only when this is necessitated by excess demand for the package itself. Similarly, the elimination of the overflow problem removes a bias against small bidders that is present in the MALS design.

Efficiency and Revenue

The discussion and examples above reveal that adding packages to the clock auction can eliminate some sources of inefficiency in the clock auction proposed by MALS, and can enhance revenues as well. However, there is no strict dominance relation: one can construct examples in which adding package clocks may reduce efficiency, depending on how clocks are synchronized and how package bidders handle the exposure problem in the auction without packages.

Example 9. *Suppose there are two licenses (A and B) and three bidders with valuations*

$$\begin{aligned} v_1 &= (3, 0, 3) \\ v_2 &= (0, 6, 6) \\ v_3 &= (2, 2, 7). \end{aligned}$$

The efficient allocation gives license A to bidder 1 and license B to bidder 2. In the MALS auction, conservative straightforward bidding will yield the efficient allocation, proceeding as follows:

p_A	p_B	*demand*
1	1	A,B,A+B
2+ϵ	2+ϵ	A,B,0

In the CPA, under straightforward bidding the auction may proceed as follows:

p_A	p_B	p_{AB}	*demand*
1	1	2	A,B,AB
2	2	4	"
3	3	6	0,B,AB
3	4	7	0,B,0

Although revenue is the same, good A goes unsold.[18] *This undersell can be seen as arising from miscoordinated price clocks (recall section 7.4). For example, if the clock for license B moved at twice the speed of that for license A, the CPA would instead proceed as follows:*

p_A	p_B	p_{AB}	*demand*
1	2	3	A,B,AB
2	4	5	"
$\frac{7}{3}$	$\frac{14}{3}$	7	A,B,0

The allocation is now efficient. Further, revenues are now 75 percent higher than in the MALS auction.

To provide some comparisons of outcomes under alternative auction rules we have run

[18] To obtain strictly higher revenue from the MALS auction, modify the example so that $v_3 = (2+\epsilon, 2+\epsilon, 7)$.

a set of simulations using a stylized representation of the forward auction. We discuss the details of the simulation design in Appendix A. At a broad level, however, we generate many randomly drawn bidding environments capturing key qualitative features likely to be present in the forward auction. We use these to simulate actual bidding behavior in both the original MALS auction design and in the CPA. This enables us to compare the potential performance of the two auction designs in terms of efficiency and revenue.

Our results are presented in detail in Appendix A. They suggest that substantial efficiency and revenue gains from the CPA may be typical. For example, in our baseline simulation design, total surplus and total revenue are higher under the CPA in the vast majority of our 1,000 replications. Average revenue (across all replications) is 70% higher under the CPA. The average surplus is 17% higher. The CPA achieves an average of 97 percent of the (infeasible) first-best efficiency. Compared to the infeasible first best (fully efficient) allocation, the CPA achieves at least 90 percent efficiency in 91 percent of the replications, whereas the MALS auction achieves this level in only 37 percent of the replications. Results in alternative specifications are qualitatively similar, with larger gains when complementarities for package bidders are stronger.

9 Supplementary Bidding

As discussed before, both the Clock auction proposed by the NPRM and MALS and the CPA proposed here could leave some items unallocated. It should be an option, if the FCC finds it necessary, to resell the unsold items immediately following the main clock auction. We imagine this option to be triggered only if the FCC finds significant undersell to have resulted from the main round. Should the FCC decide to resell the unsold items, an important consideration in the auction format design is to minimize possible adverse effects it may have on the main clock auction. For instance, if the unsold items were sold in a "pay-

as-you-bid auction," bidders may have incentives to signal low values in the clock phase in an attempt to lower the prices they face in the supplementary round.

For this reason, a clock auction, which is relatively simple and has a transparent pricing rule, is preferred. We do not envision package bids to be allowed for this round, in light of the fact that package bidding in the main round will have treated much of the exposure problem. We do not envision package bids to be allowed for this round, in light of the fact that package bidding in the main round will have addressed much of the exposure problem. A proxy version of the clock auction could be used if a speedier resolution of the forward auction is an important concern.

An alternative more comprehensive approach would put all licenses, including those sold in the initial clock phase, back into sale in the supplementary round. This is the approach prescribed by the Combinatorial Clock Auction (CCA), mentioned as an option in the NPRM (for package bidding). CCA begins with a clock phase (with a different bid withdrawal rule than the MALS clock auction), but adds a supplementary round of proxy bidding for packages following the clock phase. In the (supplementary) proxy phase, all clock bids (i.e., prices for winning quantities) are added as default package bids, but bidders are allowed to submit additional sealed bids for these packages and to bid, with some limitation, for other packages. Winners are then determined to maximize the total bids, and are charged with the VCG-nearest core prices.[19]

There are several concerns with such a comprehensive supplementary bidding approach. First, the pricing rule (i.e., the VCG-nearest core pricing) means that the final clock bids and the prices winners eventually pay would differ substantially (even when the winning

[19] The VCG rule charges each winning bidder the social opportunity cost associated with his winning licenses—the net social value that was foregone due to the winning by the bidder of these licenses. A core pricing rule is a profile of prices that would leave no profitable deviation either by an individual or by a group of individuals through reallocation of licenses within them or through their non-participation. A VCG-nearest core pricing selects the VCG prices if they are in the core, and selects the core point that is the closest to, and in equal distance across all winning bidders away from, the VCG in case the VCG is not in the core. See Ausubel, Cramton, and Milgrom (2006) and Cramton (2012) for detail.

allocation does not change across the two phases),[20] and the relationship between the two phases and the activity rule governing it are complex and may be perceived as opaque by the bidders.

Second, the outcome of the proxy phase is unpredictable in the sense that the winners of the clock phase may not secure the licenses they have won from the clock phase. The prevailing activity rule provides some protection in this regard, for each winner of the clock phase may reclaim the winning package from the the clock phase by raising his bid for that package by the final clock prices of the unsold items (see Cramton (2012) and Ausubel and Cramton (2011)). But that may prove too expensive for this option to be of practical value to the bidders.

Third, when all items are sold by the end of the clock phase, the allocation remains unchanged, but the prices the bidders pay depend on their opponents' bids only. Since their winning licenses remain unchanged and their payments do not depend on their bids, the bidders become indifferent among all feasible package bids (allowed by the standard revealed preference activity rule). As explained in detail in Appendix B, this ambiguous bidding incentive in the proxy phase could lead to excessively low revenue for the seller, susceptibility to collusion, and distorted incentives in the clock phase and inefficiencies.

Overall, the feature that "everything is up for grabs again in the supplementary round" can be perceived as introducing too much complexity/uncertainty into the process for the participants. Such uncertainty may in turn make it difficult for the bidders to form a valuation for the clock phase. And this could hinder price discovery (of even individual items) and may entail underbidding in the clock phase.

Limiting the scope of supplementary bidding to only those items that have not been sold by the clock phase makes the procedure much simpler and more predictable and transparent

[20] In the UK 10-40 GHz auction which used a version of CCA, the final prices of licenses were 20-30% of the winning clock bids in the initial phase, even though the relative prices were stable across the two phases (see Cramton (2008)).

in terms of the consequence of the bidding behavior in the clock phase. In particular, those items that are sold in the initial clock phase will not be subject to any further uncertainty in terms of allocation and prices. The fact that the items sold in the clock phase will be unavailable and the uncertainty on whether the FCC will opt to resell the unsold items immediately will also encourage more sincere bidding in the clock phase, contributing to the efficient allocation of the licenses through the clock phase.[21]

10 Improved Assignment Phase

As noted earlier, the current procedure for assignment does not allow bidders to express preferences for horizontal contiguity across licenses won in different EAs. Here, we propose simple modifications of the MALS assignment procedure that can enhance efficient assignment and horizontal contiguity. Obviously, the problem of allocational efficiency and horizontal contiguity can be treated most effectively by introducing package bids, as envisioned by our Clock Package Auction proposal. The methods discussed here will be most useful if such a comprehensive bidding approach is not adopted, but may be useful even with its use, to the extent that the number of packages allowed may be limited, or when bidders desire vertical contiguity between a package and single EA license in an area covered by the package.

[21] Some demand that would be present if all units are available for sale may not be present if only some items are available for sale, and this may make the supplementary bidding not as competitive as it could be, and in principle this may create incentives for bidders to strategically reduce demand in the clock phase. We do not believe that this is a significant issue. The risk of the desired items being sold in the clock phase (and thus not being available for the supplementary phase), and the uncertainty regarding the FCC's exercise of the option for immediate resale will make such strategic behavior very costly.

10.1 Random Priority with Enriched Preferences

The NPRM suggests a possibility of a Random Priority ("RP") assignment of specific frequency blocks. Efficiency could be enhanced by enriching the preference language for alternative frequency blocks across multiple EAs, and applying the Random Priority rule with respect to these preferences. More precisely, instead of rank-ordering alternative frequency blocks in each EA separately, the FCC would allow bidders to rank-order alternative *combinations* of frequency blocks across different EAs. To illustrate, recall Example 2 introduced earlier: there are two EAs, EA_1 and EA_2; each EA_i has three frequency blocks: A_i, B_i, C_i for $i = 1, 2$; all three blocks are cleared in EA_1 but only two of them are cleared in EA_2; and the remaining station in EA_2 can be moved to any block. There are three bidders, 1, 2, 3 in the forward auction. Bidder 1 and bidder 2 each won 1 license in each EA, whereas bidder 3 won only one license in EA_1 in the forward auction.

Suppose bidder 1 ranks: $A_1A_2 - B_1B_2 - A_1B_2 - B_1A_2 - \cdots$. Bidder 2 may rank similarly: $A_1A_2 - B_1B_2 - B_1A_2 - A_1B_2 \cdots$. One can then define the random priority rule analogously but over both EAs. To illustrate, suppose that bidder 3 ranks $C_1 - B_1 - A_1$. In this case, again bidder 3 will get C_1 in EA_1. And bidders 1 and 2 will get (A_1A_2, B_1B_2) and (B_1B_2, A_1A_2) with equal probability 1/2. Hence, in this way, we achieve full horizontal contiguity.

The example was (deliberately) simple. Matters become more complicated if bidder 3 ranks: $A_1 - B_1 - C_1$, and the remaining station in EA_2 must keep C_2, or C_2 is too impaired to be of any value to the bidders. In that case, with probability 1/3, bidder 3 goes first and will pick A_1 in EA_1, in which case the next bidder will get B_1B_2, and the last bidder will get C_1A_2. More precisely, each of the following six assignments,

$$(A_1A_2, B_1B_2, C_1), (B_1B_2, A_1A_2, C_1), (A_1A_2, C_1B_2, B_1)$$
$$(C_1B_1, A_1A_2, B_1), (B_1B_2, C_1A_2, A_1), (C_1A_2, B_1B_2, A_1)$$

will be selected with probability 1/6 (where again the first component denotes bidder 1's assignment, the second denotes bidder 2's assignment, and the third denotes bidder 3's).

In this case, the new version of the RP assignment does not work as well in preserving horizontal contiguity.[22] A further improvement can be made if the FCC restricts the set of admissible assignments to be those that guarantee (or optimize on) horizontal contiguity. For instance, if it is known that bidder 3's gain from having A instead of B is not very large whereas the loss from not having inter-EA contiguity is very large, then the FCC may declare only two assignments, (A_1A_2, B_1B_2, C_1) and (B_1B_2, A_1A_2, C_1), to be admissible. In this case, horizontal contiguity can be guaranteed, although bidder 3 may be worse off. Of course, the FCC may take a middle ground by declaring C_1A_2 or A_1C_2 to be too inefficient to be a part of an admissible set of assignments. In that case, the RP will be run so that each winner at his turn can only choose from the set of assignments that does not include these two outcomes.

More generally, the improved version of the RP assignment procedure can be stated as follows.

- The FCC picks an extended area $\mathcal{X}$ (which could be the entire nation or one or multiple MEAs or REAGs) which contains multiple EAs. The extended area $\mathcal{X}$ should be chosen to be the minimal region such that a failure to attain horizontal contiguity across different EAs within $\mathcal{X}$ would entail a nontrivial loss to a bidder.

- The FCC next picks the set of "admissible" ways of allocating the cleared blocks in the EAs contained in $\mathcal{X}$ to the winners of the corresponding objects. For instance, the FCC could first impose vertical contiguity (to the extent this is guaranteed, as with the NPRM and MALS) and horizontal contiguity for the packages (for which hori-

[22] Nevertheless, this rule does a better job of accounting for bidders' preferences for horizontal continuity than does the NPRM proposal. In fact, the new version produces an assignment that is Pareto efficient, whereas the outcome from simple the RP assignment fails to be Pareto efficient. Furthermore, the procedure is strategy-proof, making it a weakly dominant strategy for each bidder to reveal his preferences truthfully.

zontal contiguity is guaranteed) and identify the set of feasible assignments satisfying these guarantees. Next, the FCC may impose a suitably-chosen degree of horizontal contiguity it deems as desirable based on an appropriate metric. For instance, the FCC may require that each admissible assignment should satisfy horizontal contiguity over a certain minimal fraction of areas over which each bidder has won licenses (e.g., measured by the number of pairs of adjacent EAs in which a bidder has won licenses).

- Each winner of any license within $\mathcal{X}$ ranks his possible allocations from the set of admissible allocations.
- The FCC next runs the RP assignment procedure based on the preference rankings submitted by the bidders.

The next result is standard:

Theorem 3. *The generalized RP is strategyproof and produces an assignment that is Pareto efficient within the set of admissible allocations.*

Vertical contiguity and horizontal contiguity may sometimes be in conflict with each other, and it may be impossible to satisfy both. The current proposal will resolve the tradeoff in three ways: (1) through the contiguity guarantee that comes with a package, (2) through the set of admissible assignments determined by the FCC, and (3) through the rich preferences submitted by the winners.

To illustrate, suppose there are three EAs: EA_1, EA_2 and EA_3. EA_1 and EA_2 have each 3 blocks, A, B and C, cleared from the reverse auction. EA_3 has 2 blocks: A and B. Suppose all three EAs are pairwise adjacent. Two bidders have won in these EAs. Bidder x won two licenses in EA_1 and one license in each of EA_2 and EA_3. Bidder y won two licenses in EA_2 and won one license in each of EA_1 and EA_3.

Let us first see that it is impossible to satisfy both vertical and horizontal contiguity of assignments. Vertical contiguity for bidder x in EA_1 means that he should win either AB

or BC in EA_1. For the same reason, bidder y should win either AB or BC in EA_2. In case bidder x wins AB in EA_1, horizontal contiguity between EA_1 and EA_2 demands that bidder y should win BC in EA_2. Finally, horizontal contiguity for bidder x between EA_1 and EA_3 means that he should get A in EA_1. But then bidder y must get B in EA_3, violating the contiguity between EA_1 and EA_3 for that bidder. The case in which bidder x gets BC has a similar violation of horizontal contiguity.

The proposed assignment scheme would resolve the conflict in the following way. First, horizontal contiguity guaranteed for a package must be respected. Second, the FCC may ensure vertical contiguity within each EA for the winners (to the extent it can). Third, the FCC may maximize the number of pairs of adjacent EAs for which horizontal contiguity of licenses (won as single licenses and between single licenses and package of licenses) is satisfied.

To illustrate, assume that the three EAs form a single MEA. Suppose first that each of the two bidders won one MEA package and one single EA license (one in EA_1 for x and one in EA_2 for y). Then, the above procedure results in two admissible assignments.

Table 1: Admissible Assignments with Two Package Winners

	A	B	C	A	B	C
EA_1	x	y	x	y	x	x
EA_2	x	y	y	y	x	y
EA_3	x	y		y	x	

Notice that vertical contiguity must be violated for one bidder, since the horizontal contiguity guarantee that comes with each MEA package must be respected first. Of these two admissible assignments, one will be chosen by the RP rule. Unless the specific frequency block matters much, the first assignment will be chosen if bidder y is selected to go first (since it ensures vertical contiguity for y but not for x) and for the same reason, the second assignment will be chosen if bidder x is selected to go first.

Suppose next that only bidder x has won MEA package (and two single EA licenses), and bidder y won all licenses as single EA licenses. In this case, the assumed procedure yields a unique admissible assignment.

Table 2: Admissible Assignment with One Package Winner

	A	B	C
EA_1	x	x	y
EA_2	x	y	y
EA_3	x	y	

Bidder x enjoys vertical contiguity across licenses within each EA and horizontal contiguity across EAs. Bidder y attains vertical contiguity of licenses within each EA, but the horizontal contiguity between EA_1 and EA_3 is not satisfied.

10.2 Assignment Auction

The random priority assignment is sensible only when the bidders do not find the value differences across particular frequency blocks to be large, and the FCC can limit the set of admissible assignments to guarantee contiguity of frequency assignments across regions for the winners of geographically adjacent licenses. An alternative would be to hold an auction to determine the assignment. One possibility is to use the assignment auction prescribed by Cramton (2012), also used in the UK 10-40 GHz auction. According to this method, winners of the principal auction stage bid for preferred assignments. The winners can submit multiple (or possibly no) bids for their preferred assignments that are consistent with their winning awards of the principal auction, and the auction manager selects a collection of bids, at most one bid from each bidder, that are maximal among all possible collections that produce feasible assignments. The winning bidders are then charged the VCG-nearest core prices for their assignments.

In the example from Section 10.1, even without the FCC limiting the admissible assignments, such an auction is likely to produce contiguous assignments across the regions for bidders 1 and 2. If bidder 3 has weak preferences over alternative frequencies in EA_1, then he will bid very little, if any, for his preferred frequency block, and bidders 1 and 2 will bid seriously for A_1A_2 and B_1B_2 (to the extent that they value contiguous assignments), so they will outbid bidder 3 and secure a contiguous assignment. At the same time, the need to respect the horizontal contiguity for the package items will still limit the set of admissible assignments.

While there may be potentially many assignments a bidder can bid for, the auction will be relatively straightforward from the perspective of bidders since important matters such as how many licenses they win in each region will have been already settled. In particular, a bidder can, and will typically, bid for a small number of select assignments (as was the case with the UK auction). The pricing rule also limits the incentives for non-truthful bidding and is envy free.

11 Other Concerns and Recommendations

11.1 Generic Licenses

The treatment of licenses as generic within market and class of license is essential to the MALS design and our CPA proposal. This feature has a number of desirable properties as long as licenses designated as generic actually are equivalent. It is essential that the band plan be designed to minimize interference or other impairment of licenses, so that genericity of licenses is genuine. If in limited cases licenses do unavoidably differ substantially, they must be treated as non-fungible in the forward auction. Failure of the auction design to distinguish adequately between heterogeneous licenses would lead to a significant exposure problem, conservative bidding, and inefficient allocations.

11.2 Bidding Credits

The NPRM proposes offering bidder credits of 15 percent to "small businesses" and 25 percent to "very small businesses." Bidding credits have been used toward this end in past FCC spectrum auctions, and the FCC proposes to do so again in the forward auction.[23]

However, an important difference from past auctions is the interaction between the forward and reverse auctions. Consequently, the result of favoring designated entities through discounts will not merely be to favor designated entities in the allocation of spectrum for wireless services. It will also favor the status quo, i.e., allocation of spectrum to current broadcast television licensees. Discounts offered to designated entities may result in a failure of closing conditions for a target quantity of spectrum, even when bidders in the forward auction are offering prices sufficient to meet the net revenue requirement.[24] The result will not be the intended one: instead of tilting the allocation toward designated entities in the mobile wireless industry, the quantity of spectrum made available to mobile wireless—including to designated entities—will be reduced.

What is needed is an alternative that preserves the desired preferential treatment of designated entities when it comes to the question of *how* mobile wireless spectrum is allocated, but does so without adversely influencing the question of *whether* spectrum is allocated to mobile wireless. This is possible with a simple modification of the NPRM proposal. Bidding credits could be made contingent on satisfaction of the net revenue requirement, and phased in gradually to allow the maximum feasible bidding credit (up to the 15 and 25 percent

[23] Ayres and Cramton (1996) point out that bidding credits could sometimes enhance revenues by creating competition for licenses attracting few large bidders. This outcome may be less likely with the proposed auction design due to the use of generic licenses. Nonetheless, our proposal below would not affect any revenue enhancing feature of bidding credits.

[24] Consider an example with one license and two bidders: a *very small business* with valuation 65 and a non-designated entity with valuation 80. Suppose that the net revenue requirement is 62. The designated entity's 25% bidding credit allows it to become the provisional winner in the clock auction at a price of 80. However, its payment would be only 60. Thus the net revenue requirement fails. Here this occurs even though both bidders would be willing to pay more than the required net revenue of 62 for the license.

levels) that can be accommodated without leading to a revenue shortfall.[25] This need not introduce uncertainty for designated entities. They can be told the bidding credit they are eligible for at each price vector. Nor would the auction be disrupted when the bidding credits "kick in," since the only effect would be an increase in demand. This modification of the bidding credit program would require only relaxation of the activity rule for designated entities, allowing them to take advantage of the credits. This should be straightforward.

This proposal is a sharply targeted remedy to the problem that bidding credits could lead to net revenue failure. Under straightforward bidding, the proposed modification would have no effect when the net revenue requirement would have been satisfied under the original proposal. Likewise, if the net revenue requirement fails under our proposed bidding credit system, it would also fail under the original system. Thus the only cases in which our proposed change would have an effect is when the net revenue condition would be satisfied under our proposal but would have failed under the original proposal.

11.3 Activity Rule

The purpose of the Activity rule is to prevent bid sniping[26] and encourage straightforward bidding, both of which are important for effective price discovery. The basic idea behind such an activity rule is to constrain bidding behavior to be consistent with straightforward bidding. Traditionally, the activity rule used by the FCC in past auctions has been a "monotonicity rule," requiring that the aggregate quantity demanded by a bidder—typically measured by

[25] In the simple example above, bidding credits would kick in as soon as the price reached 62. At a price of 65, for example, the very small business could receive a bidding credit of 3; at a price of 70, a bidding credit of 8.

[26] Bid sniping refers to the strategy of waiting (i.e., bidding low or insincerely) until the last minute of the auction to bid seriously. When permitted, bidders have incentives to engage in such behavior in order to conceal their preferences and thereby increase their chances to win desired items at low prices.

MHz $\times$ Population—not increase over the course of the auction.[27] This rule works well when the items are homogeneous, but not well when they are heterogeneous. For instance, the prices of different EA licenses may vary widely on a per MHz $\times$ Pop basis. In that case, straightforward bidding behavior may require switching to a larger package when its price becomes relatively cheaper, but this behavior will not be allowed by the monotonicity rule. This activity rule is also susceptible to "parking," a strategy of bidding initially on underpriced or low-value objects with high quantity so as to keep the the prices on desired objects from rising quickly. Such behavior inhibits price discovery, and may distort prices and hinder efficient allocation.

An alternative "revealed preference" activity rule proposed by Cramton (2012) and Ausubel, Cramton, and Milgrom (2006) is more flexible and is immune to parking behavior. In words, the revealed preference requirement would allow a bidder to switch to a larger package as long as that package has become relatively cheaper than the package she demanded at the previous round. The hybrid version suggested by Ausubel and Cramton (2011), which uses the traditional eligibility monotonicity rule but allows bidders to switch to large packages as allowed by the revealed preference requirement,[28] appears to offer further flexibility to the bidders. These rules appear to be sensible for both the clock auction proposed by the NPRM and the CPA proposed here.

[27] Specifically, according to this rule, each bidder i must bid within his eligibility point E_t^i, which is set initially (say at E_0^i) based on the deposit posted by the bidder, and evolves over time to equal the smaller of his bidding activity $e \cdot q_t^i$ at round t and the eligibility point E_{t-1} at the previous round (where e refers to the vector of eligibility points for the products the bidder is bidding on, q_t^i refers to the quantity bidder i demands or bids at round t.)

[28] More precisely, under the Simplified Revealed Preference rule, at any round in the Clock Phase a bidder can bid on a larger package than would be permitted by the bidder's current eligibility, provided that the package satisfies "revealed preference" with respect to each prior round's bid in which eligibility was reduced (Ausubel and Cramton (2011)). The rule states that in Clock round t, bidder i can bid an package q_t if

$$e \cdot q_t \leq E_t^i,$$

or

$$(p_t - p_s) \cdot (q_t - q_s) \leq 0,$$

for each previous round s at which her eligibility was reduced.

Part III

Reverse Auction

12 The NPRM and MALS Proposals

Broadcast television bands currently occupy 294 MHz of spectrum in five different bands allocated for broadcasting use. The density of broadcast television licensees varies significantly across markets, and licensees themselves differ substantially in their geographic coverages ("contours"), depending on such factors as location, transmitter power, antenna height, local terrain, etc. In many markets, substantial spectrum in the broadcast television allocation is unused. Because television and mobile wireless uses are incompatible, reallocating portions of the spectrum to mobile wireless uses requires relocating television licensees. By shifting broadcasters to a single portion of the spectrum, sufficient bandwidth may be cleared to permit viable mobile wireless services to be offered in the remaining portion.

Although legislation gives the FCC authority to relocate ("repack") broadcast television licensees within or across the broadcast television blocks, this must be done in a way that does not unduly affect licensees' contours. The ease of meeting this requirement will vary considerably across markets and across incumbent licensees within markets. Further, in some large metropolitan markets there are many television licensees. In such markets, even after repacking there might be relatively little spectrum available for wireless services. Such markets may, however, also be some of the most valuable markets for mobile wireless services.

The Spectrum Act authorizes the FCC to resolve the competing demand for the scarce spectrum through voluntary participation in "incentive auctions" in which television licensees can offer to relinquish their licenses. The market design problem for the FCC is to provide

an auction mechanism that selects voluntary offers to relinquish while also accounting for the constraints on repacking broadcasters in a way that adequately respects their contours. This need to repack without introducing interference introduces significant complications to the design of the reverse auction. Repacking constraints are "global," in the sense that placing a broadcaster in one market in a particular frequency can affect the feasibility of placing broadcasters in the same or nearby frequencies in other markets. For example, Washington, D.C. and Philadelphia, PA are sufficiently proximate that use of a UHF television channel in one may preclude use of the same channel in the other market. For the same reason, decisions regarding channel usage in Philadelphia may affect New York City, which then may affect Bridgeport, CT, and then Boston, MA. Similarly, a Washington D.C. assignment may affect feasible assignments in Baltimore, MD and possibly Richmond, VA. Thus, channel usage can have a "daisy-chain" effect that can link major metropolitan areas—as well as smaller communities—that are hundreds of miles apart.

12.1 Descending Clock Auction

MALS proposes a simultaneous descending clock design for the reverse auction. The reverse auction would begin with provisional target quantities of spectrum to be cleared in each market. Although there would be a single nationwide reverse auction, it will utilize different clocks for each market and each *relinquishment option*—e.g., go off the air, share with another station, or move to a lower band. The option to "remain in the current band" (i.e., to be repacked) is always available as well. Bidders who do not participate in the auction are automatically assigned to this option. Participation in the auction is strictly voluntary. Clock prices may differ across bidders within a market and may move at different speeds, due to differences in coverage areas, in the feasibility of each option, in the costs of repacking, or in the effect of repacking one station on the ease of repacking others.

The auction clocks begin with high initial ("reserve") prices chosen by the FCC for each

feasible relinquishment option in each market. Each bidder selects the option he finds most attractive at these prices. Roughly speaking, prices are then lowered, bidders again express their preferences, and the process iterates until prices reach a level just low enough that the quantity of spectrum offered in each market equals the target quantity.

Complicating this simple description is the fact that feasibility considerations will limit repacking options. Each clearing target determines the amount of spectrum available for repacking bidders who choose to stay on the air. Before prices are adjusted during the auction, the feasibility of repacking each remaining bidder (i.e., the feasibility of adding that bidder to the set to be repacked) must first be checked. If it becomes infeasible for a given bidder to be repacked, his current relinquishment offer will be provisionally accepted at the current clock price for that option. The feasibility checking iterates until it is the case that each remaining bidder could feasibly be repacked. Only at this point do clock prices decline for these remaining bidders.

A significant virtue of the clock design is its simplicity from the perspective of bidders. Although complicated repacking constraints operate in the background, the rules of the auction are transparent, making it easy for bidders to see how their actions determine outcomes and payments. Further, given appropriate rules for controlling clock prices,[29] bidders have clear and strong incentives to follow a straightforward bidding strategy—i.e., always to select the option that would maximize one's own profit if the current clock prices were to be the final prices.

Theorem 4. *Consider the MALS reverse auction and assume that clock prices decline continuously and with speeds that do not depend on the actions of bidders. Then straightforward bidding is a weakly dominant strategy for all bidders.*

Proof. See Appendix C. □

[29] The NPRM and MALS are not explicit about the rules that will govern adjustment of clock prices for feasible relinquishment options. As Theorem 4 suggests, we see some potential for distortion of incentives if the rates at which prices adjust depend on bidder offers.

12.2 Other Reverse Auction Designs

The NPRM also suggests an alternative to the descending clock auction design. Details are not provided, but broadly the proposal involves collecting price offers from reverse auction bidders and choosing winners (or, perhaps, provisional winners in each of a sequence of rounds) to minimize payments to bidders subject to repacking constraints.

13 Primary Concerns

13.1 Computational Complexity

Constraints on repacking broadcasters cause issues of auction design and computational complexity to be intertwined here in a way that has not previously been well explored. As already noted, two types of auction design have been proposed by MALS and the NPRM. One is a descending clock auction, using real-time feasibility checking. The other is an unspecified sealed bid auction design in which optimization over relinquishment offers (subject to feasible repacking) might play a prominent role.

In general the types of feasibility checking and constrained optimization problems involved in such auction designs can present severe computational challenges. The NPRM is vague about the nature of the repacking constraints and imprecise about the amenability of the constrained optimization problem to solution using standard or specialized algorithms. In some cases the NPRM discusses use of approximate solutions. In the worst case, approximation approaches can perform extremely poorly. Further, here the quality of an approximation depends not only on proximity to the true solution, but also on how the optimization affects the performance of the auction as a whole.

Without details on the repacking constraints, it is impossible to evaluate the likely performance of potential full solution or approximate solution algorithms. Although certain

auction designs may ease or worsen the computational complexity or performance of approximate solutions, similar issues are likely to arise in any of the contemplated reverse auction designs.

We elaborate on these issues in section 15 below.

13.2 Delay and Uncertainty Due to Target Failures

If the FCC chooses initial clearing targets appropriately,[30] these will be quite high, reflecting an attempt to maximize opportunities for efficient trade. This will almost certainly lead to multiple clearing targets being tried before one is found that allows satisfaction of closing conditions for the grand auction.

Under the current rules, each time the target is reduced, the forward auction must pause while reverse auction bidders are reconvened in order to obtain new "supply" prices for the reduced target quantities. In addition to the burden this creates for bidders, this feature of the auction design will delay completion of the grand auction. It may also introduce uncertainty for reverse auction bidders, since truthful bidding would require some broadcasters to take actions that commit them to assignments days or weeks ahead of other bidders.

14 Single-Pass Reverse Auction

An alternative to the proposed sequence of reverse auctions contemplated by MALS is to conduct the reverse auction in a single pass. The simple idea is that instead of stopping the auction when prices for the most optimistic target Q_1 are reached, the auction would continue and trace out the "supply curve" over the entire range of potential clearing targets. We describe two variations of the basic idea. These differ in whether bidder optimization over the alternative relinquishment options is done by bidders themselves or by proxy.

[30] MALS propose to set initial clearing targets based on the supply offered at high initial reserve prices.

We see at least four potential gains from the single-pass option:

1. greater simplicity for reverse auction bidders;

2. avoidance of delay and inconvenience for bidders when a closing target fails;

3. enabling improved efficiency in a two-sided closing trial (see section 18);

4. avoiding real-time feasibility checking.

The first three gains can be achieved with our baseline proposal. The last takes advantage of proxy bidding.

14.1 Single-Pass: Baseline

Our baseline proposal would alter the reverse auction design only slightly. Instead of conducting a sequence of reverse auctions, each with a progressively smaller clearing target, just one reverse auction would be held. Let $Q_1, Q_2, \ldots, Q_T$ represent all possible clearing targets entertained by the FCC, listed in descending order. In the single pass reverse auction, the FCC would start the auction at prices more than sufficient to clear Q_1, just as it would in the first of its sequence of reverse auctions under the MALS proposal. But instead of stopping when prices for this clearing target are reached, the auction would continue with prices falling until the quantity of spectrum offered in each market reaches Q_T. Bidders' exit prices would be recorded, allowing the FCC to "replay" the reverse auction from the beginning to any desired clearing target. These "replayed" auctions would be used to reveal the payments required for any possible clearing target.

The interaction with the forward auction would then be exactly as originally proposed. The clearing target Q_1 would be tried first in the forward auction. If the revenues obtained there exceeded the total cost implied by the reverse auction bids for the target Q_1, the grand auction would end. Otherwise the forward auction would continue with the lower

clearing target Q_2. However, rather than reconvening the reverse auction to establish the (lower) prices for the new target, these new prices would simply be reconstructed from the single-pass reverse auction.

The single-pass option changes bidding in the reverse auction very little. A bidder must still come to the auction with a reservation value in mind for each of the possible relinquishment options. A bidder's options during the auction would be identical to those under the original proposal, and the rules determining prices paid to bidders for each relinquishment option would be no different. Just as in the original proposal, bidders' choices between relinquishment options would be binding offers. We also see no change in a bidder's incentive for straightforward bidding.[31]

The single pass option offers several advantages. One is elimination of the need for a new reverse auction each time a clearing target fails. This would simplify participation in the reverse auction. It would also avoid delay: rather than pausing the forward auction to reconvene reverse auction bidders each time the clearing target is adjusted, the forward auction could proceed without interruption.

The single-pass design also simplifies participation of reverse auction bidders in a "two-sided closing trial" and would further allow the FCC to minimize the likelihood of "overshooting" during a closing trial (see section 18 below). This could lead to more cleared spectrum. Another advantage is that bidders would be assured that all broadcaster offers were chosen the same day; unlike the MALS design, here a bidder need not worry that the

[31] Consider a simple example with 3 bidders in a market where the clearing target may be 1 or 2 licenses. Suppose that the only options for bidders are to go off the air or remain in their original band (exit). We can divide the auction into two phases: phase 1 covers the period before any bidder exits, and phase 2 is the period between the first and second exits. Suppose that exits are revealed during the reverse auction, so that bidders know the current phase. Consider phase 1. Exiting implies obtaining zero profit (zero gain over the value of remaining on the air). So by standard arguments, exiting at a price above one's valuation is weakly dominated. Further, since the price will only decline further in phase 2, standard arguments imply that remaining in the auction at prices below one's valuation is weakly dominated. Now consider phase 2. The price for clearing 2 licenses has already been determined. So what remains is a single-unit descending auction, where standard arguments imply that bidding one's reservation value is weakly dominant.

final offers of different TV stations might be made days or weeks apart. Such concerns could adversely affect participation and bidding in the auction if bidders believe that new information affecting valuations might arrive in the period between the first MALS reverse auction and the last.

A possible concern is that reverse auction bidders might be reluctant to reveal information unnecessarily. For example, consider a bidder with a reservation value for going off the air that is well below what turns out to be the final market clearing price. Under the MALS design, such a bidder would have no need to reveal just how low a price he would have been willing to accept, whereas a single-pass reverse auction may collect this information.[32] However, we understand that the FCC has well established procedures for protecting confidential information.

14.2 Single-Pass with Proxy Bidding

Conducting the single-pass auction by *proxy* may offer additional benefits. With proxy bidding, bidders would be asked once to report reservation values for each relinquishment option through proxy-agent software. The rules of the auction for a given target Q_t would be identical to that originally proposed. However all bidding would be done by the proxy agent. The proxy agent would implement a straightforward bidding strategy for each bidder. Specifically, at each vector of prices offered by the auction's descending price algorithm, the proxy agent for bidder i would choose the relinquishment option (or "exit") that is most profitable to i according to i's reported reservation values. The proxy auction would stop when prices for the target Q_T are reached.

The primary gain from proxy bidding is that there would be no need for real-time feasibility checking or other optimization. This will ensure that the auction will not stall between

[32] Any such bidder is one who ends up accepting an offer to clear, and bidders giving up their licenses may be less concerned about revealing their reservation values.

rounds due to computational difficulties. It may also allow more complete solutions of the underlying repacking problems, leading to more efficient clearing, i.e., assurance that the most favorable supply offers are accepted.

15 Addressing Algorithmic Issues

Stepping back from any particular reverse auction design, optimal clearing of a given target quantity of spectrum would minimize the total costs of clearing (i.e., the value of relinquished spectrum allocations) and of repacking television broadcasters who remain on the air. Reaching this fully optimal solution is certainly infeasible. One problem is that of *incentive compatibility*: current licensees cannot be compelled to reveal the values they place on their current spectrum allocations and must voluntarily agree to the terms of any relinquishment. This alone makes it impossible to pay each cleared television licensee the lowest price it would accept for its license. A second problem is the computational complexity involved in finding a cost-minimizing allocation. This complexity arises from the effect of repacking one station on the feasibility (or cost) of repacking others. Even if bidders' reservation values were known to the FCC, the cost minimization problem is an integer programming problem of a type known to be computationally hard in general. The unique challenge in the reverse auction design is to handle adequately both incentive compatibility and computational feasibility while also keeping the rules sufficiently simple and transparent. Here we discuss this challenge in further detail.

The MALS clock auction offers an approach in which each bidder has a strong incentive to offer to relinquish whenever the price exceeds his true reservation value (recall Theorem 4). Taking these strategies as given, the MALS clock auction design replaces minimization of total cost with minimization of payments to cleared licensees, subject to sequential verification of repacking feasibility. As long as more bidders than necessary are volunteering to

be cleared, prices fall, leading to repacking of bidders with the highest reservation values. In the simplest form of the proposed design, repacking constraints would enter only through verification that it is feasible to repack a bidder before he is offered a new set of prices. This approach puts priority on the cost of clearing relative to the cost of repacking. Only when it is infeasible for a bidder to be repacked would the auction allow repacking costs to affect the choice of which broadcasters are to be cleared. Possible variations include using repacking constraints to adjust relative clock speeds or to score bidders' offers. This would allow repacking costs to play a larger role, but repacking would still be done sequentially, possibly leading to suboptimal choices.

Of course, the clock auction design is also what leads to the simple and transparent incentives for bidders. Other auction designs might improve on the repacking optimization *given* a set of price offers from bidders, but these offers may be systematically different from those in a clock auction. How such tradeoffs could affect the overall efficiency of the MALS design relative to other options may depend on the nature of the repacking constraints, about which the FCC has thus far released little information.

Further, the MALS clock auction does not avoid significant computational challenge. Formally, feasibility checking takes the form of a "graph coloring problem," which is known to be computationally hard in the worst case. Without knowing the fine details of repacking constraints, it is impossible to determine whether the feasibility checking required by the MALS proposal is itself computationally feasible.

The NPRM also entertains other types of reverse auction designs, where full optimization over bids and repacking costs might play a more prominent role. Few details are provided, making a careful analysis of such options difficult.

Below we elaborate on these issues. However, our overriding message is that by releasing more detailed specifications of the repacking constraints involved, the FCC would enable outside experts to better assess the likely performance of the proposed reverse auction design

and alternatives. Such analysis could clarify which of the mechanisms under consideration may be vulnerable to the computational concerns we discuss, and allow development of new specialized algorithms for the repacking problem that might yield substantial improvements in performance.

15.1 Background and Context

Both the NPRM and the MALS proposal discuss several variations for the structure of the reverse auction. The overarching goal of the reverse auction is to clear a targeted amount of broadcast spectrum in an efficient manner, ideally while minimizing overall costs (in the form of direct payments to the broadcasters and costs associated with repacking broadcasters remaining on-air). Both documents correctly emphasize that the primary computational challenge in meeting this goal arises from the *repacking constraints*. In the absence of such constraints, the reverse auction would require nothing more than selecting those broadcasters demanding the lowest prices (regardless of the auction mechanism details), and paying them to clear their spectrum (up to the targeted amount), while repacking the highest bidding broadcasters. In the presence of repacking constraints, minimizing costs for clearing the desired spectrum may become computationally intractable, and force consideration of various heuristic and suboptimal algorithms.

The repacking constraints are physical, engineering and policy constraints that are exogenous to broadcaster prices, bids and valuations. Broadly speaking, they arise from interference considerations due to the physical and frequency proximity of broadcasters — i.e. if two broadcasters are close enough geographically, and are assigned the same or adjacent channels, interference may occur. Geographic terrain also influences the strength of broadcaster signals. Such sources of interference already exist within the current assignments of broadcasters to frequencies, and define the current "coverage area" or "contour" of a given broadcaster. The repacking constraints arise from the regulatory requirement that

any broadcaster choosing to remain within their current band must be repacked in a way that adequately respects the broadcaster's current coverage area or service contour.[33]

To a first approximation, then, repacking constraints can be thought of as constraints between certain *pairs* of broadcasters: if broadcasters A and B are geographically proximate, and currently on sufficiently different channels that neither interferes with the other's service area, but relocating them on the same or adjacent channels would create too much new interference (as defined by the regulatory requirements), then they cannot be repacked together in this way.

We can view these pairwise constraints as forming a *network* or *graph* in which there is a node or vertex representing each broadcaster in the nation, and there is an edge or link between any pair of vertices whose corresponding broadcasters are constrained in the above manner (i.e. cannot be relocated on the same or adjacent channels without creating too much new interference). This is a large, complex and dense network, and its meaning for the repacking process is clear: once we have decided to repack broadcaster A on channel c, we are then unable to repack any network neighbor of A on any of channels $c-1, c, c+1$. Repacking decisions thus have consequences that *propagate* in both the spatial and frequency dimensions: repacking A on channel c not only constrains repacking geographically proximate broadcasters on c (spatial propagation), but also on channels $c-1$ and $c+1$ (frequency propagation). In other words, "local" decisions can have "long-distance" effects.

It is such long-distance influences through the repacking constraint network that give rise to a computationally challenging repacking problem for *any* proposal for the reverse auction mechanism. The simplest version of the repacking problem is referred to as *feasibility checking* in the NPRM and MALS documents, and can be formulated as follows: *Given the repacking constraint graph G over n broadcasters (vertices) described above, and a subset R*

[33] The NPRM discusses several different possible interpretations of this requirement, none of whose details materially alter the subsequent discussion.

of the broadcasters to be repacked, determine if there is an assignment of the broadcasters in R onto k contiguous channels in a way that obeys all the repacking constraints in G. In an *optimization* version of the problem, there is a price or valuation associated with each broadcaster, and the goal is to find the set R of size k that can be feasibly repacked whose sum of prices or valuations is maximized (e.g. thus minimizing the cost for clearing the set of winning broadcasters).

As we shall discuss, depending on the details of the particular reverse auction mechanism under consideration, one of these variants of the repacking problem arises.[34] But the computational complexity of all of these problems is that they are all provably intractable on worst-case inputs.[35] This means that if the graph G is arbitrary, then the best algorithm for solving these problems will require computation time that scales *exponentially* with the number of broadcasters; in practice, this would mean that these problems could be feasibly solved only for very small instances, much smaller than the number of broadcasters who will participate in the reverse auction.

Given this worst-case computational intractability of repacking problems, there are three broad approaches that can be considered:[36]

1. Employ general-purpose algorithms known to find optimal or exact solutions, even though their worst-case running time may be computationally infeasible, and hope that the actual running times on the "real data" (most importantly, the actual repacking constraints, but also potentially including clearing targets, prices, etc.) will in reality be manageably modest.

[34] The first variant arises in the descending clock auction, while the second arises in sealed-bid mechanisms.

[35] This can be proven via a reduction from the well-known graph coloring problem.

[36] It is worth remarking that some variations of the mechanisms under consideration could greatly ease the real-time computational burdens of the reverse auction. For example, the single-pass clock auction with proxy bidding discussed in Section 14.2 would permit feasibility checking computations to be performed "offline" (that is, not during the auction itself, but after the fact), which might allow slower algorithms that find better solutions.

2. Employ general-purpose algorithms known to be computationally efficient, but which may find suboptimal or approximate solutions.

3. Design special-purpose algorithms that exploit the structure of the actual repacking constraints, hopefully achieving fast computation time and near-optimal solutions.

Approaches 1 and 2 require no advance knowledge of the repacking constraints (though knowledge of them may permit simulations that shed light on the efficacy of these approaches, which we discuss later), while Approach 3 inherently assumes such knowledge. Note further that hybrids of the three approaches are also possible, and may yield the most appealing tradeoffs.

We now proceed to discuss the computational challenges presented by repacking in the context of the specific reverse auction mechanisms under consideration, concentrating primarily on the descending clock auction of the MALS proposal. Our primary intent is again to show that the release by the FCC of considerably more detailed data on and models for the repacking constraints could allow (a) the assessment of how likely drawbacks are to arise in the actual auction, via computational simulations; and (b) the development of new, specialized approaches to repacking that may yield considerably better outcomes in terms of the amount of spectrum cleared, and the expenditures to do so.

15.2 Computational Complexity in a Descending Clock Auction

The NPRM and MALS documents both describe a descending clock auction, which in its simplest form gradually reduces the price offered to each broadcaster to clear their spectrum.[37] Once a broadcaster declines the current clock offer and exits the auction, it must be repacked. Since it is a weakly dominant strategy for each broadcaster to remain in the auc-

[37] Throughout we shall simplify the discussion by assuming the only options available to broadcasters are to clear their spectrum entirely, or to be repacked in their current band. The NPRM discusses a number of other possible options as well, none of which would ease the computational challenges we are discussing.

tion until its clock offer falls below its private valuation for remaining on-air, this auction can be thought of as processing broadcasters in descending order of valuations (since this is the order in which they will choose to exit the auction under their weakly dominant strategies), and is thus mathematically equivalent to a setting in which the broadcaster valuations are known and we use a "greedy" algorithm that attempts to repack higher-valuation bidders first.

In this mechanism or algorithm, we must ensure the invariant that at each point, each broadcaster currently remaining in the auction could be feasibly repacked, given the set of broadcasters we have already committed to repack. Thus, upon adding a new broadcaster b to the current feasible set R of repacked broadcasters, we must check that each remaining broadcaster b' could be added to R and still obey all repacking constraints. If not, then in the language of the proposals, b' must be *frozen* at its current clock price and paid this price to clear its spectrum, since it can no longer be repacked. The version of the repacking problem that is thus relevant to this mechanism is *feasibility checking* — we must determine whether the given set $R \cup \{b'\}$ can be feasibly repacked — and under weakly dominant strategies, the broadcaster valuations determine the sequential construction of a set of $k = n - t$ broadcasters to repack, where t is the clearing target.

As noted, the major source of computational complexity in the clock auction is the repeated feasibility checks to determine which bidders must be frozen as the repacking set R is gradually expanded; this problem is computationally intractable in general. As per the algorithmic approaches mentioned above, one approach is to solve each feasibility check exactly — that is, employ an algorithm guaranteed to correctly answer each feasibility check, and to produce an assignment of the repacked set R to the targeted number of contiguous channels.

There are indeed a number of general-purpose algorithms for solving such problems, including what are broadly known as *satisfiability* or *constraint satisfaction problem* algo-

rithms.[38] While many such algorithms yield fast computation times on various large-scale, real-world problems and benchmarks, the question of how well they would perform in the context of the actual reverse auction is an empirical one that can only be approached via simulation and detailed knowledge of the repacking constraints.

The NPRM and MALS proposals seem to suggest the intention to use such a general-purpose, exact algorithm for feasibility checking in the clock auction. An alternative approach would be to employ an algorithm for feasibility checking that is ensured to be computationally efficient, but may find suboptimal or inexact solutions. We describe one simple such algorithm here. Suppose that for the current repacking set R we have already found an assignment of each broadcaster in R to one of the k contiguous channels $1, \ldots, k$, in a way that violates no repacking constraint. Then to decide if broadcaster b is a feasible addition to R, and to extend the assignment to channels, we can simply consider assigning b to the first free (not already assigned) channel for which no neighbor of b in the repacking constraint network has already been assigned to an adjacent channel. If no such channel exists, we declare that b cannot be repacked given the current R and assignment. The difference between this algorithm and an exact feasibility check is that once a repacked broadcaster is assigned to a channel, the algorithm never considers changing that assignment in order to accommodate later repackings. For this reason we shall refer to this as the *myopic* feasibility checking algorithm, since it makes short-term repacking decisions without regard for later or global consequences.

While it is not difficult to find xamples where this myopic procedure produces suboptimal

[38] `http://en.wikipedia.org/wiki/Constraint_satisfaction_problem`

results, in the sense of being forced to clear more than the desired number of broadcasters,[39] it is an empirical question whether this heuristic, or some other one, would badly underperform in the actual auction. With enough knowledge about the repacking constraints, it is possible that a feasibility checking procedure balancing performance with computational efficiency could be designed.

Repacking Inefficiency in the Descending Clock Auction

In addition to the computational challenges and trade-offs discussed so far, the descending clock auction format may limit the ability to reach near-optimal solutions as measured by repacking efficiency (that is, the sum of valuations of the repacked bidders), because repacking decisions are made sequentially. In its simplest form the FCC would process the broadcasters "greedily" by descending valuation in a completely myopic fashion, without regard to the constraints on later repacking such greedy decisions might impose. A simple example can illustrate the issue.

Example 10. *Suppose there are 5 broadcasters A, B, C, D, E, currently broadcasting on channels 2, 4, 6, 8 and 10 (thus there are no current interferences at all, since no pair is on adjacent channels), and that the target is to clear three of them and to repack the other two onto channels 1 and 2, thus freeing up channels 3 through 10 for wireless spectrum. Suppose that the geographical proximities of the broadcasters transmissions are such that the following pairs of broadcasters* cannot *be repacked together: AB, AC, and AD. We can think of A as a high-power, wide-area broadcaster who would have interference with the nearby broadcasters*

[39] For example, let there be five broadcasters A, B, C, D, E to be considered in turn for repacking on 5 channels, and assume that the geographical proximities are such that the following pairs of broadcasters *cannot* be repacked together: AB, AC, BC, BD. We first add A to R, assigning it to channel 1. When we next consider B, we must repack it on channel 3, since the constraint AB prevents assignment to channel 2. Broadcaster C is assigned to channel 5 due to the constraints AC and BC. At this point, D cannot be added to this assignment: only channels 2 and 4 are free, and B is adjacent to both, and BD is a constraint. E can be placed on channel 2, giving a final ordered assignment of $AEB * C$, where $*$ denotes an unused channel, and we have failed to repack all broadcasters. However, it is easily verified that there *is* a way to repack all five: the assignment $ADCEB$ violates no constraints.

B, C and D; whereas E is sufficiently distant (or low power) that it can be repacked with any of the others.

Table 3: Bidder Values from Repacking

Broadcasters	A	B	C	D	E
Values of being on air	100	99	99	1	1

Suppose the bidders' values for remaining on air are as shown in Table 3.[40] *Given the repacking constraints, the clock auction proceeds as follows. Suppose the price clock is initially set at 100 and descends gradually. Again, it is a weakly dominant strategy for each bidder to drop out when the clock price reaches their valuation. At the initial price of 100, A is first to drop out, so is added to the repacking set R. But once A is added to R, broadcasters B, C and D cannot be added to R due to repacking constraints. This leaves only E, which can be added to R, so the price clock runs down until E drops out. Hence, we get $R = \{A, E\}$, $W = \{B, C, D\}$. If we evaluate the clock auction by the sum of the valuations of the repacked broadcasters, in this example that sum is $100 + 1 = 101$. However, there is a much better solution: we could instead choose $R = \{B, C\}$, $W = \{A, D, E\}$, which yields a total repacked valuation of $99+99 = 198$, almost twice as much as for the clock auction. The problem in this example is that while A has the highest valuation, it also represents the greatest constraints on subsequent repacking.*

Other simple examples (see for instance Example 11) also show that the actual *expenditures* of the clock auction for clearing the desired amount of spectrum can be much more than under other mechanisms such as VCG.

This is an extreme example intended to illustrate a point. We emphasize that the excess

[40] The great variation in valuations in this and subsequent examples is deliberate, and simply intended to show the extent to which different mechanisms can yield very different outcomes, expenditures, etc. Of course, it is worth noting that such variation in broadcaster valuations must be the primary source of any such differences.

expenditure of the clock auction presented in this example is not meant as a critique of the mechanism, but simply to illustrate the potential for suboptimal results, and the way in which it may depend on repacking constraint details.

Hybrid Algorithms, Discounting, and Variable Clock Rates

Of course, there are other algorithms for feasibility checking that could give different tradeoffs than an exact or optimal algorithm which may take exponential time, or a suboptimal or approximate algorithm guaranteed to run efficiently. In particular, it is quite common in such situations to consider various *hybrid* algorithms. For example, we could implement some form of *lookahead* in creating the channel assignment which tried to determine whether repacking a broadcaster will cause severe constraints on further repackings within the next few steps.[41]

The NPRM suggests the possibility of modifying broadcaster bids to exit their spectrum through the use of *weights* or *scores* that would combine the actual bids with a variety of other factors, including the potential difficulties posed by repacking a broadcaster. In particular, one proposal is to score or reweight the bids of broadcasters whose repacking could greatly constrain further repacking, thus making the optimization problem more difficult. Scores would be used for determining the greedy order in which broadcasters are considered for repacking, while the original (unscored) bids would still be used to determine prices for clearing.

Similarly, in the context of a descending clock auction, the analogous idea would be to have the clock prices of "difficult to repack" broadcasters descend more slowly, thus making

[41] Various types of lookahead are quite common, as one example, in chess-playing computer programs, where rather than simulate all possible future trajectories of play after a contemplated move (which would be computationally infeasible), one simulates just the next few possible moves, and chooses moves based on the "quality" of these intermediate states. The idea is to balance near-term reward with longer-term consequences — in the same way we may want to defer repacking a high-valuation broadcaster now because of the future constraints that would impose, we may want to sacrifice capturing a pawn on this move if it could put us in danger of checkmate several moves from now.

them less likely to exit the auction early and thus constrain the repacking process. While the specific goals of introducing such schemes are not discussed at length in the NPRM, presumably one hope is that such scored or modified bids might elicit more computationally and economically efficient behavior from the repacking algorithms.

Another simple example demonstrates the difficulty of designing such scoring or variable clock rate schemes in a way that would have the intended effects, and that actually circumvent the algorithmic problems we have already highlighted. The example also shows a case where the expenditures for clearing are much higher for the clock auction than for VCG.

Example 11. *Let there be the seven broadcasters A, B, C, D, E, F, G whose valuations are as shown in Table 4.*

Table 4: Bidder Valuations

Broadcasters	A	B	C	D	E	F	G
Values of being on air	100	99	3	1	1	1	1

Suppose we wish to clear 5 broadcasters and repack 2. Let the pairs of broadcasters who cannot be repacked on the same or adjacent channels be AB, AC, BD, CE. Then similar to an earlier example, this is a case where the greedy (or clock auction) approach will find a suboptimal solution: First A drops out at price 100*. Then B and C can no longer be repacked, so their clock prices are frozen at* 100*. We then repack D and clear E, F and G at their valuations. The total expenditure is thus* $100 + 100 + 1 + 1 + 1 = 203$*. But a better feasible solution is to repack B, C, and clear A, D, E, F, G, and the associated total expenditure (under VCG) is:* $101 + 2 + 2 + 2 + 2 = 109$*.*

In order for some scoring scheme to avoid this excess expenditure when a greedy algorithm or clock auction is applied, it would need to make the scored price (or clock rate) of A less (or slower) than that of B and C, since it is the first step of choosing A that dooms greedy in this

example. But on what principle would such a scoring or varying rate be based? Notice that all of A, B and C occur in exactly two constraints each, so a simple "constraint counting" scheme will not suffice. Furthermore, this example can be easily modified to actually have B and C have many *more* constraints than A, and yet still elicit the same suboptimal behavior from the greedy or clock approach. It thus seems quite difficult to imagine a simple scheme of this type that eradicates the drawbacks of this approach. The basic problem is that the mere number of constraints a broadcaster appears in, or even information about the more detailed structure and interaction of these constraints, may not help in designing scoring schemes, since one cannot know in advance which constraints will actually matter in (that is, affect the choices of) the greedy repacking process. In this example, the constraints BD and CE were irrelevant once B and C had to be cleared.

15.3 Computational Complexity in Sealed-Bid Auctions

In addition to the descending clock mechanism, the NPRM raises the possibility of some form of sealed-bid reverse auction. In a sealed-bid mechanism, broadcasters are asked to each submit once a price or bid offered for going off-air and clearing their currently used spectrum. Let $B = \{1, \ldots, n\}$ denote the set of n broadcasters or bidders, and for simplicity let us suppose that there is only a single option on which to bid — vacating broadcast spectrum entirely, or not at all. Let $V = \{v_1, \ldots, v_n\}$ denote the *private valuations* the broadcasters assign to remaining on air — that is, the lowest payments they would accept in order to go off-air. Depending on the mechanism, the broadcasters may bid differently than their valuations — for instance, in a pay-as-bid mechanism, there will be an incentive to bid higher than one's valuation, whereas in VCG it is a weakly dominant strategy to bid one's valuation. Thus we also introduce *prices* or *bids* $P = \{p_1, \ldots, p_n\}$ submitted by the broadcasters.

In the same way that the descending clock auction encounters the feasibility checking

variant of the repacking problem, sealed-bid approaches entail a distinct but related computational problem. More precisely, for a targeted number $t \leq n$ of channels to be cleared, we now have an easily stated optimization problem with a well-defined objective function: find that subset W of t "winning" broadcasters to be cleared such that the total expenditure $E(W) = \sum_{i \in W} p_i$ is minimized, *subject to the constraint* that the remaining $n - t$ broadcasters in the set $R = B - W$ can be repacked together. Again, it is this complex combinatorial constraint that makes the computation of the optimal W intractable in general. Note that in the special case of a VCG auction, broadcasters bid their private values as a weakly dominant strategy, so the expenditure $E(W)$ coincides with the *value function* $V(W) = \sum_{i \in W} v_i$, whose minimization corresponds to maximizing the sum of valuations in R.

The NPRM outlines two classes of algorithmic approaches to this problem: *global* algorithms that are generally guaranteed to find an optimal (cost-minimizing) or approximately optimal solution, but that may require inordinate computation time to do so; and what the NPRM refers to as *sequential* (but which could instead be termed *local* or *greedy*) approaches whose solution may be far from optimal, but whose computation time is more modest.

The NPRM further suggests that the repacking constraints are such that the optimization problem falls into the well-known class of Integer Linear Programming (ILP) programs — that is, a linear objective function optimization (in our case, the expenditure function $E(W)$) subject to linear constraints over both continuous and discrete variables. The discreteness arises from presumably multiple sources, including but not limited to the fact that broadcasters must either vacate or not, as opposed to vacating "fractionally," and certain pairs or sets of broadcasters being either mutually exclusive for repacking purposes, or entirely

compatible, but not "partially repackable."[42]

The NPRM discusses[43] taking standard algorithmic approaches to the ILP problem. There exist a wide variety of both open-source and commercial software packages for encoding and solving (integer) linear programming problems.[44] In the case of large scale ILP, none of these packages can guarantee rapid convergence (computation time scales polynomially with the number of variables and constraints) to an optimal or even approximately optimal solution. Since presumably the number of constraints defining the feasibility function F_C is almost certainly in the thousands (possibly even tens or hundreds of thousands), we cannot claim that we have a "small" instance of ILP and argue that brute-force search for the optimal solution would succeed in a reasonable amount of time. The NPRM suggests, without providing any supporting evidence or detail, that existing ILP packages might suffice for finding good approximately optimal solutions. This conjecture is an empirical one that cannot be evaluated without simulation studies using specific ILP packages and specific ILPs based on the actual repacking constraints (or at least constraints broadly similar in their number, size and structure).

15.4 Empirical Evaluations of Reverse Auction Mechanisms

The discussion and examples above emphasize the problems of computational and expenditure inefficiency that *could* arise under the reverse auction designs in the NPRM and MALS proposals. But these examples were obviously based on hypothetical repacking constraints

[42]For example, suppose for each broadcaster i and channel c, we introduce a binary variable $x_{i,c}$ that assumes value 1 if and only if i is relocated to c under repacking, and is 0 otherwise. Then if broadcasters i and j are connected to each other in the repacking constraint graph, in an ILP approach we could introduce, for all channels c, the linear constraints $x_{i,c} + x_{j,c} \leq 1$, $x_{i,c} + x_{j,c+1} \leq 1$, and $x_{i,c} + x_{j,c-1} \leq 1$. These constraints, along with the restriction that the variables $x_{i,c}$ are integer-valued (more precisely, binary), encode the fact that i and j cannot be assigned the same or adjacent channels. (To satisfy each inequality, only one of its two variables may assume value 1.) In this way we can simply represent the repacking constraint network as an ILP.

[43]NPRM, para. 45

[44]See e.g. `http://en.wikipedia.org/wiki/Linear_programming`

of the type suggested in the NPRM, and were designed to exhibit worst-case behaviors of various kinds (though they were simple and did not require complex or unrealistic constructions). The extent to which such difficulties would be encountered in the actual auction depends on a variety of unknown factors, including the detailed structure of the repacking constraints and the likely valuations and bidding behavior of broadcasters.

While eliciting or accurately estimating broadcaster valuations and behavior may be infeasible, doing so for the repacking constraints is not, and would alone permit a variety of activities that could shed significant light on the likely outcomes and potential problems with the various reverse auction designs. Even in the absence of full specification of all repacking constraints, crude approximations — such as identification of which pairs of broadcasters are likely to create interference if repacked on the same or adjacent channels (the aforementioned repacking constraint network) — would allow much better assessment of the proposed auction designs than is currently possible.

The two main activities that would be permitted by having model repacking constraints are simulation studies and the design of specialized algorithms and mechanisms. We discuss each in turn.

Simulation Studies

With model repacking constraints, one could extensively simulate the main proposals for the reverse auction — the descending clock auction and its variants employing algorithms for repacking feasibility checking, and sealed-price mechanisms combined with global optimization using Integer Linear Programming for winner determination. Of course, in both cases one would have to also have a model for broadcaster valuations and bidding behavior, but one could run simulations over a wide variety of assumptions on broadcasters. For example, the simplest model for bidder behavior in the descending clock auction (and the one that in fact motivates that design) is staying in the auction until the clock drops below

the broadcaster's valuation. Armed with models for repacking constraints and valuations, we could thus run large-scale simulations that answered some of the key questions we have raised here:

- For a greedy or descending clock approach, how difficult is the exact feasibility checking problem? How effective are heuristic repacking solutions, such as the myopic feasibility algorithm discussed above? And for these and other variants, how suboptimal are the solutions found in terms of expenditures and amount of spectrum cleared?

- For the sealed-bid/ILP approach, is the computation of winning bids subject to repacking likely to be impractically difficult and slow? If so, is the ILP approach able to at least find acceptable approximately optimal solutions quickly? How much worse are these approximations than the global optimal solution?

To illustrate the kinds of simulation studies that could be performed, the questions they could help investigate, and the benefits of more detailed repacking constraint information, we have implemented a very preliminary simulation framework that allows us to compare various quantities (such as clearing expenditures, computation time, and many others) for the main reverse auction mechanism proposals (as well as potential future variants thereof), and for mechanisms that provide useful economic benchmarks. For example, our framework (which is currently implemented in a mixture of Matlab code and open-source optimization algorithm software) permits the simulation of the following mechanisms:

- The descending clock auction, using either an ILP or constraint satisfaction solver for feasibility checking, under the assumption that broadcasters remain in the auction until their offer falls to their valuation for remaining on-air.

- The descending clock auction, but with the exact solution for feasibility checking replaced by the aforementioned and much faster myopic construction of the repacked set and assignment to channels.

- The sealed-bid VCG mechanism, again under truthful bidding, using an ILP solver for the selection of the expenditure-minimizing set of broadcasters to clear.
- A sealed-bid pay-as-bid (first price) reverse mechanism, evaluated under full-information Nash equilibrium bidding, and again employing ILP for the selection of broadcasters to clear.

Essentially any other variant or proposed mechanism could be incorporated into our simulation framework. Our framework also permits the specification of essentially any set of pairwise repacking constraints and broadcaster valuations. For instance, this allows us to simulate varying numbers of broadcasters, with varying density or number of repacking constraints; varying distributions (parametric forms, variances and means, etc) of broadcaster valuations, etc.

In Appendix D, we provide some very preliminary sample simulation results, which highlight the ways in which different reverse auction mechanisms are influenced by repacking constraints and broadcaster valuations, and the fact that which mechanism is "best" (in several senses) depends strongly on these constraints and valuations, thus emphasizing the need for real data. We expect the scale and sophistication of our simulations to improve with such data and the development of our framework.

Design of Specialized Algorithms

The second activity enabled by model repacking constraints would be the design of specialized mechanisms and algorithms that exploit the special structure of these constraints. The majority of algorithmic work in computer science is devoted to finding good algorithms for special cases of problems that are intractable in the general case. A classic example of this is the Traveling Salesman Problem (TSP), which is NP-hard without any assumptions on the network of "cities" and "distances" between them, but for which there is a very efficient

algorithm yielding very good approximations to the optimal solution if the network corresponds to a physical, 2-dimensional map. TSP is more generally an excellent example of a hard problem on which tremendous practical progress has been made through a combination of simulation studies and designs for special cases.[45]

Armed with model repacking constraints, one could similarly investigate whether a specialized algorithm for cost-minimizing winner selection in a sealed-bid auction could be considerably faster than with a generic ILP approach. The same could be done for the previously discussed problem of feasibility checking in the descending clock auction. Fast and (near-)optimal algorithms for these problems could materially change the assessment of the corresponding mechanism proposals.

15.5 Specific Requests for Repacking Constraint Data

In light of the discussion, examples, and simulations above, it is clear that repacking complexity is a central concern in any reverse auction mechanism, and that the details of the actual repacking constraints and broadcaster valuations will significantly impact the potential computational complexity, costs for clearing, and other properties of the reverse auction. We therefore now discuss various types of information that could greatly aid the study of reverse auction proposals, and lead to the development of better repacking algorithms specialized to the actual constraints.

An ideal along these lines would be a complete mathematical description of all the known repacking constraints, for all broadcasters across the nation, specified in some formal, machine-readable language or notation (e.g. a network of pairwise incompatibilities for adjacent channels, an integer linear program or constraint satisfaction program, etc.) Related, but slightly more general (and thus less informative about the actual specific constraints) would be a program or parametric model that permits the generation of such complete

[45] See e.g. `http://en.wikipedia.org/wiki/Travelling_salesman_problem`

descriptions under varying assumptions (e.g. power and interference assumptions, service contours, acceptable degradations of service, etc.)

It would also be extremely valuable to have a simple network or networks giving pairwise repacking constraints over broadcasters (i.e. the repacking constraint network), or again, parametric mathematical models for the repacking constraint network under varying assumptions. Related data of value would be geographical (latitude and longitude coordinates) for the transmission location(s) of every broadcaster eligible for participation in the reverse auction.

Part IV

Closing Rules

16 The NPRM and MALS Proposals

An important component of the grand auction design is the integration of the forward and reverse auction. This is where "supply" and "demand" meet to determine how much spectrum will be allocated to TV stations, and how much to wireless carriers. Of course, there are important differences from the classic supply and demand setting. One is that prices paid by forward auction buyers must cover not only payments to reverse auction sellers, but costs of repacking and of the auction itself. Another is that the forward and reverse auction prices do not reflect the valuations of bidders on the margin.

Example 12. *Suppose there are two bidders on each side of the market. One of the forward auction bidders ("buyer H") has valuation 100 and the other ("buyer L") has valuation 50. Likewise, one of the reverse auction bidders ("seller H") has valuation 100, and the other ("seller L") has valuation 50. Suppose the target is to clear one license and that there are no repacking constraints. The reverse auction will end at a price of* 100*, the second lowest seller valuation. Seller L will be provisionally assigned to sell his license. The forward auction will end at a price of* 50*, with bidder H the provisional winner. Clearly the net revenue requirement fails: the provisional forward auction revenue is only half the reverse auction cost. This is not because the transfer of spectrum from seller L to buyer H is inefficient; indeed, this trade would double the surplus created by the spectrum. The problem is that instead of comparing buyer H's willingness to pay with seller L's valuation, the auction rules compare buyer L's willingness to pay to seller H's valuation. This comparison has nothing to do with whether trade should occur.*

The fundamental problem is the separation of the forward and reverse auction markets. Although the purpose of the incentive auctions is to allocate scarce spectrum competitively, a clock auction in the forward market induces competition only between mobile wireless carriers; these bidders compete to be among the provisional winners, but do not compete with television stations for final ownership of spectrum. Likewise, a reverse clock auction creates competition only between current broadcast television licensees. Reverse auction bidders compete to be provisional sellers, but the two sides never compete directly with each other to resolve the question of how much spectrum should be transferred from potential sellers to potential buyers. The result is that both the forward and reverse auction will tend to stop too soon, i.e., at prices that are unnecessarily low in the forward auction and unnecessarily high in the reverse auction. Uncorrected, this could undermine efficiency, just as in the example above.

This limitation is recognized by MALS and underlies their proposal that when net revenue falls short the forward auction clock prices would continue rising until either the revenue condition is satisfied or demand falls short of the current target. This can be interpreted as a one-sided *closing trial* for the grand auction at the current target. It allows forward auction bidders to express their willingness to pay prices above the provisional forward auction prices if necessary to achieve satisfaction of closing conditions at the clearing target.

17 Primary Concerns with the One-Sided Closing Trial

The one-sided closing trial contingency still leaves more room for inefficiency than necessary. This is easily seen in Example 12. A price anywhere strictly between 50 and 100 would result in trade. However, no trade will occur even with the closing trial because buyer H will not be willing to beat the provisional reverse auction price of 100. The problem is that while a one-sided closing trial allows forward auction bidders to express their willingness to

offer better prices when necessary to ensure that they are allocated the licenses they seek, there is no such provision for the supply side. Reverse auction bidders lack the opportunity to improve their price offers in the event that closing conditions fail. Thus, even if there are reverse auction bidders who would like to offer prices substantially below those obtained in the reverse auction (recall that these are the maximum prices that clear exactly the target), those bidders will have no opportunity to express this. Put differently, with a one-sided closing trial there is still a barrier to full buyer-seller competition for ownership of the marginal units of spectrum. The result will be unnecessary inefficiency. Some trades that buyers and sellers would all prefer will not take place, not due to the inherent constraints of incentive compatibility, but due to the auction design.

18 Two-Sided Closing Trial

One possible solution to the limitations of a one-sided closing trial seems clear: allow both sides of the market to participate in the closing trial when this phase is required.

18.1 Baseline Proposal

In the baseline proposal, no change to the main forward or reverse auction is needed. However, if the forward auction reaches a point where excess demand is zero but the net revenue condition fails, all parties would be told that the clearing conditions have failed. Prices would then be raised in the forward auction while lowered in the reverse auction. For example, in a sequence of rounds, prices in the forward market could rise by a percentage ρ while those in the reverse auction fall at the same rate. Intra-round bids could be used to avoid overshooting. Bidders on each side would express demand/supply at the clock prices, just as in the original forward and reverse auctions.

Let p_D and p_S denote vectors of clock prices in the forward and reverse auctions, respec-

tively. Let $D(p_D)$ denote the vector of total quantities (e.g., MHz) demanded of each object at the forward market prices, with $S(p_S)$ denoting the vector of total quantities offered for supply at the reverse auction prices. Let Q_t denote the current target clearing quantities.[46] At the beginning of the closing trial we have

$$D(p_D) = S(p_S) = Q_t.$$

The two-sided closing trial would end as soon as either

(a) the revenue requirement is satisfied, or

(b) $\min\{D(p_D), S(p_S)\} < \alpha Q_t$ for some $\alpha \in (0, 1]$.

Condition (b) corresponds to the case in which the closing trial fails. Here $<$ represents the component-wise strict partial order. Thus, if $D^m(p_D)$, $S^m(p_S)$ and Q_t^m are the components of $D(p_D)$, $Q_S(p_S)$ and Q_t corresponding to market m, the condition

$$\min\{D(p_D), Q_S(p_S)\} < \alpha Q_t$$

holds iff *both*

$$\min\{D^m(p_D), S^m(p_S)\} \leq \alpha Q_t^m \ \forall m$$

and

$$\min\{D^m(p_D), S^m(p_S)\} < \alpha Q_t^m \ \exists m.$$

Thus, if $\alpha = 1$, part (b) stops the auction as soon as one bidder (from either side of the market) exits the closing trial. Smaller values of α (for example, $\alpha = \frac{Q_{t+1}}{Qt}$, if clearing targets are uniform across markets) would allow a degree of incomplete clearing of the current target Q_t before triggering a nationwide adjustment to the target to Q_{t+1}. Variations on this rule

[46] Recall that we denote the sequence of clearing targets, beginning with the first, as $Q_1, Q_2, \ldots$.

are possible. For example, one might set the trigger threshold in condition (b) based on nationwide or regional clearance levels rather than by the "worst" market.

If the closing trial ends with condition (a) above, the closing trial succeeds. The grand auction would then terminate. If condition (b) terminates the closing trial, the attempt to clear the target Q_t would fail, the target would be reduced to Q_{t+1}, and the forward and reverse auctions would continue from this point as envisioned in the original MALS proposal.

As long as the clocks in auction $t+1$ are started from the final prices in the auction t closing trial (i.e., strict continuation from the closing trial), incentives for reverse auction bidders are identical to those in the original reverse auction design. The proposed modification does not appear to change incentives in the forward auction either.

The following example illustrates the two-sided closing trial.

Example 13. *Consider a one-market example in which the FCC is attempting to clear 90MHz of spectrum (fifteen channels) in the reverse auction and sell 80MHz of this spectrum in the forward auction in the form of eight 10MHz (5+5) paired licenses (the remaining 10 MHz is reserved for guard bands or other uses). Suppose that the reverse auction stops at a price of 75, whereas each of the 15 stations electing to go off the air at this price values its license at only 50. In the forward auction, prices stop at 100 per license, although the 9 provisional winners each place a value of 130 on a license. Comparing the provisional forward auction revenue of 800 to the provisional clearing cost of 1125, we have a shortfall. Furthermore, a one-sided closing trial is certain to fail: the maximum willingness to pay among the 8 provisional winners in the forward auction is 1040 (i.e., 8×130). Thus, with the MALS auction design, this target will fail and the target quantity will shrink. A two-sided closing trial could avoid this inefficient outcome. Suppose that in the closing trial, prices rise in the forward auction and fall in the reverse auction at equal speeds, adjusting by 1 unit per round. After 15 such rounds, the forward auction revenue (*$8 \times 115 = 920$*) would (more than) cover the reverse auction cost (*$15 \times 60 = 900$*). Thus the closing conditions*

can be satisfied. Note that all bidders should be happy to accept these prices in the closing trial: exiting the closing trial implies moving to a lower target, where the reverse auction price will fall to 50 and the forward auction price will rise to 130. Thus, there will be many information structures in which bidders will voluntarily participate in the closing trial.

18.2 Closing Trial with Proxy Bidding

Including reverse auction bidders in the closing trial would require them to be called back to the auction when the original MALS proposal would not have required this. This would be required only when net revenue falls short and would be required under the MALS proposal as well unless the one-sided closing trial succeeded. Nonetheless, under the proposal for a single-pass reverse auction (see section 14), this could be avoided altogether, potentially simplifying the closing trial contingency. With the single-pass reverse auction, each bidder will have indicated his willingness to relinquish his license across the full range of prices consistent with the possible clearing targets. This means that the FCC could serve as a proxy bidder for TV stations in a closing trial, keeping a bidder in the auction as long as necessary if the price remains above the minimum price acceptable to the bidder.

We emphasize that taking advantage of this does *not* require that the single-pass auction itself be conducted with proxy bidding.

As long as reverse auction bidders trust the proxy system, this would not alter reverse auction bidders' incentives in the single-pass reverse auction. And up to the inherent ambiguities created by the repacking optimizer, it would be possible for bidders to verify the actions of the proxy agent ex post.

The next section will demonstrate an additional advantage of the single-pass reverse auction in promoting efficiency in the closing trial.

18.3 Avoiding Overshooting

A remaining source of inefficiency in the closing trial arises from potential miscoordination of price clocks. For example, consider a market in which one license is to be cleared. Normalize the net revenue requirement to zero. Suppose the provisional prices and valuations of provisional winners are as follows:

	Forward	Reverse
provisional price	6	9
valuation of provisional winner	10	8

In the closing trial, if the forward and reverse auction clocks move at equal absolute speeds, the closing trial will fail when the forward auction clock reaches a price of 7 and the reverse auction reaches a price of 8. This causes the target to fail even though there are substantial gains to trade remaining. Here, in fact, two-sidedness of the closing trial harms the outcome: a one-sided closing trial would have cleared the target at a price of 9.

Ideally, the clocks would by synchronized in a way that reflected the relative gaps between prices and valuations. In the example above, if the forward price moved at a speed proportional to $(10 - 6)$ while the reverse clock moved at a speed proportional to $(9 - 8)$, the closing trial would end successfully with forward and reverse prices equated at 8.4. Even imperfect coordination can improve outcomes. For example, if the forward clock moves at twice the reverse clock speed, the auction again ends successfully, this time at prices equated at 8. Unfortunately, whether it is better to speed up or slow down one clock relative to another depends on bidders' (unknown) valuations.

Note, however, that the key to efficiency is not actually that the relative clocks speeds be coordinated perfectly, but that the clock does not *overshoot* valuations on one side before allowing bidders on the opposite side to express their full willingness to adjust the provisional prices. With the single-pass reverse auction, substantial progress toward this goal can be

achieved using variable clock speeds, exploiting the fact the supply at any possible price vector is already known. As a simple example, forward and reverse auction clocks could be adjusted at identical speeds in the closing trial as long as this does not cause the closing conditions to fail due to a drop in supply, i.e., as long as at the new prices p_S

$$Q_S(p_S) \geq \alpha Q_t.$$

When the proposed change in the clock prices would violate this condition, the reverse auction clocks would stop, and only the forward auction clocks would continue. Variations on this example could achieve the same goal. The key is that, with a single-pass reverse auction, overshooting on the supply side can be avoided.

This modification does not prevent overshooting in the forward auction during the closing trial. Of course, the risk of such overshooting is only worse in a one-sided closing trial. Further, by beginning the two-sided closing trial with the forward auction clock moving more slowly than the reverse auction clock (the latter controlled to avoid overshooting as described above), one could minimize the chance of any overshooting.

One possible concern with our proposed strategy for avoiding overshooting is that it creates incentives for reverse auction bidders to manipulate their bids, exiting at prices a bit above their reservation values. However, because there will be many reverse auction bidders, the expected gain to a single bidder from such behavior may be small relative to the cost of forgoing profitable selling opportunities.

Appendices

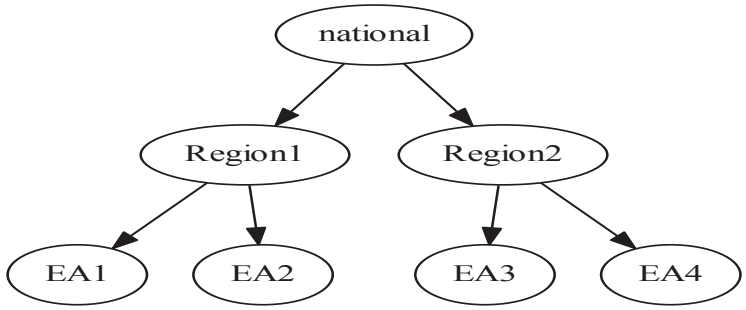
A Clock Package Auction Simulations

The goal of these simulations is to explore the potential performance of the CPA relative to the simple clock auction proposed by MALS. The simulations are not intended to be "realistic" in all aspects. For example, we consider a small number of EAs and do not attempt to create valuations that are realistic in terms of dollar values. Rather, our goal is to illustrate relative performance of the CPA design in a variety of settings aimed at capturing the essential qualitative features likely to be present in the forward auction. The code is written in Matlab and is sufficiently flexible to allow a wide range of further modifications.

A.1 Simulation Design

Licenses and Objects

We specify a three-tier hierarchical structure in which the objects for sale are EA objects, regional objects, and national objects. The scale of the hierarchical structure is controlled by a parameter m. There are $4m^2$ EAs and $2m$ disjoint regions. For our baseline specification we set $m = 1$, yielding the structure illustrated below



The feasible supply of each object is controlled by a parameter k. In our baseline specification we model the case of partially unequal spectrum clearing across EAs. For three quarters of the EAs, we set the feasible supply equal to k; for the remaining quarter, we set the feasible supply to $k-1$. For package objects j, $q_j^f = \min_{k \in \chi_j} q_k^f$ (recall that χ_j represents the children of object j). We set $k = 4$ in the baseline specification.

Bidders

We model three types of bidders: *national bidders*, *regional bidders*, and *local bidders*. National bidders value all objects and obtain additional value (complementarities) when they can obtain a regional license or nationwide license with a guarantee of horizontal contiguity. Each regional bidder is associated with a single region. A regional bidder values the EA licenses in "his" region, and obtains complementarity when he can obtain the regional license with its guarantee of horizontal contiguity. Each local bidder is associated with a single EA and desires one only a license for that EA.

For our baseline specification we have 4 nationwide bidders. We start with 3 regional bidders for each regional license and 2 local bidders for each EA license. However, we use randomization to reduce the numbers of regional and local bidders in each replication, creating variation in the level of competition. This is explained below.

Valuations

Valuations are generated randomly for each replication. The valuations of bidder i are characterized by a vector $V_i = (V_{i1}, \ldots, V_{iJ})$ with one component for each object. We construct the components of each bidder's valuation as

$$V_{ij} = V_{ij}^{+} \times \tilde{V}_{ij}$$

where V_{ij}^{+} is either zero or one (indicating which objects bidder i may place positive value on) and $\tilde{V}_{ij}$ is a random variable reflecting the valuation itself.

For a nationwide bidder i, we set $V_{ij}^{+} = 1$ for all objects j. For a regional bidder i, $V_{ij}^{+} = 0$ for all j with probability α_1. With probability $(1 - \alpha_1)$, $V_{ij}^{+} = 1$ for j corresponding to his regional package and the EAs contained in that package. The randomization has the effect of creating variation across simulations in the number of regional bidders, since assigning a bidder to have no positive valuations is equivalent to eliminating this bidder. Similarly, for a local bidder i, $V_{ij}^{+} = 0$ for all j with probability α_2. With probability $(1 - \alpha_2)$, $V_{ij}^{+} = 1$ for the EA j with which i is associated. All other V_{ij}^{+} are zero. In our baseline simulations we set $\alpha_1 = 1/3$ and $\alpha_2 = 1/2$. This leads to an average of 1 local bidder for each EA license, and an average of 2 regional bidders for each regional package.

For EA objects j, we let

$$\tilde{V}_{ij} = \begin{cases} 0 & \text{w.p. } \alpha_3 \\ \text{u}[0,1] & \text{w.p. } 1 - \alpha_3 \end{cases}$$

for each bidder i (equivalently, for each i such that $V_{ij}^{+} = 1$), where u$[0,1]$ indicates a random draw from a standard uniform distribution. The parameter α_3 is used to create random variation in the number of local bidders, but also introduced additional heterogeneity in package bidders' valuations. These valuations for EA licenses are the building blocks of all valuations. We set $\alpha_3 = 0.1$ in the baseline simulations.

For regional objects j, we let

$$\tilde{V}_{ij} = (1 + \beta_1) \sum_{k \in \chi_j} \tilde{V}_{ik}$$

where β_1 is a random parameter determining the degree of complementarity. For our baseline

specification we let β_1 =u$[0, 1/2]$. Similarly, for the nationwide object, we specify

$$\tilde{V}_{ij} = (1 + \beta_2) \sum_{k \in \chi_j} \tilde{V}_{ik}$$

where β_2 is a random parameter. For our baseline specification we let β_2 =u$[0, 1]$.

Observe that the vectors V_i have length equal to the number of objects. From V_i we construct valuations for all possible subsets of objects i might purchase. For simplicity, we allow bidders to value at most one unit of each object and at most one unit of each EA, whether purchased alone or in a package. To obtain valuations for bundles, when these bundles are not themselves objects, we assume additive valuations. Thus, for example, a national bidder i who purchases a regional license j and an EA license k, where $k \not\subset j$, has valuation for this bundle equal to $V_{ij} + V_{ik}$. Similarly, a regional bidder who obtains two EA licenses j and k without the guarantee of horizontal contiguity provided by the package is assumed to value the component EA licenses with no complementarity, so that his valuation is $V_{ij} + V_{ik}$ for the pair. We let $\bar{V}_i$ denote the resulting extended vector of valuations, which now includes valuations for all objects and for all bundles of objects consistent with the restrictions above.

Note that the costs of the bundles which are not themselves objects in the package auction can be constructed from clock prices in the same way as done for the valuations. For example, if $P = (P_1, \ldots, P_J)$ denotes the current clock prices associated with each object, the cost of purchasing two objects j and k (for example, the regional license and excluded EA license described above) is $P_j + P_k$. We let $\bar{P}$ denote the resulting extended price vector.

Clock Package Auction

The auction begins at a reserve price $r = 10^{-6}$ for each EA object. Reserve prices for package objects are additive in the reserve prices of the EAs they contain We use a negligible bid

increment of 10^{-4}.

We run the CPA with straightforward bidding. At each new vector of prices, for each bidder i we construct the vector

$$\bar{\Pi}_i = \bar{V}_i - \bar{P}$$

which is a list of profits the bidder would obtain from each possible choice of demand if the current prices turned out to be the final prices. Bidder i expresses 1 unit of demand for the profit-maximizing choice from this list. Once the straightforward demands of all bidders are constructed, we calculate the excess demand for each object as described in the text. Clock prices then adjust on objects with excess demand until we reach prices at which there is no excess demand for any object.

MALS Clock Auction

Using the same valuations, we also run the clock auction without packages. The setup is the same, but there are no package objects for sale. Because straightforward bidding in the MALS auction involves significant exposure risk to bidders who have complementary valuations,[47] we assume conservative straightforward bidding. For purposes of generating bids, this is equivalent to setting the complementarity parameters (β_1 and β_2) to zero and having bidders follow straightforward bidding strategies. Thus, given this modification of valuations (and the elimination of package objects in the auction), we generate bidders' profit maximizing demands at each price vector exactly as described above. However, we do not eliminate the complementarities when assessing the value bidders obtain from the final allocation. Thus, if a bidder ends up with all components of a package, we assume he receives a payoff reflecting his full complementarities. This gives a potentially significant "unfair" advantage to the MALS clock auction, since it ignores the fact that complementarities may

[47] Further, in some cases—for example, with symmetric information in Example 1—it requires such bidders to follow strategy that is certain to lead to a loss.

depend on frequency contiguity. Thus the performance gains we find for the CPA will tend to be understated.

A.2 Results: Baseline Specification

We begin with the results under the baseline specification described above. Table 5 summarizes the parameters of our baseline specification.

Table 5: Baseline Parameters

m	=	1
k	=	4
α_1	=	0.33
α_2	=	0.5
α_3	=	0.1
β_1	=	u[0,0.5]
β_2	=	u[0,1]
increment	=	10^{-4}
reservation price	=	10^{-6}
n simulations	=	1000
national bidders	=	4
regional bidders	=	6
local bidders	=	8

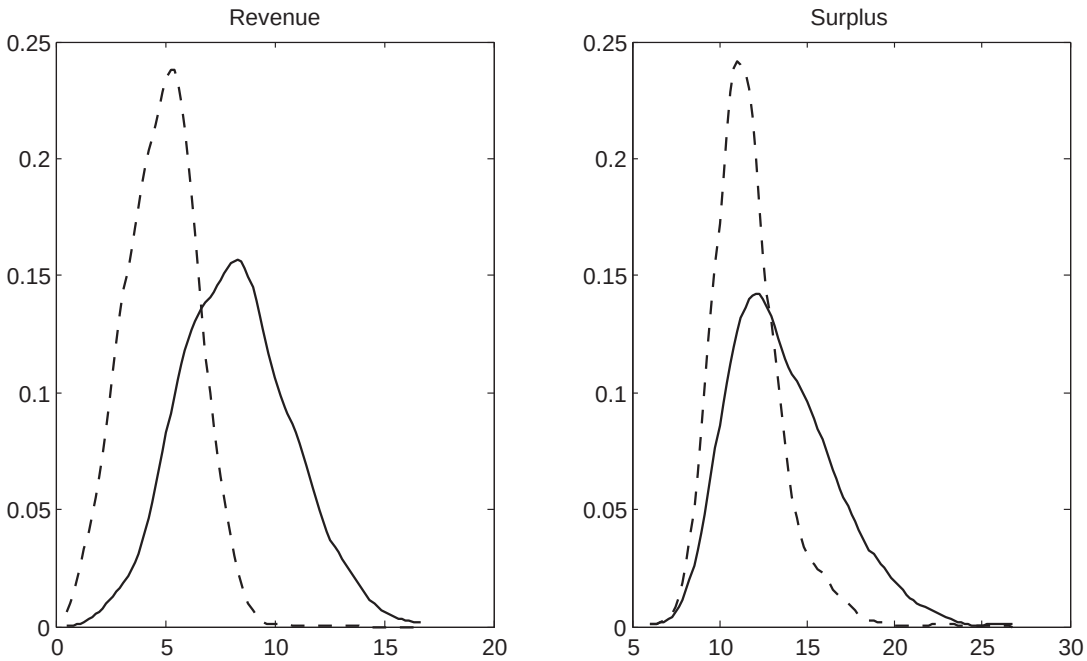
Note that we use the same simulation draws for both the CPA and MALS auction. This avoids introducing simulation error into comparisons and will allow us to make pointwise (replication by replication) comparisons between the two types of auction.

We first examine the performance of the CPA and the MALS clock auction in terms of revenue and efficiency. We measure efficiency by total surplus, i.e., the sum of winning bidders' valuations for the objects they win. This ignores the potential influence of revenues on efficiency via the quantity of spectrum ultimately cleared. Because the CPA consistently generates higher revenue in our simulations, this implies that our comparisons of efficiency are (again) likely to understate the gains from the CPA. We also do not consider re-offering

of unsold licenses when undersell occurs. As seen below, there is slightly more undersell in the CPA, so allowing the re-offer of unsold licenses would only further strengthen the relative performance of the CPA.

Figure 3 illustrates the revenue and surplus outcomes using kernel density estimates applied to the realized revenue and surplus across all 1000 replications.[48] The left panel shows a significant rightward shift in the distribution of revenue when moving to the CPA, indicating significant gains in revenues. There is a similar but smaller rightward shift in the distribution of surplus.

Figure 3: Distribution of Revenue and Surplus



Note: This figure shows kernel density fits to the realized revenue (left panel) and surplus (right panel) across 1000 replications. Solid curves = CPA; dashed curves = MALS auction.

Table 6 shows key summary statistics for these outcomes. Here we report the mean, standard deviation, median, 25th percentile, and 75th percentile of each outcome measure.

[48] Kernel density estimates can be thought of as smoothed histograms. Thus, they illustrate the relative "frequencies" (more precisely, estimates of the relative "likelihoods") of outcomes across the sample.

On average the CPA produces 70 percent higher revenues than the MALS auction, and surplus that is 17 percent larger. In both cases the standard deviation of outcomes is somewhat higher under the CPA. However, much of this is can be accounted for by a change in scale corresponding to better outcomes under the CPA. In particular, the coefficient of variation for revenue is only slightly higher under the CPA than under the MALS design, and the coefficient of variation for surplus is smaller under the CPA.

Table 6: Summary Statistics

	Revenue		Surplus		% Units Sold		Surplus/Optimal	
	CPA	MALS	CPA	MALS	CPA	MALS	CPA	MALS
Mean	8.2	4.8	13.6	11.6	96.8%	99.7%	97.2%	84.3%
Std	2.5	1.6	3.0	1.9	5.1%	1.5%	4.4%	11.1%
Median	8.1	4.9	13.0	11.4	100%	100%	100%	85.5%
q25	6.4	3.7	11.4	10.4	93.3%	100%	95.0%	76.5%
q75	9.9	5.9	15.4	12.6	100%	100%	100%	94.2%

Note: This table reports summary statistics for the baseline simulations. The labels "q25" and "q75" indicate the 25th and 75th (respectively) percentile values of each outcome measure.

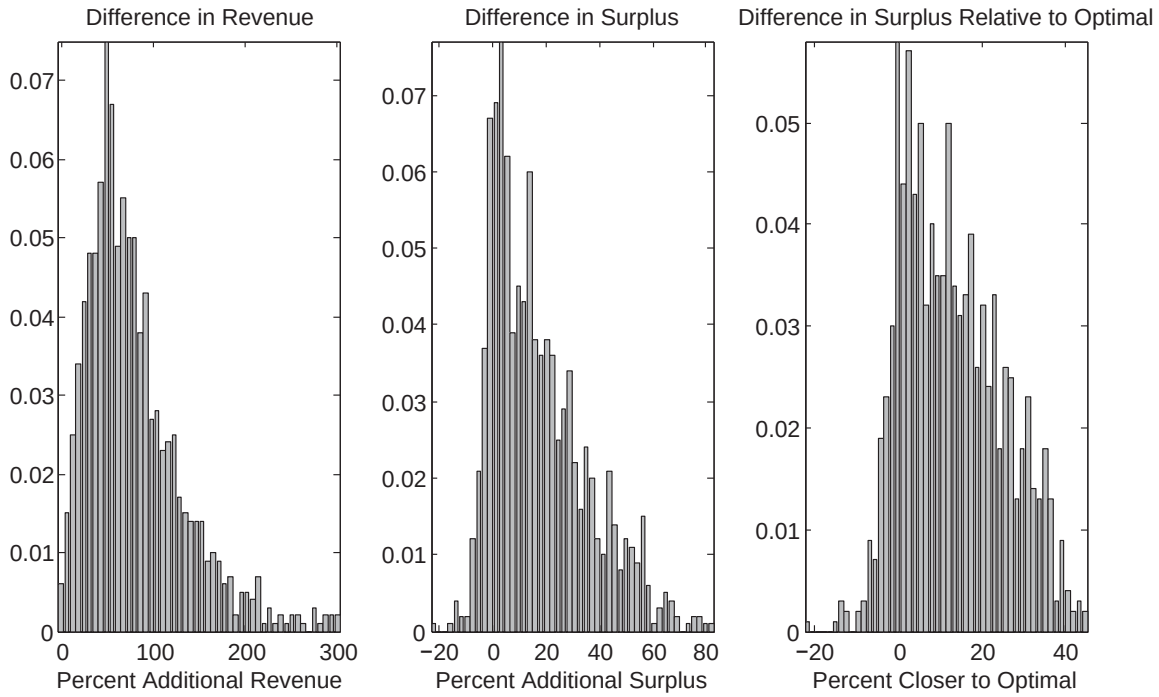
Table 6 also shows the share of licenses sold. The CPA sometimes results in undersell, typically a failure to sell one unit of one EA license. This undersell is occasionally due to lack of demand for some EA object (recall that the number of regional and local bidders with positive valuations is stochastic), but most often due to imperfect coordination of price clocks (recall Example 9). Nonetheless, the degree of undersell is small, with 97 percent of licenses selling on average, and 100 percent of license selling in more than half the replications. Undersell occurs rarely in the MALS auction under conservative straightforward bidding.

Table 6 also reports the surplus achieved as a share of that in the efficient (i.e., first-best) allocation. This comparison shows that the gains in efficiency simply could not be much

greater than what is achieved by the CPA. The CPA significantly outperforms the MALS auction, achieving 100 percent of the efficient surplus more than half the time, and 97 percent on average. The MALS auction achieves full efficiency much less often and yields only 84.3 percent of the efficient surplus on average.

Figure 4 provides another way of looking at the same outcomes. Here we show histograms of the differences in revenue, surplus, and share of the efficient surplus *replication by replication*. We knew that there was no strict dominance relation between the two auction designs. Further, even if the CPA outperforms the MALS auction with high probability, there could in principle be replications in which the CPA does much worse. Figure 4 reveals that this is not the case. Each panel summarizes the pointwise (replication by replication) differences in performance. These difference can be interpreted as the gains from the CPA, although the "gains" can be negative. The first panel shows that the CPA generates higher revenues in virtually all (99.6 percent) of the replications. The magnitude of the gap is often quite large. As shown in Table 7, the median percentage gain in revenue from the CPA is 67.1 percent, and the 75th percentile gain is more than 100 percent.

Figure 4: Distribution of the Percent Difference



Note: This figure shows the histogram of the pointwise (replication by replication) differences between the CPA and MALS auction designs in terms of revenue, surplus, and share of first-best surplus achieved.

The second panel of Figure 4 shows that CPA also generates strictly greater efficiency than the MALS auction in a large majority (85.9 percent) of the replications. Table 7 shows that the median efficiency gain is 13.5 percent. In 11.7 percent of the replications the CPA yields lower surplus, but on average the CPA yields a 17.5 percent gain.

Table 7: Summary Statistics : Pointwise CPA Gains

	Revenue	Surplus
Mean	82.8%	17.5%
Std	70.0%	18.0%
Median	67.1%	13.5%
q25	42.7%	3.2%
q75	105.1%	28.0%

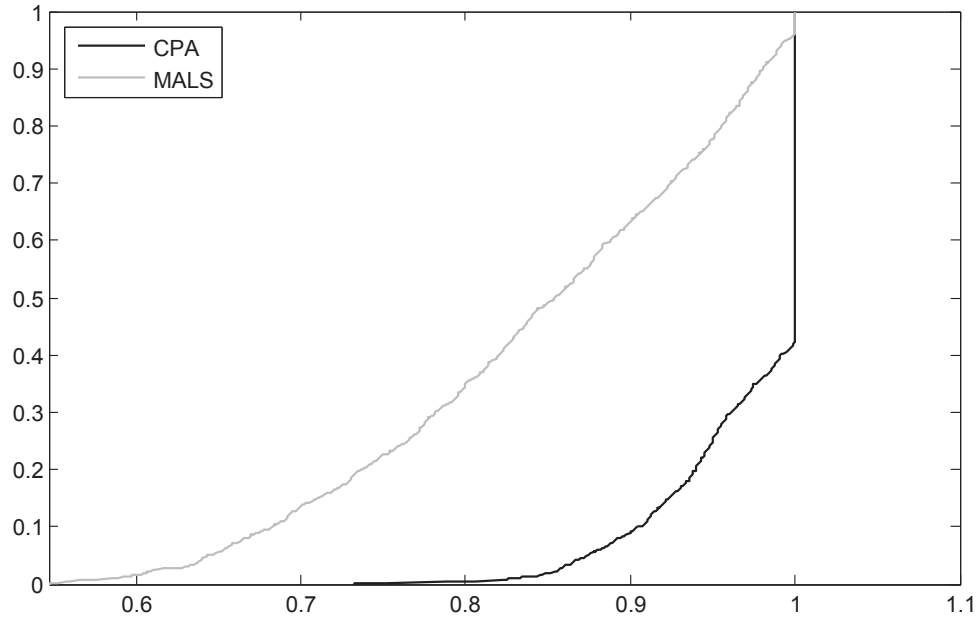
Note: This table summarizes the distribution of outcomes obtained across 1000 simulations. The numbers represent the percent differences between the outcome in the CPA and that in the MALS auction.

In the third panel of Figure 4 we normalize (divide) the surplus outcomes by the first-best surplus, showing the distribution of differences in the share of the efficient surplus achieved (i.e., share under CPA minus share under MALS). As already shown, there are some replications in which the MALS auction is closer to full efficiency. However the gap in these cases is typically small, and a preponderance of replications demonstrate significant efficiency gains from the CPA design. As already shown in Table 6, these gains reach full efficiency in more than half the replications.

Figure 5 illustrates the efficiency outcomes in yet another way, showing the empirical distribution of total surplus achieved normalized by the first-best surplus.[49] Here we see the substantially stronger performance of the CPA. For example, the CPA achieves at least 90 percent efficiency in over 91 percent of the replications. The MALS auction achieves this level of efficiency in only 37 percent of the replications.

[49] The *empirical distribution* plots the share of replications (on the vertical axis) in which the efficiency achieved is *lower* than the level indicated by the horizontal axis. For example, at 100 percent efficiency (horizontal axis equal to 1) the figure shows that fewer than 42 percent of the replications yielded less than full efficiency. Put differently, the vertical segment of the CPA empirical distribution at 100 percent efficiency indicates that more than 58 percent of replications achieved the first-best allocation.

Figure 5: Empirical Distribution of Surplus Relative to the Optimal



A.3 Sensitivity Analysis

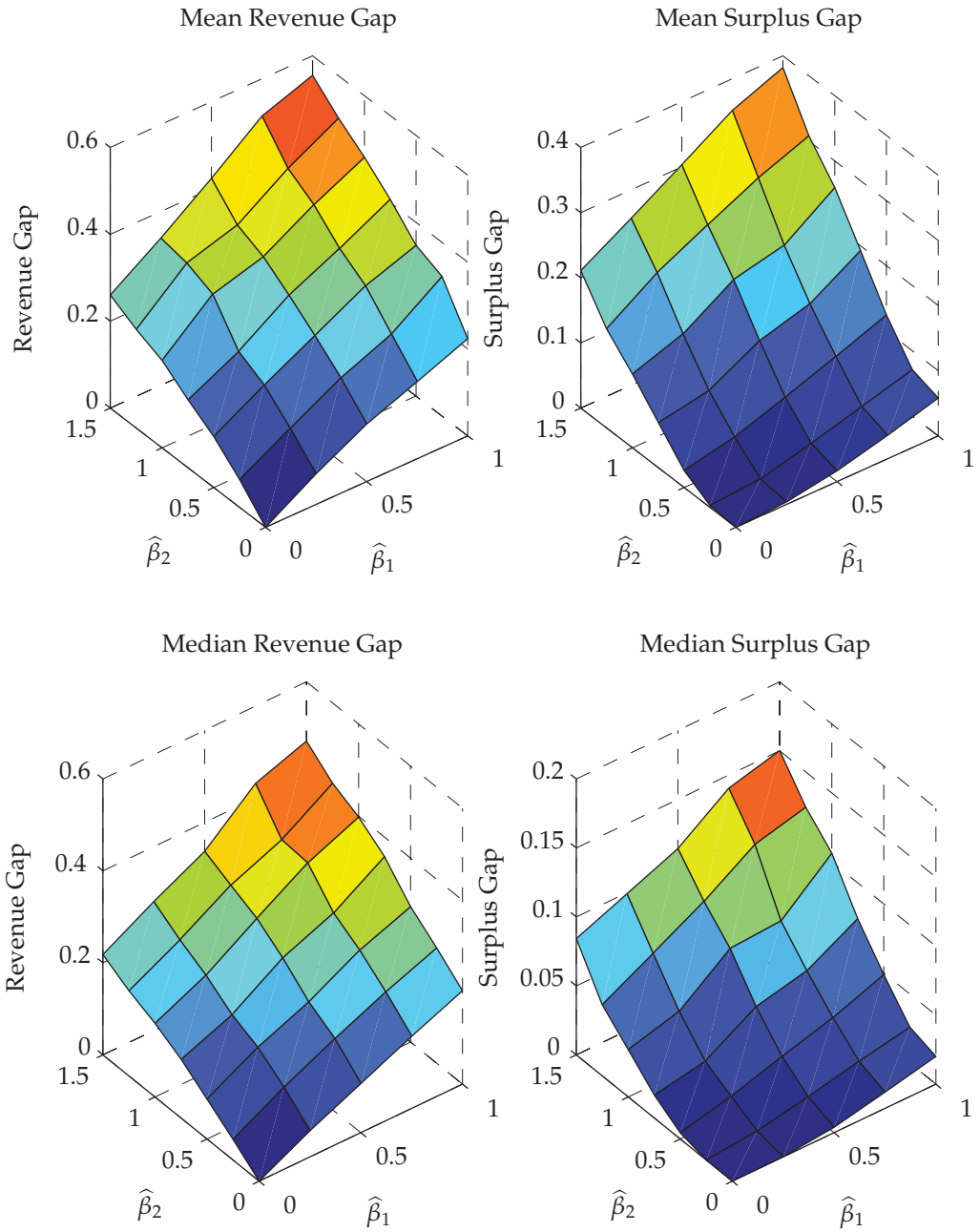
Strength of Complementarities

We first consider the sensitivity of the simulation results to the strength of the complementarities, as determined by the distributions of the parameters β_1 and β_2. We do this by altering the supports of the uniform distributions. Specifically, we let $\beta_1 \sim u[0, \hat{\beta}_1]$ and $\beta_2 \sim u[0, \hat{\beta}_2]$ and re-run the simulations using different combinations of values for the parameters $\hat{\beta}_1$ and $\hat{\beta}_2$. We let $\hat{\beta}_1$ vary between 0 and 1, while $\hat{\beta}_2$ varies between 0 and 1.5. At each pair of values $(\hat{\beta}_1, \hat{\beta}_2)$ we run 500 simulations.[50]

We summarize our findings in Figure 6, where we show the mean and median gains in revenue and surplus from the CPA at each combination of parameters. As we would expect, larger values of the complementarities lead to larger gains from the CPA. However, the qualitative findings remain consistent with those in our baseline specification.

[50] Results change very little with a larger number of draws.

Figure 6: Sensitivity Analysis



Note: These figures show the percent difference (CPA minus MALS) in revenue and surplus of the mean and the median comparison over 500 simulations. For each set of simulations, β_1 and β_2 are drawn randomly for each auction from uniform distributions with supports $[0, \hat{\beta}_1]$ and $[0, \hat{\beta}_2]$, respectively.

Within-Auction Complementarity Heterogeneity

In our baseline specification the complementarity parameters β_1 and β_2 were drawn once for each auction replication. Thus the same complementarity parameter applied to every regional and national bidder. Because these parameters interact multiplicatively with valuations, this implies different levels of complementarities for each bidder. Nonetheless, it may be more reasonable to treat the complementarity parameters as themselves varying across bidders. We have therefore re-run the baseline simulations drawing β_1 and β_2 randomly for each bidder in each simulated auction. We summarize the results in Tables 8 and 9. Comparing the results to those in Tables 6 and 7, we see that the outcomes are nearly identical to those in the baseline specification.

Table 8: Summary Statistics

	Revenue		Surplus		% Units Sold		Surplus/Optimal	
	CPA	MALS	CPA	MALS	CPA	MALS	CPA	MALS
Mean	8.1	4.9	13.7	11.6	96.2%	99.7%	97.0%	82.6%
Std	2.0	1.6	2.4	1.8	5.9%	1.6%	4.8%	8.9%
Median	8.1	4.8	13.5	11.5	100%	100%	100%	82.7%
q25	6.8	3.8	12.1	10.5	93.3%	100%	95.0%	76.3%
q75	9.5	6.0	15.3	12.5	100%	100%	100%	89.2%

Note: This table summarizes outcomes obtained across 1000 simulations using random draws of β_1 and β_2 for each bidder.

Table 9: Summary Statistics : Pointwise Comparison

	Revenue	Surplus
Mean	77.9%	18.9%
Std	55.0%	15.4%
Median	66.2%	17.8%
q25	44.3%	7.4%
q75	96.9%	29.1%

Note: This table summarizes the distribution of outcomes obtained across 1000 simulations using random draws of β_1 and β_2 for each bidder. The numbers represent the percent differences between the outcome in the CPA and that in the MALS auction.

B Other Concerns with CCA Supplementary Bidding

We provide further details on the concerns associated with a combinatorial clock auction (CCA) approach to supplementary bidding in Section 9.

First, bidders in the proxy phase may not have appropriate incentives for bidding for all relevant packages, and clock bids that are used to impute for the missing package bids may not accurately price the "social opportunity costs." To illustrate, suppose there are four units of a (homogeneous) license, and there are two bidders 1 and 2, each of whom values his i-th unit at $5-i$, for $i = 1, 2, 3, 4$. Suppose the clock price rises in small increments each round from zero. If bidders bid straightforwardly and truthfully, then the clock auction ends with each bidder winning two units at the price of 2. All four units are sold, and this means that under the suggested activity rule (e.g., Ausubel and Cramton (2011)) the allocation is not changed, and more importantly, any profile of feasible strategies by the bidders forms an equilibrium, meaning that each bidder is indifferent across all feasible package bids (see Levin (2011) for instance). It is then conceivable that the bidders may not bid at all or only bid for their winning packages. Suppose the bidders make no supplementary bids.[51] In that case, the "proxy agent" uses the clock bids to impute the bidder's package bids, so the bids of 4, 6 and 4 will be entered as bids for packages of 4, 3 and 2 units, respectively.[52] Notice that these package bids understate the bidder's true values, which are $10(=4+3+2+1), 9(=4+3+2)$ and $7(=4+3)$, for 4, 3 and 2 units, respectively. Since the preferences are substitutable, the prices charged for the winning bidders are VCG, but importantly they are computed based on the "imputed" package bids. Consequently, each bidder pays $2 = 6 - 4$,[53] below the true VCG payment, $3 = 10 - 7$.

[51] A similar result holds if they bid only for the winning package of the clock phase.

[52] Interestingly, the package bids can be non-monotonic. Of course, the non-monotonicity may arise even if the bidders do make supplementary bids, given their indifferences. Incidentally, such a non-monotonicity has been observed in the UK 10-40GHz auction.

[53] That is, the price is the value of the most profitable package for the opponent, which is no more than 6, minus the value of the opponent's winning package, which is 4.

Second, the ambiguous bidding incentives in the proxy phase may make CCA susceptible to collusion. Bidders have a relatively simple way to support a collusion. They can (tacitly) agree to divide the licenses among themselves, and they can drop their demands quickly (but dropping one unit at a time for each increment) to their agreed-upon levels. In the proxy phase, they can simply go "quiet" and not make any supplementary bids, unless some bidder has deviated in the clock phase, in which case they all bid truthfully for the packages in the proxy phase.[54] This behavior can be supported as an equilibrium due to the feature that bidders become indifferent over all of their feasible bids in case all license are sold; the indifference means that a bidder has no obvious incentive to deviate from a collusive agreement. More importantly, even bidding straightforwardly during the clock phase can lead to a collusive outcome, as illustrated above.

Third, the ambiguous bidding incentives in the proxy phase could compromise bidders' incentive for bidding truthfully in the clock phase and could lead to an inefficiency, as pointed out by Levin (2011). To see this, consider the above example again. There exists an equilibrium in which bidder 1 bids slightly more than 3 for the third unit to win 3 units and bidder 1 bids true marginal values to win only 1 unit, and thereafter in the proxy phase bidder 1 bids truthfully and bidder 2 goes "quiet" and makes no bid. As noted, since all items are sold in the clock phase, any strategy profile, including the described behavior, is an equilibrium in the proxy phase. Given this behavior in the proxy phase, the described behavior of the bidders in the clock phase is supported as an equilibrium.[55] Clearly, the resulting allocation is inefficient.

[54] This is possible if they had demanded such packages in the clock phase.

[55] Against the truthful bidding by bidder in the proxy phase, bidder 2 can do no better than bidding true marginal values in the clock phase. Against the "quiet" behavior by bidder 2, bidder 1 pays only $2 = 6 - 4$, whereas if he wins only 2 units, he will still pay $2 = 6 - 4$ (as observed earlier).

C Proof of Theorem 4

Theorem 4. *Consider the MALS reverse auction and assume that clock prices decline continuously and with speeds that do not depend on the actions of bidders. Then straightforward bidding is a weakly dominant strategy for all bidders.*

Proof. Consider an arbitrary bidder i. Let $v_{i0}, v_{i1,} \ldots, v_{iK}$ denote i's valuations of each option, where option 0 is "exit" (remain in one's currently assigned band) and options $1, \ldots, K$ are relinquishment options. Let $p_i = (p_{i0}, \ldots, p_{iK})$ denote the clock prices offered to bidder i at a given instant in the auction. The price p_{i0} is always zero. The price of an option k that is infeasible for bidder i is specified as $p_{ik} = -\infty$. For each $k = 0, \ldots, K$ let

$$\pi_{ik}(p_i) = v_{ik} + p_{ik} - v_{i0}.$$

Thus, $\pi_{ik}(p_i)$ represents the gain (relative to the "exit" option) i would realize at the current clock prices by choosing option k. Of course, $\pi_{i0}(p_i) = 0$. Let

$$\bar{\pi}_i(p_i) = \max_k \pi_{ik}(p_i).$$

We will need to consider three possible types of deviations from the straightforward bidding strategy (the strategy of choosing option $k^*(p_i) \in \arg\max_k \pi_{ik}(p_i)$ at every price vector p_i). (i) Suppose i exits when $\bar{\pi}_i(p_i) > 0$. Since exit is irreversible, this deviation has no effect on i if he would ultimately have been assigned option 0 by following straightforward bidding. So this deviation can affect i only when it changes his final assignment from some $k > 0$ to 0. Since straightforward bidding guarantees i a payoff of at least v_{i0} and could have led to strictly higher payoff (e.g., if all others exited immediately at their current price offers), exiting when $\bar{\pi}_i(p_i) > 0$ is weakly dominated at p_i. (ii) Now suppose i chooses an option $k > 0$ even though $\bar{\pi}_i(p_i) < 0$. Relative to straightforward bidding when the price

vector is p_i, the only way this choice could change i's payoff is if i ends up assigned to some option $k > 0$. But in such cases i's payoff is strictly less than v_{i0}. Since v_{i0} is the lowest payoff i can receive under straightforward bidding, this deviation is weakly dominated. (iii) The remaining possible deviations from straightforward bidding involve choosing an option $j \notin \arg\max_{k>0} \pi_{ik}(p_i)$ when $\bar{\pi}_i(p_i) > 0$. Because this choice does not change the subsequent price offers to i or other bidders, the only way this deviation from straightforward bidding can change i's payoff is when p_i turns out to be the final price vector i is offered. In this case, he would have been strictly better off following the straightforward bidding strategy. Thus, at any p_i, straightforward bidding is weakly dominant.

D Reverse Auction Simulations

In this section we describe simulation results for the following four reverse auction mechanisms:

- The descending clock auction, using either an ILP or constraint satisfaction solver for feasibility checking, under the assumption that broadcasters remain in the auction until their offer falls to their valuation for remaining on-air. In the figure legends below, this mechanism is referred to as *descending clock*.
- The descending clock auction, but with the exact solution for feasibility checking replaced by the much faster myopic construction of the repacked set and assignment to channels. In the figure legends below, this mechanism is referred to as *myopic clock*.
- The sealed-bid VCG mechanism, again under truthful bidding, using an ILP solver for the selection of the expenditure-minimizing set of broadcasters to clear. In the figure legends below, this mechanism is referred to as *VCG*.
- A sealed-bid pay-as-bid (first price) reverse mechanism, evaluated under full-information Nash equilibrium bidding, and again employing ILP for the selection of broadcasters to clear. In the figure legends below, this mechanism is referred to as *pay-as-bid full-info Nash*.

For these four mechanisms and equilibrium concepts, we consider all six pairwise comparisons of expenditures for clearing 7 broadcasters out of 10 and repacking 3. In Figure 7, the repacking constraint network is generated randomly at various edge densities (0.25, 0.5, and 0.75) over the 10 broadcasters, and the valuations of broadcasters are independent random values between 0 and 100. Each point in Figure 7 corresponds to a single such random trial, and shows the expenditure for clearing three broadcasters for each method on that trial. Points above the diagonal are a win for the mechanism+equilibrium concept on the

x-axis, while points below are a win for the one on the y-axis. In general, the problems become harder with higher edge density (more repacking constraints). Figure 8 is similar in spirit, but instead shows comparisons at the fixed edge density 0.5, but with the number of broadcasters k to be repacked varying from 2 to 4.

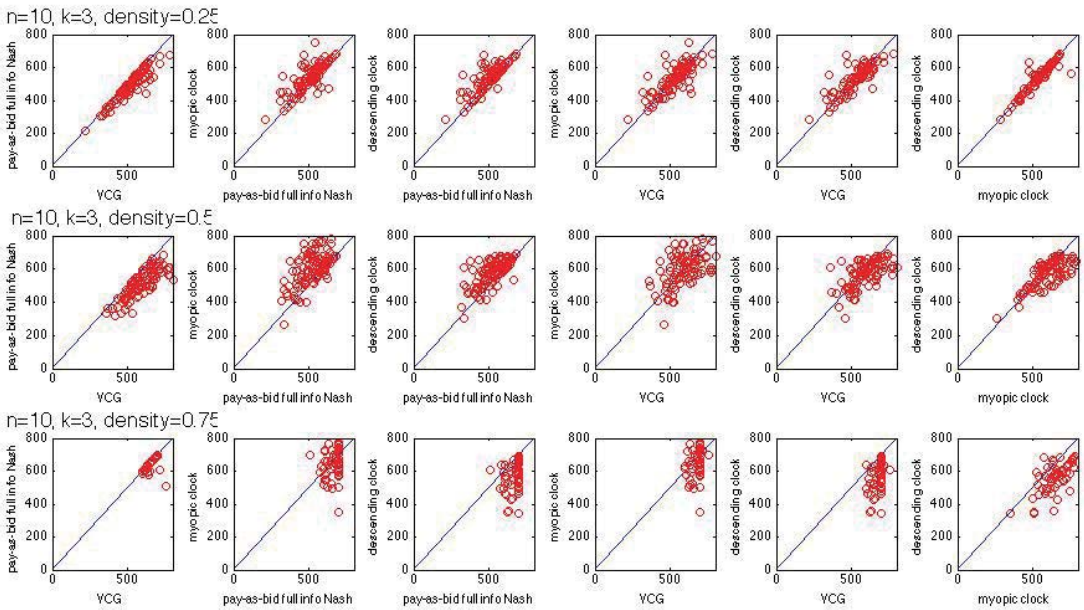


Figure 7: Comparison of mechanism expenditures with varying repacking constraint network edge density.

The main takeaways from these preliminary plots are:

- Even within this artificial family of generated networks, valuations, etc., there are significant differences between the expenditures and other properties of the solutions found by the various mechanisms, and these differences depend on the parameters.
- For example, the clearing expenditures of the clock auction are generally higher than those of pay-as-bid Nash at low edge density, but are generally lower at high edge density. The clock auction expenditures are generally comparable to those of VCG, except at high edge density, where the clock auction tends to spend less.

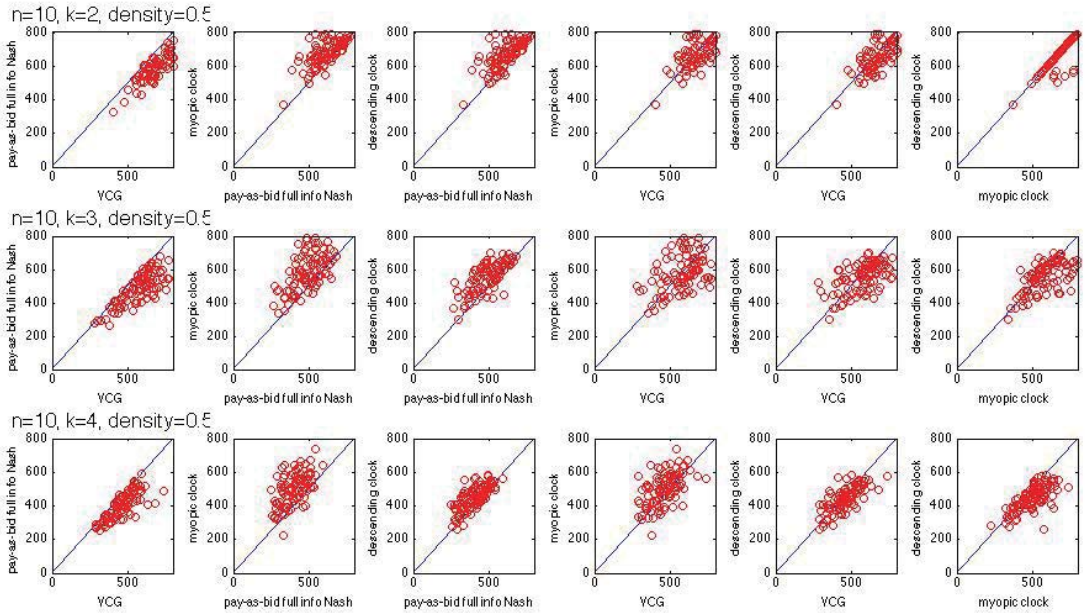


Figure 8: Comparison of mechanism expenditures with varying clearing targets.

- The myopic clock auction — the version of the clock auction where exact feasibility checking is replaced by the computationally efficient myopic assignment algorithm — competes well with the standard clock auction at low to moderate edge density. At high edge density, it starts to underperform due to its clearing more stations than necessary.

- Related observations can be made for varying numbers of broadcasters to repack.

Figure 7 and 8 compare the mechanism expenditures in absolute ("dollar") terms, but perhaps more relevant are the relative expenditures, as measured by the ratio of expenditures for each pair of mechanisms as we vary edge density or clearing target. The maximum and minimum ratios for each pair of mechanisms is thus shown in Figure 9 for each setting of the parameters.

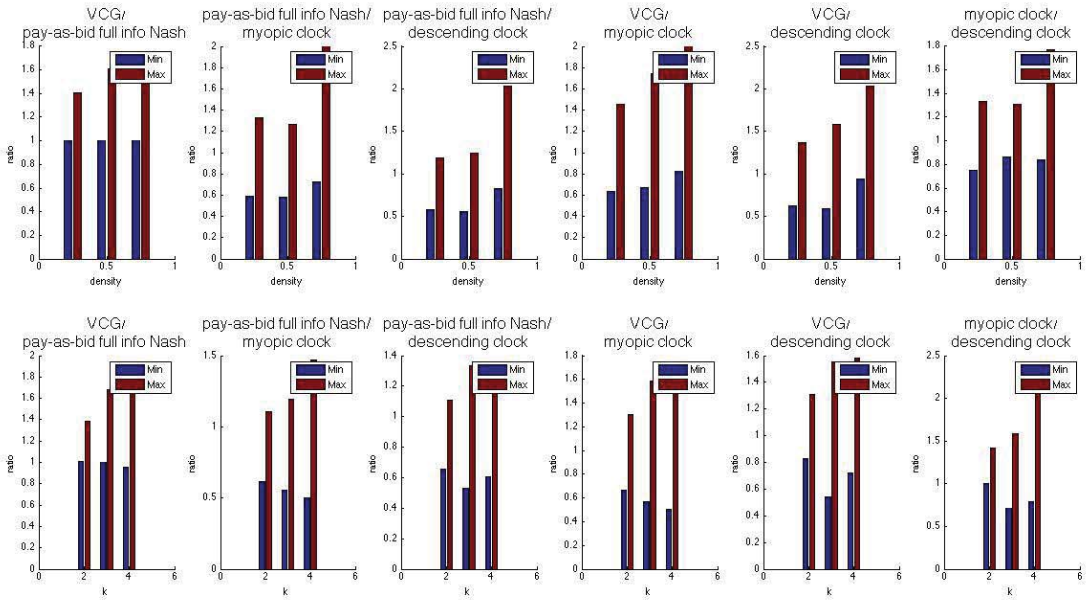


Figure 9: Maximum and minimum expenditure ratios for the mechanisms.

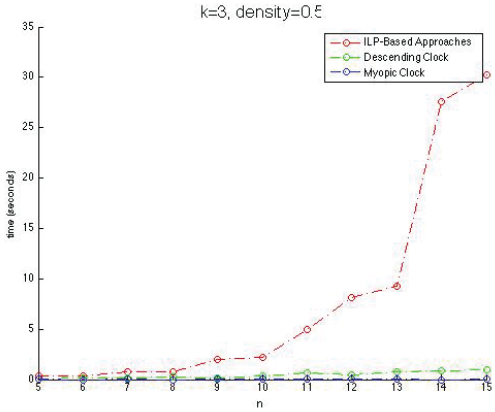


Figure 10: Computation time for the mechanisms as a function of problem size.

Finally, in addition to comparison of solution properties such as clearing expenditures, our simulation framework also permits computational comparisons and benchmarking. For example, in Figure 10, we show computation time (averaged over multiple trials) for each mechanism as a function of the number of broadcasters n. Since the computation time for both VCG and pay-as-bid sealed full-information Nash are dominated by calls to an ILP

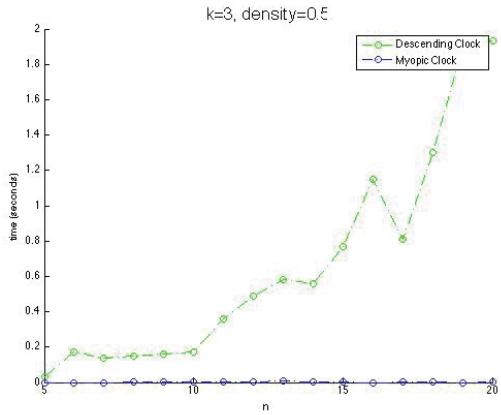


Figure 11: Computation time for the clock mechanisms as a function of problem size.

solver, we plot them together as "ILP-based approaches". We can see that the computation for these approaches grows rapidly as n increases, much more so than for the two clock auction variants. Since the scale is dominated by the ILP running time, in order to compare the clock auctions we show their computational needs on a separate plot in Figure 11. Here we see the standard clock auction running time growing much more rapidly than the guaranteed-efficient myopic clock auction.

References

Ausubel, L. M., and P. Cramton (2011): "Activity Rules for the Combinatorial Clock Auctions," Discussion paper, University of Maryland.

Ausubel, L. M., P. Cramton, and P. Milgrom (2006): "The Clock-Proxy Auction: A Practical Combinatorial Auction Design," in *Combinatorial Aucions*, ed. by P. Cramton, Y. Shoham, and R. Steinberg, pp. 115–138. MIT Press.

Ausubel, L. M., and P. Milgrom (2002): "Ascending Auctions with Package Bidding," *Frontiers of Theoretical Economics*, 1.

Ayres, I., and P. Cramton (1996): "Deficit Reduction Through Diversity: How Affirmative Action at the FCC Increased Auction Competition," *Stanford Law Review*, 48, 761–815.

Cramton, P. (2008): "A Review of the 10-40 GHz Auction," Discussion paper, Office of Communications, United Kingdom.

Cramton, P. (2012): "Spectrum Auction Design," Discussion paper, University of Maryland.

Cramton, P., Y. Shoham, and R. Steinberg (eds.) (2010): *Combinatorial Auctions*. MIT Press.

Federal Communications Commission (2012): "Notice of Proposed Rulemaking," FCC 12-118, September 28, 2012.

Levin, J. (2011): "New Development in Auction Theory and Practice," Lecture Slides, Cowles Foundation, Yale University.

Milgrom, P., L. Ausubel, J. Levin, and I. Segal (2012): "Incentive Auction Rules Options and Discussion," Auctionomics and Power Auctions.

Myerson, R. B., and M. A. Satterthwaite (1983): "Efficient Mechanisms for Bilateral Trading," *Journal of Economic Theory*, 29, 265–281.

Pagnozzi, M. (2010): "Are Speculators Unwelcome in Multi-Object Auctions?," *American Economic Journal: Microeconomics*, 2, 97–131.

ATTACHMENT 2

Reply Comments of AT&T Inc.
March 12, 2013

BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON D.C. 20554

In the Matter of	)	
Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions	)	GN Docket No. 12-268

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March 12, 2013

TABLE OF CONTENTS

INTRODUCTION AND SUMMARY 1

ARGUMENT 12

I. The Commission Should Design a Band Plan that Extracts the Greatest Possible Value from the 600 MHz Band and Elicits the Greatest Possible Forward-Auction Participation 12

A. The Record Reveals Key Points of Consensus Concerning the Design of the Band Plan, Including a Need for Certain Changes to the NPRM's Proposal 12

B. The Commission Should Reject Calls To Create a TDD-Focused Band Plan 15

C. The Duplex Gap and Other Guard Bands Should Be No Larger Than Technically Reasonable To Prevent Interference to Licensed Operations 20

1. The Duplex Gap Should Be 10-12 Megahertz Wide, and the Proper Width of Other Guard Bands Depends on the Power Levels of Potentially Interfering Operations on the Other Side 21

2. The Spectrum Act Requires the Commission To Determine the Size of the Duplex Gap or Other Guard Bands Based Only on Technical Considerations Concerning the Prevention of Interference 24

3. Enlarging the Duplex Gap or Other Guard Bands to Promote Unlicensed Uses Would Impose Large Opportunity Costs, Reduce Forward-Auction Revenues, and Increase the Risk of Auction Failure 27

4. Any Unlicensed Uses in Guard Bands Must Not Interfere with Licensed Operations and Must Accept Interference from Mobile Broadband Operations 34

C. The Commission Should Design Its Band Plan to Promote Handset Interoperability but Should Reject Requests to Impose Interoperability Requirements on 600 MHz Handsets 37

II. The Commission Should Maximize Forward-Auction Revenues and the Odds of Auction Success By Rejecting Proposals to Limit Auction Eligibility 40

A. As Commission Precedent Recognizes, Sound Economic Considerations Foreclose Proposals to Limit Auction Participation on the Basis of Existing Spectrum Holdings 42

B. Distinctions Between "High Band" And "Low Band" Spectrum Cannot Justify Restrictions on Auction Participation 45

C. Restrictions on Auction Participation Would Dramatically Increase the Risk of Auction Failure 48

D. Proposals for "Bidding Credits" Based on Existing Spectrum Holdings Are As Untenable As Other Restrictions on Auction Participation 50

E. The Spectrum Act Prohibits the Commission from Excluding AT&T and Verizon from this Auction on the Basis of Spectrum-Aggregation Policies, Given the Alternative of Allowing Them to Participate and Then Make Any Necessary Divestitures to Preserve Compliance with Those Policies 52

III. The Commission Should Design Efficient Auction Mechanisms—Including Package Bidding—to Maximize the Odds that Forward-Auction Results Will Meet the Statutory Revenue Requirements 53

IV. The Commission Should Reject Proposals to Limit Its Repacking Discretion 60

A. The Statute Requires Balancing Broadcaster Interests Against the Public Interest in Reallocating Additional Spectrum to Mobile Broadband 61

B. The $1.75 Billion Cap on the Repacking Fund Does Not Limit the Commission to Repacking "400-500 Stations" 64

CONCLUSION 68

INTRODUCTION AND SUMMARY

As the opening comments underscore, the statutory task Congress has assigned the Commission is as unprecedented in its complexity as it is critical to the future of mobile broadband. Much of that complexity arises from a central and unprecedented feature of the Spectrum Act. By statutory design, this auction can succeed, and spectrum can be reallocated, only if the Commission elicits forward-auction revenues that exceed reverse-auction revenue requirements plus administrative and estimated repacking costs. The goal of meeting that statutory condition for the maximum possible amount of freed-up spectrum should guide every important decision the Commission makes in this proceeding. In other auctions, there might be some margin for error if the Commission makes speculative policy judgments that impair the value of auctioned spectrum or that keep it from promptly reaching the providers who can produce the greatest consumer benefits with it. Regulatory missteps might needlessly reduce the auction proceeds that are deposited into the Treasury, but consumers nonetheless benefit from the reallocation of spectrum to mobile broadband uses, and secondary-market transactions can normally be expected to produce the eventual assignment of spectrum assets to the providers most capable of putting them to the uses most valued by consumers.

This auction is different, and there is *no* room for regulatory error, because the consequences of such error would be much more severe: less (or no) spectrum would be reallocated for mobile broadband in the first place. To avoid that outcome and free up as much spectrum as possible, the Commission should (1) adopt a sound band plan that maximizes the prospective value of this spectrum to forward-auction bidders; (2) avoid anticompetitive, revenue-reducing restrictions on who may participate in the forward auction; (3) allow forward-

auction participants to express the full value of this spectrum in the form of high winning bids by creating efficient mechanisms for package bidding; and (4) retain full discretion to repack television stations efficiently in order to reduce the number of broadcasters who must be paid to cede spectrum rights.

1. Designing an optimal band plan

Overview. The opening comments reveal widespread support for key aspects of the NPRM's[1] proposed band plan but also a strong consensus that other aspects should be modified. First, there is a consensus against the NPRM's proposals to place (i) television stations in the duplex gap, (ii) all paired downlink blocks below channel 37, and (iii) uplink blocks as far down as current Channels 42-46. Each of those features would create substantial interference and other implementation problems and devalue the spectrum for carriers and consumers alike. Second, as a number of commenters explain, the NPRM proposes excessive market-to-market variation in the number of uplink blocks, a feature that would exacerbate the risk of co-channel interference across neighboring markets in which differing amounts of spectrum have been cleared. That said, the Commission should *not* err in the opposite direction by adopting NAB's proposal to limit cleared spectrum in *all* markets to the blocks that are cleared in markets with the *least* cleared spectrum. Instead, the Commission should adopt a middle-ground band plan that allows a limited amount of market-to-market variation but confines such variation to supplemental downlink spectrum, as AT&T's proposal would do.

TDD/FDD issues. The Commission should reject Sprint/Clearwire's proposal to designate some or all of the 600 MHz band for TDD operations. First, TDD is an outlier

[1] *See* Notice of Proposed Rulemaking, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, 27 FCC Rcd 12357 (2012) ("NPRM").

technology in the United States; with the exception of a single carrier (Sprint/Clearwire itself), all U.S. LTE providers rely exclusively on FDD technology. As a result, there would likely be few bidders—and perhaps only one—for any TDD-designated spectrum in this auction, and the lack of competition for that spectrum would suppress bid levels. Second, TDD operations in the 600 MHz band would create serious risks of harmonic interference to FDD operations in other bands. Third, given the severe incompatibility of TDD and FDD, any mixed TDD/FDD environment would create substantial risks of adjacent and co-channel interference within the 600 MHz band. Such interference could be mitigated only by imposing substantial guard bands and/or exclusion zones that would reduce the amount or usability of licensed spectrum. Fourth, even for spectrum dedicated *entirely* to TDD operations, the coexistence of multiple TDD-based carriers in the same band would present substantial and costly coordination challenges among those TDD operators (or require substantial guard bands between them). Finally, a TDD-only band plan would require complex coordination between TDD operators and television broadcasters that operate on the same channels in adjacent markets in order to manage co-channel interference.

Guard band size and unlicensed spectrum. A key type of guard band—the duplex gap—is needed in any FDD environment to prevent interference between uplink and downlink operations. A strong consensus among carriers and equipment manufacturers is emerging that a duplex gap of 10-12 megahertz is sufficient to perform that role. As Professors Reed and Tripathi explain in their reply analysis,[2] there are also technical reasons to cap the size of the

[2] Jeffrey Reed and Nishith Tripathi, *The 600 MHz Spectrum Auction: An Analysis of the Band Plan Framework and Response to Certain Proposals*, at 22-25 (Mar. 12, 2013) ("Reed/Tripathi Reply") (attached as Exh. A).

duplex gap at 15 megahertz, given technological constraints on efficient antenna design. The proper width of other guard bands depends on a variety of factors, including the transmission power of any adjacent television station, but will fall in the range of 6-12 megahertz.

Led by Google and Microsoft, a few commenters ask the Commission to devote far more spectrum to the duplex gap and other guard bands—not because that extra spectrum is genuinely needed to prevent interference to licensed uses, but simply to reserve more spectrum for unlicensed uses. Although AT&T supports creating additional unlicensed spectrum in other bands, the Google/Microsoft proposal for the 600 MHz band would be unlawful and unwise. First, the Spectrum Act means what it says: the Commission must limit any guard bands in the 600 MHz band to a size that is "no larger than is technically reasonable to prevent harmful interference between licensed services."[3] That mandate applies as much to the duplex gap as to any other type of guard band and prohibits the Commission from artificially enlarging guard bands to accommodate unlicensed uses.

Congress had good reason for including this limitation on the Commission's authority: allocating wide swaths of spectrum for unlicensed uses in the 600 MHz band would impose major opportunity costs on the American public. The question is not whether allocating prodigious new spectrum for unlicensed uses would create value; the question is whether, taking opportunity costs into account, the Commission would create more value by locating such spectrum in this band or in some other band. This auction presents the Commission's best opportunity in a generation to free up large amounts of much-needed new spectrum for *mobile*

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[3] Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, Tit. VI, § 6407(b), 126 Stat. 156, 231 (Feb. 22, 2012) ("Spectrum Act") (codified at 47 U.S.C. § 1454(b)).

broadband uses in the bands below 3 GHz, which, as the National Broadband Plan has noted, have propagation characteristics well-suited to wide-area mobile uses. Google and Microsoft have not shown (and cannot show) that any benefits that might flow from diverting scarce mobile broadband spectrum to unlicensed uses would more than compensate for the consumer-welfare losses that would follow from the resulting reductions in mobile network capacity. In short, it would make a great deal more sense to focus on freeing up substantial new spectrum for unlicensed devices in bands that do *not* pose these opportunity costs for mobile networks, such as the 5 GHz band.

Even if the statutory language permitted the Google/Microsoft proposal (which it does not), and even if that proposal were plausible from an opportunity-cost perspective (which it is not), that proposal would still be untenable because exempting large swaths of unlicensed 600 MHz spectrum from competitive bidding would lower aggregate forward-auction revenues and thus reduce the odds that the auction will satisfy the statutory revenue requirement. Google and Microsoft cite abstract scenarios in which reductions in available spectrum blocks would not reduce aggregate revenues. But as Professor Katz et al. explain, such scenarios are exceedingly unlikely to arise in the real world, and needless reductions in the supply of spectrum subject to auction would indeed increase the risk of auction failure.[4]

First, reducing the supply of licensed spectrum blocks will reduce forward-auction revenues if the demand of potential bidders for those blocks is elastic, and it almost certainly is. Through numerous Monte Carlo simulations, Professor Katz et al. demonstrate that supply

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[4] Michael Katz, Philip Haile, Mark Israel, and Andres Lerner, *Spectrum Aggregation Policy, Spectrum-Holdings-Based Bidding, and Unlicensed Spectrum*, at ¶¶ 64-79 & Appx. A (Mar. 12, 2013) ("Katz et al. Reply Decl.") (attached as Exh. B).

reductions typically lead to substantial revenue reductions under a broad variety of auction scenarios involving bidders with widely differential valuations. Second, even if demand were inelastic in general, revenues would still fall if the incremental unlicensed spectrum that is withheld from the auction is *a substitute for licensed spectrum* and will therefore diminish the value that a carrier could expect to derive from the purchase of new licensed spectrum. Unlicensed spectrum is indeed a substitute for licensed spectrum, and on two levels: from the perspective of wireless carriers (because it is an alternative spectrum input and thus dilutes the value of licensed spectrum) and from the perspective of retail consumers (some of whom will choose unlicensed uses that rely on free spectrum inputs over wireless carriers that rely on licensed spectrum). In short, the Google/Microsoft proposal would substantially reduce auction revenues and thus increase the risk of auction failure.

AT&T does not necessarily oppose unlicensed uses in properly sized guard bands (including the duplex gap). As the Spectrum Act provides, however, the Commission must ensure that such uses will not cause harmful interference to licensed services. Conversely, such unlicensed uses should be required to accept any interference from licensed mobile broadband operations. Absent such protections for licensed operations, the value of licensed blocks would decrease, forward-auction revenues would fall, and paired blocks would become non-fungible.

Interoperability. The Commission *should* promote free-market solutions to efficient interoperability by designing a band plan that reduces the threat of disproportionate interference to particular blocks within the band (for example, by unlicensed devices or TDD operations). But the Commission should *not* usurp the traditional role of standards-setting organizations by requiring all devices that utilize 600 MHz spectrum to support all blocks in that band. Those organizations have always addressed interoperability issues in a collaborative, open, and

technologically flexible process that accounts for the diverse interests of providers, manufacturers, and consumers. In all events, it would be premature for the Commission even to consider imposing such mandates before it has even settled on a band plan.

2. Maximizing forward-auction participation

Some commenters—most of them wireless carriers hoping to minimize forward-auction competition—ask the Commission to adopt various mechanisms to keep AT&T and Verizon from purchasing the spectrum they need to compete as effectively as possible to meet their customers' accelerating bandwidth demands. That outcome would thwart the public interest and radically increase the risk of auction failure.

First, disparities in spectrum holdings are not a "problem" that requires a regulatory solution; larger and more successful carriers need more spectrum than others because they face unusually intense capacity challenges. It would serve no valid purpose to deny them the opportunity to buy the additional spectrum inputs they need simply because, through marketplace success, they have won many customers and thus have already needed to purchase significant spectrum holdings.

Second, AT&T does not have "excessive" spectrum holdings by any measure; indeed, it has far less spectrum than Sprint/Clearwire. Various commenters try to obscure that fact by artificially gerrymandering spectrum holdings into "high-band" and "low-band" spectrum and attaching disproportionate importance to the latter. That gerrymander lacks any rational basis, as AT&T has explained elsewhere and briefly summarizes below.

Third, excluding AT&T and Verizon would risk auction failure by reducing forward-auction revenues, as Professor Katz et al. explain. Indeed, in the words of potential broadcaster participants in the reverse auction, if the Commission "restrict[s] Verizon and/or AT&T from

participating in the forward auction," then "the auction will not produce the revenues necessary to meet the expectations of the potentially willing broadcast sellers"; "the auction will fail"; "there will be no new spectrum allocated for consumer use of wireless devices"; "there will be no surplus to fund an interoperable network for public safety first responders"; and "there will be no surplus for deficit reduction."[5] Moreover, as those broadcasters emphasize, even the fear of that outcome would subvert prospects for auction success by deterring them and other broadcasters from participating in the *reverse* auction.

Fourth, the Spectrum Act prohibits the Commission from relying on spectrum-aggregation policies to exclude any carrier from participating from any auction for 600 MHz spectrum, whether in particular localities or more broadly. Section 6404 provides that "the Commission may not prevent" an otherwise qualified bidder "from participating in a system of competitive bidding" on the basis of its spectrum holdings, subject only to the proviso that the Commission may exercise whatever authority it previously had "to adopt and enforce rules of general applicability, including rules concerning spectrum aggregation that promote competition." Of course, the Commission need not "prevent" bidders "from participating in a system of competitive bidding" in order to "adopt and enforce" any valid spectrum-aggregation "rules of general applicability." Instead, should it determine that spectrum acquisitions in the auction would result in an aggregation of spectrum that threatened to foreclose competition, it could simply allow winning bidders, post-auction, to divest existing spectrum in order to comply with the rules while rationalizing their spectrum holdings. That alternative bars the Commission

[5] Comments of the Expanding Opportunities for Broadcasters Coalition at 13-14 ("EOBC Comments").

from disqualifying carriers if they agree to make divestures that will keep them from ever coming into violation of any otherwise valid spectrum-aggregation policy.

Finally, some commenters advocate a novel scheme of "bidding credits" that would confer arbitrary bidding advantages on carriers in inverse proportion to their existing spectrum holdings below 1 GHz. That scheme would suffer from the same defects as other restrictions on participation by AT&T and Verizon. Indeed, if the scheme achieved its intended objective—altering the identities of the winning bidders—the amounts those bidders would pay at auction would necessarily be lower than the amounts that would otherwise be paid by the winning bidders in the *absence* of bidding credits. Simply as a matter of mathematics, therefore, these bidding-credit proposals could not achieve their purpose without increasing the risk of auction failure.

3. Providing for efficient package-bidding mechanisms

Package bidding is necessary to avoid a bid-suppressing *exposure problem* that is well-recognized both in Commission precedent and in the auction literature: the risk to a bidder of "winning" a hodgepodge of scattered spectrum assets that lack much of the value they would have presented had they been part of a seamless geographic package. In the absence of a package-bidding solution, that exposure problem would reduce forward-auction revenues and increase the risk of auction failure. Tellingly, many opponents of package-bidding in this proceeding simply ignore the exposure problem.

Some commenters suggest that the exposure problem must not be real because the Commission did not rely on package bidding in the AWS auction and permitted package bidding for only a single block in the 700 MHz auction. That argument is flawed on two levels. First, the Commission assigned very large geographic areas to certain licenses sold in these auctions

and thus established a rough (but quite imperfect) proxy for package bidding. Second, the Commission may well have forgone substantial auction revenues in the AWS and 700 MHz auctions precisely because it did *not* make adequate provision for package bidding there. Indeed, there is compelling evidence for that conclusion in the form of the enormous sums that carriers have subsequently paid one another in the secondary market to rationalize their spectrum holdings and achieve geographic complementarities. Given the statutory auction-closing condition, the Commission has no similar luxury here to allow much of the value of geographic complementarities to be captured by bidders that sell their spectrum in that multi-year process of post-auction spectrum rationalization. Instead, the Commission should take the steps needed to capture that value up front, in the forward auction itself, and that means creating efficient mechanisms for package bidding.

Finally, whereas some commenters attack straw man package-bidding mechanisms with various design defects, the specific form of package bidding AT&T has proposed—the clock package auction set forth by Professors Che, Haile, and Kearns—would not add undue complexity to this auction or unfairly benefit large carriers over small ones. That mechanism will pick winners solely on the basis of which combination of bids expresses, and can be expected to produce, the greatest economic value for consumers. In addition, as Professors Che and Haile explain in their attached reply analysis,[6] their proposed clock package auction will present no incremental risk of any "threshold problem" (*see* Section III below) beyond the risk already presented in the Auctionomics proposal (with or without any package-bidding component), and it also will present no significant risk of strategic bid manipulation.

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[6] Reply Analysis of Yeon-Koo Che and Phil Haile (Mar. 12, 2013) ("Che/Haile Reply Analysis") (attached as Exh. C).

4. Providing for efficient repacking

As discussed in our opening comments (at 74-79), this proceeding will succeed only if the Commission retains flexibility to repack remaining broadcast stations as efficiently as possible. Efficient repacking is the key to reducing the statutory revenue requirements by limiting the number of stations that must be paid compensation for ceding spectrum rights.

The Commission should thus reject efforts by various broadcasters to hamstring its repacking discretion. First, Congress granted the Commission enormous flexibility to repack televisions stations in the public interest, and it rejected proposals to cabin that flexibility in the ways that broadcasters mistakenly attribute to the statutory language. The Commission need only "make all *reasonable* efforts to preserve, as of the date of the enactment of this Act, the coverage area and population served of each broadcast television licensee." Spectrum Act § 6403(b)(2) (emphasis added). The qualifier "reasonable" means that broadcaster interests, while important, must sometimes yield to the public's equally important interest in freeing up additional spectrum for mobile broadband.

Second, the Commission should reject the contention of the major broadcaster associations that "the Commission should not plan on relocating more than 400 to 500 stations because otherwise relocation costs will exceed the amount of the [$1.75 billion] Fund Congress established to fully reimburse broadcasters."[7] In fact, the Commission might well need to repack more than 500 stations under a successful auction scenario, and it is free to do so. As an initial matter, the Spectrum Act nowhere suggests that the $1.75 billion figure constrains the Commission's discretion to repack as many stations as it deems appropriate to reallocate

[7] Comments of ABC, CBS, FBC, and NBC Affiliates Associations at 47 ("Affiliates Associations Comments").

spectrum for mobile broadband. In any event, even if the Commission repacks more than 500 stations, the costs the Commission must reimburse—those "reasonably incurred" by broadcasters in connection with repacking—will likely remain well below $1.75 billion. The Commission has abundant discretion to ensure that outcome through a proper implementation of the undefined term "costs."

ARGUMENT

I. THE COMMISSION SHOULD DESIGN A BAND PLAN THAT EXTRACTS THE GREATEST POSSIBLE VALUE FROM THE 600 MHZ BAND AND ELICITS THE GREATEST POSSIBLE FORWARD-AUCTION PARTICIPATION

A. The Record Reveals Key Points of Consensus Concerning the Design of the Band Plan, Including a Need for Certain Changes to the NPRM's Proposal

The Commission faces a tremendously complex task in designing a 600 MHz band plan. Nonetheless, the record reveals significant points of consensus about the design of that band plan. Carriers and vendors alike agree with the Commission's proposal to auction spectrum in five-megahertz blocks.[8] Commenters also support the Commission's key insight that spectrum blocks should be grouped into generic categories in which all individual blocks are treated as fungible.[9] Further, they agree with the Commission that uplink blocks in an FDD band plan should be placed downward from channel 51, followed by a duplex gap and then paired

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[8] *E.g.*, AT&T Comments at 18-19 n.6; Cellular South Comments at 6; Leap Comments at 5; MetroPCS Comments at 17; T-Mobile Comments at 14; Verizon Comments at 15-16; Alcatel-Lucent Comments at 13; Nokia Siemens Comments at 9; Qualcomm Comments at 5; Research in Motion ("RIM") Comments at 6; Letter From Joan Marsh (AT&T), Peter Pitsch (Intel), Rick Kaplan (National Association of Broadcasters), Dean Brenner (Qualcomm), Kathleen Ham (T-Mobile), & Charla Rath (Verizon Wireless) to Gary Epstein & Ruth Milkman (FCC), GN Docket No. 12-268, at 1 (filed Jan. 24, 2013) ("Jan. 24 Joint Letter").

[9] *E.g.*, AT&T Comments at 41; Alcatel-Lucent Comments at 4; Qualcomm Comments at 2, 5; T-Mobile Comments at 19; Verizon Comments at 44-45.

downlink blocks.[10] All parties further agree that any operations in the duplex gap and other guard bands should not cause interference to adjacent licensed operations, although, as discussed below, there is some disagreement concerning the appropriate size of those guard bands.[11]

A striking consensus has also emerged, however, that the Commission should make certain changes to the NPRM's band plan proposal. First, all parties addressing the issue—from broadcasters to carriers to equipment vendors—agree that television stations should *not* be placed in the duplex gap because doing so would create a risk of substantial intermodulation interference in a variety of downlink frequencies, not only in the 600 MHz band itself, but also in other bands such as the PCS band.[12] Second, all carriers and vendors support an approach that maximizes the amount of paired spectrum *above* channel 37.[13] Placing all paired downlink blocks below channel 37, as the NPRM proposes, would create implementation problems by materially increasing the size of the antennas needed for devices and base stations in a 600 MHz

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[10] *E.g.*, AT&T Comments at 32-33; Alcatel-Lucent Comments at 3-4; Qualcomm Comments at 4-5; RIM Comments at 7-8; T-Mobile Comments at 10; Verizon Comments at 5; Jan. 24 Joint Letter at 1.

[11] *E.g.*, AT&T Comments at 22-23; Alcatel-Lucent Comments at 24; MetroPCS Comments at 25; Qualcomm Comments at 23 & n.38; Jan. 24 Joint Letter at 1. Other points of agreement include permitting existing operations in channel 37 to remain there and facilitating international harmonization and coordination. *See* AT&T Comments at 39-40, 48-49; National Association of Broadcasters ("NAB") Comments at 5; Nokia Siemens Comments at 12, 20; Sprint Comments at 7; WMTS Coalition Comments at 17-18; Jan. 24 Joint Letter at 2.

[12] *E.g.*, AT&T Comments at 24-26; T-Mobile Comments at 8; Verizon Comments at 5-6; Alcatel-Lucent Comments at 14-16; Nokia Siemens Comments at 8; NAB Comments at 33-38; Jan. 24 Joint Letter at 1.

[13] *E.g.*, AT&T Comments at 33-34; T-Mobile Comments at 3; Verizon Comments at 14-15; Alcatel-Lucent Comments at 13; Nokia Siemens Comments at 10-11; Qualcomm Comments at 5; RIM Comments at 7-8.

network.[14] In addition, placing uplink blocks as far down as current Channels 42-46, as the NPRM proposes (for markets where fourteen or more stations are cleared), would create harmonics-related interference for handsets simultaneously using both the 600 MHz and other receive bands such as PCS and EBS/BRS.[15]

Finally, a number of commenters explain that the NPRM's proposed band plan goes too far in varying the number of uplink blocks from market to market depending on how much spectrum is cleared in each market.[16] As AT&T and others have stressed, that maximum-uplink-variation approach would unduly increase the risk of co-channel interference across neighboring markets in which differing amounts of spectrum have been cleared. At the same time, AT&T disagrees with NAB's lowest-common-denominator proposal to limit cleared spectrum in *all* markets to the blocks that are cleared in markets with the *least* cleared spectrum.[17] That approach would reduce the amount of spectrum available for mobile broadband and, by reducing forward-auction revenues, increase the risk of auction failure.[18] An appropriate band plan likely will steer a middle course, as AT&T's band-plan proposal does, between the maximum uplink variation in the Commission's proposal and any lowest-common-denominator approach.[19]

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[14] *See, e.g.*, AT&T Comments at 5-6; RIM Comments at 8; T-Mobile Comments at 8-9; Qualcomm Comments at 13-15; Verizon Comments at 14.

[15] *E.g.*, AT&T Comments at 19-20; Alcatel-Lucent Comments at 13; CTIA Comments at 26; Nokia Siemens Comments at 13; Qualcomm Comments at 7-10; Verizon Comments at 8.

[16] AT&T Comments at 16-17, 35; CTIA Comments at 23-24; US Cellular Comments at 24; Verizon Comments at 38.

[17] *See* NAB Comments at 45-47.

[18] AT&T Comments at 15-17.

[19] *See id.* at 32-33, 35-36.

B. The Commission Should Reject Calls To Create a TDD-Focused Band Plan

Although most commenters agree with the Commission's proposal to designate the entire 600 MHz spectrum for FDD operations, Sprint/Clearwire ask the Commission to devote much or all of the 600 MHz spectrum for TDD operations.[20] The Commission should reject that suggestion for several reasons.

As an initial matter, the vast majority of carriers—indeed, all carriers in the United States *except* Sprint/Clearwire—use FDD technologies to provide LTE service. Reed/Tripathi Reply at 4. As a result, there would be fewer bidders (and perhaps only one) for any spectrum blocks designated for TDD than for FDD spectrum, and that lower demand would predictably generate far less revenue from the sale of those blocks. As Professors Reed and Tripathi explain, a carrier using FDD would not even be able to aggregate a 600 MHz TDD band with an existing FDD band such as PCS or AWS. Reed/Tripathi Reply at 15. By contrast—and contrary to Sprint's claim (at 8-9 & n.18) that FDD supplemental downlink is of use only to larger carriers with low-band spectrum—LTE-Advanced will permit FDD carriers to aggregate a 600 MHz supplemental downlink band with higher-band spectrum such as PCS or AWS.

Quite apart from that concern, TDD operations in the 600 MHz band would also risk significant interference for FDD operations in the 600 MHz band and other bands as well, to the detriment of carriers and consumers alike. First, as AT&T and others explain, and as even Sprint acknowledges, uplink transmissions in the frequency range of 643-665 MHz would create harmonics that fall within the receive frequencies in the PCS band (1930-1990 MHz).[21] Because

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[20] Sprint Comments at 17-26; Clearwire Comments at 6-11.

[21] AT&T Comments at 27; Qualcomm Comments at 6-7; Sprint Comments at 25. There is abundant industry precedent for such harmonic interference: in some circumstances, harmonics

TDD can transmit on any of its allocated frequencies at any time, designating spectrum blocks that include 643-665 MHz as TDD would produce such harmonic interference. Reed/Tripathi Reply at 13-14; *see also* Alcatel-Lucent Comments at 11. Indeed, that interference would occur not only within a single device that simultaneously uses both 600 MHz TDD and PCS, but also between two devices if a 600 MHz TDD device is in close proximity to a device using the PCS band. Reed/Tripathi Reply at 14; *see also* Alcatel-Lucent Comments at 11.

Second, designating any block for TDD operations would require guard bands to avoid significant adjacent-channel interference between adjacent FDD and TDD blocks. Reed/Tripathi Reply at 14, 17. In particular, as Alcatel-Lucent indicates, a ten-megahertz guard band would be needed between the frequencies assigned to FDD and TDD operations, including a guard band between the lower 700 MHz band (which uses FDD) and any TDD operations at the top of the 600 MHz band.[22] In addition, a ten-megahertz guard band would be needed between 600 MHz TDD allocations below Channel 37 and adjacent broadcast operations. Alcatel-Lucent Comments at 11. Of course, making room for these multiple substantial guard bands would reduce the overall amount of usable, licensed spectrum, thereby increasing the risk that any

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resulting from the use of 700 MHz frequencies have significantly degraded throughput and useful capacity for devices using both 700 MHz and AWS-1 (Band 4) spectrum. AT&T Comments at 27. Sprint nonetheless dismisses concerns about harmonic interference, blithely asserting that some unspecified "equipment design and operating practice" could solve the issue. Sprint Comments at 25. But blind faith in some as-yet developed design or practice is not a reasoned basis for ignoring interference concerns, particularly those with an existing track record of degrading wireless operations.

[22] Alcatel-Lucent Comments at 11; Nokia Siemens Comments at 11 ("Interleaving of FDD and TDD blocks in a random manner is not recommended as it will require guard bands at each FDD/TDD frequency border.").

TDD-focused band plan would produce inadequate auction revenues. Reed/Tripathi Reply at 14-15, 17.

Third, a mixed TDD/FDD environment such as the one Clearwire proposes—in which each carrier could choose whether to deploy TDD or FDD in its 600 MHz blocks—would create not only these risks of adjacent-channel interference, but also substantial additional risks of *co-channel* interference. Reed/Tripathi Reply at 16-17. In particular, when a TDD network and an FDD network use the same frequencies in neighboring geographic areas, the TDD network inevitably would *transmit* signals in the same frequencies on which the adjacent FDD network is trying to *receive* signals at the same time. *Id.* at 17. The signal emitted by the TDD base stations would be much more powerful than the simultaneous signals emitted on the same frequencies by FDD end user devices and thus would often interfere with the reception of those weaker signals by FDD base stations. *Id.*

AT&T has experienced just this problem in Kansas City. Although AT&T holds lower 700 MHz B and C block licenses in much of Kansas City, two other providers hold 700 MHz C block licenses in certain parts of the city and have deployed a WiMAX network using TDD technology. *Id.* Those TDD operations have inflicted severe interference on AT&T's FDD base stations in the 700 MHz C block. *Id.* That interference effectively forces AT&T to operate only with 700 MHz B block spectrum in large portions of Kansas City and thus substantially reduces the capacity and throughput in AT&T's network. *Id.* Permitting a mixed TDD-FDD environment, as Clearwire proposes, would cause similar interference throughout the country.

Even if there were no risk of interference to FDD—either because no FDD operations are permitted in the 600 MHz band at all or because a certain segment of spectrum is set off by guard bands and designated solely for TDD—TDD operations by multiple carriers in the same

band would present substantial and costly coordination challenges. Whenever two providers maintain TDD systems using adjacent spectrum, the base station of Carrier X will often *transmit* over frequencies adjacent to those that Carrier Y's nearby base station will be using to *receive* signals at the same time. Reed/Tripathi Reply at 4. In such cases, Carrier X's transmitting signal will interfere with the ability of Carrier Y's base station to receive uplink signals. And that interference will reduce Carrier Y's throughput or sever its connections, particularly when Carrier Y's customer is close to the cell edge and his signals are thus relatively weak when they reach Carrier Y's base station. *Id.* at 5. Similar adjacent-channel interference can occur between the user device of one carrier that is trying to receive a relatively weak signal from a base station (for example, because it is at the cell edge) in close proximity to another carrier's user device that is simultaneously sending a signal. *Id.* at 6. Moreover, two TDD operators operating on the same channel in geographically proximate markets could cause *co-channel* interference.

Because of this strong potential for interference, multiple operators using TDD in adjacent frequencies (or on the same channel in proximate markets) must engage in intensive coordination efforts. *Id.* at 7.[23] Even Sprint grudgingly acknowledges in a footnote that the need for such coordination is a "disadvantage of TDD." Sprint Comments at 20 n.40. Among other things, the operators must synchronize their operations to the millisecond so that they are transmitting and receiving at exactly the same time. Reed/Tripathi Reply at 8-9. That also requires the operators to agree on the precise ratio of uplink to downlink traffic. *Id.* at 9. These coordination solutions will vary widely among the different sets of multiple carriers that differ by

[23] Alternatively, the band plan could place guard bands between the spectrum of each TDD operator, but—as with FDD/TDD guard bands—doing so would substantially reduce the amount of spectrum available for mobile broadband services. Reed/Tripathi Reply at 7.

market, and they would present large transaction costs. The need for such coordination would create uncertainty for any potential 600 MHz bidder about whether it will be able to reach an acceptable accommodation with each of its neighboring carriers and how much interference it will ultimately have to accept. *Id.* at 9-10. In addition, some operators may have to settle for suboptimal coordination arrangements. For example, if one carrier wants more downlink capacity (and correspondingly less uplink capacity) than a spectrally adjacent carrier, any coordination agreement would require one or both to accept a suboptimal downlink/uplink ratio. *Id.* at 10.

The need for this detailed coordination belies Sprint/Clearwire's claim that TDD systems are typically more flexible than FDD systems.[24] Even a single operator cannot dynamically change its uplink/downlink ratio at a particular base station or cell to match traffic patterns at that location. Rather, within any operator's network, all base stations must use the same ratios. Reed/Tripathi Reply at 11. Moreover, because of the need for coordination, a given carrier could not unilaterally make such a change where multiple operators are using TDD in the same area. *Id.* Instead, a carrier that wishes to change its ratio would have to reach negotiated agreements with all other operators in the areas where it wants to make the change (and potentially also with operators in adjacent areas that use the same frequencies). *Id.*[25]

In addition to coordination among TDD operators in the 600 MHz band, a TDD-only band plan would likely also require complex coordination between TDD operators and television

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[24] Sprint Comments at 23-25; Clearwire Comments at 6-8.

[25] In other respects as well, TDD systems suffer from disadvantages as compared to FDD systems. For example, TDD systems typically feature smaller cells or have lower throughput at the cell edge. Reed/Tripathi Reply at 12-13. Further, the deployment of small cell technologies, such as femtocells, is considerably more challenging for TDD than for FDD. *Id.* at 15.

broadcasters that operate in the same channels in geographically neighboring markets. Reed/Tripathi Reply at 12. Absent a lowest-common-denominator national band plan, the spectrum cleared would vary by market, and thus some television broadcasters would probably operate on the same channels as TDD operators in nearby markets. That would present a significant risk of co-channel interference. *Id.* Moreover, unlike FDD, in which any co-channel interference on a given channel would involve *either* uplink *or* downlink operations but not both, co-channel interference involving TDD would affect both the base station and the user equipment, and the network design would have to incorporate the larger of the two exclusion zones needed to address the interference issues. *Id.*

Of course, Sprint/Clearwire can be expected to contest the precise extent of the interference and other implementation problems that would result if the Commission permitted TDD operations in the 600 MHz band, whether on an exclusive basis or as part of a mixed TDD/FDD band plan. At a bare minimum, however, potential forward-auction bidders would confront considerable uncertainty about the value of 600 MHz spectrum if it is subjected to such a band plan, and the very existence of this uncertainty and associated risks would reduce the *perceived* value of 600 MHz spectrum and thereby depress forward-auction revenues.

C. The Duplex Gap and Other Guard Bands Should Be No Larger Than Technically Reasonable To Prevent Interference to Licensed Operations

As discussed below, a duplex gap of 10-12 megahertz is sufficient to prevent interference between uplink and downlink operations in an FDD environment, and for technical reasons the gap should not exceed 15 megahertz. The proper width of other guard bands depends on a variety of factors, including the transmission power of any television station on the other side of a guard band from mobile operations. A strong consensus is emerging on these points, including

not just from carriers but also from equipment manufacturers. Led by Google and Microsoft, however, a few commenters ask the Commission to remove much larger swaths of 600 MHz spectrum from the forward auction and reserve them for unlicensed uses. That approach would violate the Spectrum Act, would impair device functionality, would inflict opportunity costs on the public by diverting 600 MHz spectrum from its most valued uses, and would increase the risk that this auction will fail altogether.

1. The Duplex Gap Should Be 10-12 Megahertz Wide, and the Proper Width of Other Guard Bands Depends on the Power Levels of Potentially Interfering Operations on the Other Side

The function of a duplex gap is to avoid adjacent-channel interference between uplink and downlink transmissions. For example, in the absence of such a gap, the downlink transmissions from one base station could interfere with the ability of nearby base stations to receive uplink transmissions from user devices, particularly given that the transmit power of base stations is much higher than the transmit power of user equipment. Reed/Tripathi Reply at 18-19. Similarly, without an adequate duplex gap, the uplink transmissions from one user device could interfere with the ability of a nearby user device to receive downlink transmissions from a base station. *Id.* at 19-20.

As suggested by an emerging consensus in the opening comments, the size of the duplex gap needed to avoid such adjacent-channel interference is 10-12 megahertz. Engineering principles and industry experience have established that a duplex gap must be at least 1 to 1.5% percent of the center frequency in which the service is operating. Reed/Tripathi Reply at 20; Alcatel-Lucent Comments at 21-22. Thus, an FDD band centered at about 650 MHz requires a duplex gap of at least between 6.5 megahertz (1%) and 9.75 megahertz (1.5%). Reed/Tripathi Reply at 21. That theoretical figure must accommodate real-world factors that can increase the

size of the required gap. For example, differences in filter manufacturing processes can lead to about a 0.15 percent variation in filter performance—a one megahertz change at 650 megahertz. *Id.* The temperature at which a filter is operating can also affect its performance by as much as 2.2 megahertz at a 650 MHz center frequency. *Id.* at 21-22. Given these factors, there appears to be a consensus among equipment manufacturers that the duplex gap must be 10-12 megahertz to protect against interference in real-world deployments.[26]

Google and Microsoft are wrong to suggest that a larger duplex gap is needed to protect mobile wireless operations from interference.[27] First, filter manufacturers themselves confirm that, contrary to Google's and Microsoft's claim, the filters required for a 10-12 megahertz duplex gap would not be appreciably more costly or complex than filters with a larger duplex gap. Reed/Tripathi Reply at 23. Second, Google and Microsoft are also wrong to assert (at 38) that the risk of intermodulation interference somehow justifies a larger duplex gap. Using a larger duplex gap to address intermodulation interference would be neither efficient nor effective, particularly given that intermodulation products have wide bandwidths. Reed/Tripathi Reply at 23. The better approach is to design the band plan to prevent intermodulation interference in the first place or, at a minimum, to weaken the power levels of intermodulation products. *Id.* That is precisely what AT&T's proposed band plan would do by, for example, excluding TV stations from the duplex gap. *Id.*

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[26] Reed/Tripathi Reply at 22; Alcatel-Lucent Comments at 21-22; Nokia Siemens Comments at 9; Qualcomm Comments at ii; RIM Comments at 12-13.

[27] Google/Microsoft Comments at 37-39 & Decl. of David Borth at ¶¶ 4-16, attached to Google/Microsoft Comments.

As discussed below, because a duplex gap of 10-12 megahertz is sufficient to guard against interference, the Spectrum Act directs the Commission to establish a gap "no larger than" that figure. Quite apart from that legal directive, however, there are independent *technical* reasons to cap the size of the duplex gap at 15 megahertz. Given engineering limits of antenna design, a device operating in 600 megahertz spectrum likely can cover no more than about 65 megahertz in a band without either (1) significantly increasing antenna size, thereby sacrificing the form factors most popular with consumers today, or (2) degrading technological efficiency. Reed/Tripathi Reply at 23-25. Given this constraint, if a band plan has five paired blocks of five megahertz (i.e., a 2 x 25 configuration), that leaves no more than 15 megahertz for the duplex gap. *Id.* at 25; *see also* Qualcomm Comments at 13-15. A larger duplex gap would mean (1) that the band plan would need to have fewer paired blocks; (2) that devices would need an additional or substantially larger antenna, even though, as Qualcomm states (at 13), "there is no spare space in today's smartphones"; or (3) that the antenna would need to operate less efficiently, leading to degraded handset performance. *Id.* at 23-25. Thus, practical and engineering considerations militate against a duplex gap any larger than 15 megahertz.

Finally, the size of any guard bands needed to protect mobile broadband operations from interference due to adjacent *television stations* depends on the power level of a television station and whether the mobile spectrum is being used for uplink or downlink. For downlink blocks, analyses by AT&T and Qualcomm suggest that a six-megahertz guard band should be sufficient to protect against interference from a television station operating at or below 50 kilowatts. Reed/Tripathi Reply at 26-27. In the case of full-powered television stations operating at power levels up to one megawatt, analysis of filter performance and other factors indicates that a guard

band of as much as 10-12 MHz will be necessary.[28] In the case of uplink, however, a six-megahertz guard band should be sufficient regardless of the power level of the television station. Reed/Tripathi Reply at 26. Indeed, AT&T is currently operating in 700 MHz Band 17, which is six megahertz away from television channel 51, and that distance has been sufficient to protect against interference from stations operating at a variety of power levels. *Id.*

2. The Spectrum Act Requires the Commission To Determine the Size of the Duplex Gap or Other Guard Bands Based Only on Technical Considerations Concerning the Prevention of Interference

The statute directs the Commission to limit any guard bands to a size that is "no larger than is technically reasonable to prevent harmful interference between licensed services." Spectrum Act § 6407(b). For example, if a 10-megahertz guard band is sufficient to keep licensed services from interfering with one another, then that is the ceiling on the size of that guard band.

Some commenters argue that the word "reasonable" in this statutory language gives the Commission discretion to consider non-technical factors and general "policy goals" in order to enlarge guard bands *beyond* the size needed to prevent interference.[29] That is incorrect. Simply as a matter of syntax, the use of the word "reasonable" in this sentence does not authorize the Commission to consider policy objectives *other than* "prevent[ing] harmful interference" to licensed services as a basis for enlarging the duplex gap or other guard bands. *First*, the word "technically" modifies "reasonable," and tells the Commission what kinds of factors—namely,

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[28] Reed/Tripathi Reply at 27; Alcatel-Lucent Comments at 23; Nokia Siemens Comments at 15-19; RIM Comments at 11.

[29] *See, e.g.*, Comcast Comments at 44; Free Press Comments at 7; NCTA Comments at 13-14.

technical ones—it should consider in determining whether the size of a guard band is reasonable.[30] *Second*, a guard band may be "no larger than" what the Commission determines is technically needed to prevent harmful interference. If 12 megahertz is sufficient to stop licensed services from interfering with one another, that is the ceiling on the size of the guard band. Designating a larger guard band would read the words "no larger than" out of the statute. *Third*, section 6407(b) specifies the only purpose for which the Commission may create guard bands—namely, "to prevent harmful interference between licensed services." Given that textual direction, the Commission would violate both the Spectrum Act and the Administrative Procedure Act if it gave weight to other policy goals in exercising its judgment, such as the purported value of giving unlicensed services a capacious home in the 600 MHz band.[31]

NCTA nonetheless contends (at 11-12) that these limitations do not apply to any duplex gap because, it suggests, a duplex gap is not a guard band subject to these statutory limitations. That is also incorrect: as Comcast recognizes (at 44), a duplex gap is simply a "type of guard band." Under both ordinary usage and the usage employed in the Spectrum Act itself, a "guard band" is a segment of spectrum set aside—*i.e.*, not auctioned to licensed users—in order to prevent interference between licensed services. *See* Spectrum Act § 6407(b); *see also* NPRM ¶ 152 (guard bands are used "to minimize interference between dissimilar adjacent uses").[32] As

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[30] Indeed, even Google and Microsoft, which otherwise advocate large guard bands, acknowledge that section 6407(b) only gives the Commission "discretion to use its expert *technical* judgment to set appropriate guard band sizes." Google/Microsoft Comments at 36 (emphasis added).

[31] *See, e.g.*, *Massachusetts v. EPA*, 549 U.S. 497, 533-34 (2007) (agency may not take into account factors other than those made relevant by Congress).

[32] *See also* Memorandum Opinion, *Cellular Telecommunications Industry Association et al.'s Request for Delay of the Auction of Licenses in the 747-762 and 777-792 MHz Bands*

discussed, a duplex gap is designed to perform that precise function: minimizing interference between licensed uplink and downlink operations using the same spectrum band.[33]

In fact, treating the duplex gap like any other guard band is the only way to make sense of the statutory provisions addressing the use of guard bands. Section 6403(c)(1)(A) of the Spectrum Act directs that the Commission "shall" conduct a forward auction to "assign[] licenses for the use of the spectrum that the Commission reallocates." Section 6407(b) creates an exception to that requirement for "guard bands." The Commission has already recognized that, "[u]nder these provisions, [it] *must* license the spectrum [it] recover[s] through the broadcast television spectrum reorganization, with the exception of the guard bands." NPRM ¶ 234 (emphasis added). Thus, if the duplex gap were not a "guard band," the Commission would have to auction it for licensed use. In short, the statute flatly precludes any argument that (1) the duplex gap is not a guard band but (2) can somehow be exempted from the auction and dedicated to unlicensed uses. Indeed, that argument would create an irrational loophole through which the

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Scheduled for September 6, 2000 (Auction No. 31), 15 FCC Rcd 17406, 17412 n.7 (2000) (stating that a "'guard band' is so-named" because it is "designed to protect [adjacent] spectrum from unwarranted interference"); *Newton's Telecom Dictionary* 551 (26th ed. 2011) (defining guard band as "[a] narrow bandwidth between adjacent channels which serves to reduce interference between those adjacent channels.").

[33] Section I.C.1, *supra*; *see, e.g.*, Third Report and Order, *Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, Including Third Generation Wireless Systems*, 18 FCC Rcd 2223, 2243 ¶ 39 n.108 (2003) (stating that a "duplex gap" is "an unused frequency block" used "to provide isolation between base and mobile transmit frequencies"). NCTA is mistaken in claiming (at 11) that the Commission has somehow already suggested that a duplex gap is *not* a guard band. The Commission has recognized that "guard bands" are used "to minimize interference between dissimilar adjacent operations," NPRM ¶ 152, and that a duplex gap is the "required separation between the uplink and downlink bands," *id.* ¶ 166. But, as explained, a duplex gap is "required" precisely because it "minimize[s] interference between dissimilar adjacent operations"—namely, uplink and downlink operations. In short, as the Commission recognizes, a duplex gap is simply a species of guard band.

Commission could exempt any amount of spectrum from the forward auction free from the "technically reasonable" or any other limitation, simply by labeling it a "duplex gap" or some other term besides "guard band." That cannot be what Congress intended, given the clear policy choice in favor of licensed spectrum throughout the Spectrum Act.

3. Enlarging the Duplex Gap or Other Guard Bands to Promote Unlicensed Uses Would Impose Large Opportunity Costs, Reduce Forward-Auction Revenues, and Increase the Risk of Auction Failure

Even if Congress had not prohibited the Commission from needlessly enlarging the duplex gap or other guard bands, and even if antenna-related concerns did not independently cap the optimal size of the duplex gap at 15 megahertz or less, compelling policy considerations would still independently support the same outcome. Two of the Commission's most fundamental objectives in this proceeding should be (1) to reallocate 600 MHz spectrum blocks to their most highly valued uses, taking into consideration the availability of *other* spectrum bands for alternative uses; and (2) to ensure great enough participation in the forward auction to satisfy the statutory revenue requirements for reallocating *any* 600 MHz spectrum at all. The Commission would undermine each of those objectives if it allocated unnecessarily large segments of 600 MHz spectrum to accommodate unlicensed uses. First, it would inflict immense opportunity costs on consumers and the American economy; and, second, it would substantially increase the risk of auction failure.

Minimizing opportunity costs. At the outset, it is important to stress that this is *not* a dispute about whether unlicensed uses are beneficial or whether more spectrum should be made available for them. AT&T agrees that unlicensed spectrum plays an important role in spectrum policy. The question, however, is not whether it would be beneficial to free up large amounts of additional spectrum suitable for unlicensed uses, but how to achieve that goal while minimizing

the opportunity costs of doing so. That analysis might well support reallocating vast swaths of 5 GHz band spectrum for unlicensed uses, as the Commission has proposed.[34] But it forecloses allocating unlicensed spectrum in the 600 MHz band beyond the appropriately sized guard bands described above.

In particular, any greater allocation of 600 MHz spectrum to unlicensed uses would present immense opportunity costs in the form of forgone uses of this band. This auction presents the single most important opportunity to make real progress on a central goal of this Administration: reallocating much-needed new spectrum for *mobile* broadband uses in the spectrum whose signal-propagation characteristics are best suited to such uses—the bands below 3.7 GHz.[35] As the National Broadband Plan recognized, the spectrum at issue here has "excellent propagation characteristics that make it well-suited to the provision of mobile broadband services, in both urban and rural areas," and reallocating it for these mobile services "has the potential to create new economic growth and investment opportunities."[36] And every additional block allocated to unlicensed uses is, by definition, a block removed from the spectrum allocated to licensed mobile uses.

Google and Microsoft propose to divert much of this scarce mobile broadband spectrum, which others would pay billions to clear, to unlicensed uses. But they give no reason to conclude

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[34] *See generally* Notice of Proposed Rulemaking, *Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, ET Docket No. 13-49, at ¶ 22 (rel. Feb. 20, 2013) (proposing to "increase the spectrum available to unlicensed devices in the 5 GHz band by nearly 35 percent," representing 195 MHz additional spectrum).

[35] FCC, *Connecting America: The National Broadband Plan*, at 84 (2010), http://download.broadband.gov/plan/national-broadband-plan.pdf ("*National Broadband Plan*").

[36] *Id.* at 88.

that any benefits of those incremental unlicensed allocations would compensate for the huge opportunity costs of withholding this spectrum from capacity-constrained mobile providers. *See* Katz et al. Reply Decl. ¶ 52 *et seq*. Indeed, they have provided hardly any detail about what new types of unlicensed uses they envision for this spectrum. And there is abundant reason to conclude that diverting this spectrum from licensed to unlicensed uses would in fact result in far less efficient spectrum utilization. Because the transmissions of unlicensed devices are by definition not coordinated by any licensee, such devices must be subjected to stringent restrictions, such as power-level limitations, to avoid interference between similar devices in close proximity.[37] Given the need for such limitations, allocating large amounts of spectrum below 3 GHz for unlicensed uses might well make inefficient use of the key signal-propagation

[37] Although Google/Microsoft (at 16-18) claim that fixed wireless ISPs ("WISPs") might benefit from unlicensed use of 600 MHz spectrum to reach customers in remote rural areas, that claim makes no sense on several levels. *First*, "[i]n a fixed wireless deployment, each customer has a high gain directional antenna/radio combination, typically mounted outside, that focuses the signal toward the base station." WISPA, *America's Broadband Heroes: Fixed Wireless Broadband Providers*, at 4 (2011), http://www.wirelesscowboys.com/wp-content/uploads/2011/10/americas-broadband-heroes-fixed-wireless-2011.pdf. This point-to-point technology has no special need for lower-band spectrum; indeed, it allows WISPs to transmit up to 50 miles or more using 5 GHz band spectrum. *See* Ubiquiti Networks, Rocket Dish Data Sheet, http://www.titanwirelessonline.com/v/vspfiles/assets/images/at-rd_datasheet.pdf. *Second*, to the extent that WISPs need additional lower-band spectrum for "non-line of sight operations" (Google/Microsoft Comments at 17), they can make heavy use of white-space technologies because there is often no significant television presence in the rural areas where WISPs operate. *Third*, even if WISPs had some need for cleared 600 MHz spectrum, they should participate in the forward auction alongside the mobile ISPs with whom they compete. *Fourth*, in any event, it would make no sense to reserve large blocks of unlicensed spectrum *nationwide*, including in densely packed urban areas, in order to accommodate WISP operations that are prevalent mainly in rural areas.

advantages that make this spectrum unusually valuable to licensed mobile providers. *See* Katz et al. Reply Decl. ¶¶ 59, 63.[38]

Minimizing the risk of auction failure. Quite apart from these opportunity-cost concerns, reserving extra 600 MHz spectrum for unlicensed uses (beyond those permitted in appropriately narrow guard bands) would drive down forward-auction revenues and increase the risk of auction failure. Anticipating that concern, Google and Microsoft argue (at 29-31) that no matter how many slices of licensed spectrum the Commission removes from the auction, the value of the remaining slices would increase so dramatically in response that aggregate forward-auction revenues would never decline. That is incorrect. It is true that auction theorists can posit abstract auction models in which demand is highly inelastic and aggregate revenues might remain constant (or even increase) amid reductions in the amount of auctioned spectrum. But as Professor Katz et al. explain (at ¶¶ 64-79), the posited scenarios are improbable in the real world, and unnecessarily removing spectrum from the forward auction would likely reduce auction revenues by a substantial margin.

First, reducing the supply of licensed spectrum blocks in the forward auction will necessarily reduce aggregate revenues if the demand of potential bidders for those blocks is elastic, and it almost certainly is. *Id.* ¶¶ 65-70. Potential bidders have alternatives to 600 MHz spectrum acquisitions as a means of addressing escalating network demand. For example, they

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[38] In addition, to the extent that Google/Microsoft (at 13-16) stress the value of Wi-Fi offload to mobile wireless providers, they are irrationally conflating two separate issues: (1) the value of certain technologies (such as the use of extremely small cells in congested settings) and (2) the licensed/unlicensed status of the spectrum used by those technologies. *See* Katz et al. Reply Decl. ¶¶ 60-63. Moreover, as discussed below, any use by licensed carriers of unlicensed spectrum suggests that the two can be input substitutes, and that fact will tend to lower the value of licensed spectrum and increase the risk of auction failure.

could constrain that demand by raising prices. Or, to increase network capacity without purchasing new spectrum, they could "recycle" their existing spectrum holdings by conducting additional cell splits or deploying distributed antenna systems. True, those alternative measures of augmenting capacity are very expensive. But from the perspective of would-be auction participants, those measures would become increasingly attractive and efficient in comparison to 600 MHz spectrum purchases if the per-megahertz price for new licensed spectrum were to rise in response to regulatory reductions in the supply of such spectrum. *Id.* ¶ 66. In any event, because there are no precise estimates of demand elasticity in this context, Professor Katz et al. have performed numerous Monte Carlo simulations of auction results under a broad variety of scenarios involving bidders with widely differential valuations. As those simulations show, reductions in the spectrum sold at auction would typically produce substantial losses in the revenues generated.[39]

These considerations confirm that demand for auctioned spectrum in a band would be elastic even if the remaining, non-auctioned spectrum in that band were left completely fallow (or reserved only for continued broadcast uses). But even if demand were normally *inelastic* in that counterfactual setting, forward-auction prices would still fall if wide segments of spectrum are withheld from the auction and, as Google and Microsoft propose here, are *not* kept fallow but

[39] Katz et al. Reply Decl. ¶¶ 67-68 (and Appx. A). There is also no basis for Google and Microsoft's reliance on theoretical suggestions that bidding teams go into auctions with fixed budgets. Google/Microsoft Comments at 29-30 (citing Jeremy Bulow, Jonathan Levin, and Paul Milgrom, *Winning Play in Spectrum Auctions* (Feb. 2009)). As Professor Katz et al. explain, "[a]lthough *bidding teams* may face budget constraints for a particular auction (while having considerable freedom in deciding which licenses to buy within their fixed budgets), this does not mean that *budgets* do not depend on the quantity of spectrum that is being offered at the auction." Katz et al. Reply Decl. ¶ 70 (emphasis added). Indeed, budgets *must* depend significantly on the amount of that spectrum, for otherwise "the government could auction a nationwide license for 1 MHz of spectrum for tens of billions of dollars." *Id.*

are instead released into the market for unlicensed uses as the result of that auction. *See* Katz et al. Reply Decl. ¶¶ 71-79. That is because, in two different respects, such unlicensed spectrum is a substitute for the licensed spectrum offered at auction, and it would therefore reduce the value of licensed spectrum to potential bidders. *See id.*

To begin with, from the perspective of mobile wireless carriers, unlicensed spectrum can be a substitute for licensed spectrum in the input market for spectrum resources. *Id.* ¶ 72. Indeed, Google and Microsoft themselves stress (at 13-16) that unlicensed spectrum can relieve carriers' demand for additional licensed spectrum by allowing them to offload traffic onto Wi-Fi networks in certain high-density contexts. The availability of that unlicensed alternative input, while inefficient in comparison to additional licensed spectrum, tends on the margin to drive down every carrier's demand for any given supply of licensed spectrum. Katz et al. Reply Decl. ¶ 72. The more unlicensed spectrum the Commission frees up that would be suitable for mobile services, the greater that demand-reducing effect will be. Lower demand, in turn, means lower revenues and a greater risk of falling short of the statutory revenue requirements.

Just as important, services offered solely or primarily by means of unlicensed spectrum would themselves be substitutes for licensed wireless services in the downstream retail marketplace. For that reason, too, if the Commission makes any new supply of *licensed* spectrum contingent upon the release of a large new supply of *unlicensed* spectrum suitable for competing uses, it would predictably reduce the value of that new licensed spectrum to potential bidders, who would have to account for that new unlicensed competition in assessing the net revenue streams the licensed spectrum could be expected to create. *See id.* ¶¶ 73-78.

Some context is necessary to understand this point. Google and Microsoft advocate a greater role for unlicensed spectrum in the 600 MHz band not because they are dispassionate

champions of the public interest, but because they both hope to capitalize on any business opportunities that might arise. Access to this spectrum would be free to Google and Microsoft and to any other service provider that deploys the wireless routers and backhaul links needed to connect users to communications networks. To a large extent, customers would be choosing—particularly at the margins—between (1) new services that would employ unlicensed spectrum as a free input and (2) mobile services from carriers who have paid for *licensed* 600 MHz spectrum in this proceeding. *See* Katz et al. Reply Decl. ¶¶ 73-75. For example, using this spectrum as a free input, an unlicensed provider might construct a new wireless network for users within defined geographic areas, and a consumer might opt to use that provider's services for a particular device (such as a laptop or tablet) for which the consumer would otherwise buy connectivity from a mobile licensee.

Critically, however, no one will be able to use cleared 600 MHz spectrum for unlicensed uses in the first place unless someone pays broadcasters billions of dollars to vacate that spectrum. Under the Google/Microsoft proposal, the parties making those payments would be licensed mobile carriers, *not* Google, Microsoft, or any other primary user of such unlicensed spectrum. In other words, a large portion of the bids from licensed carriers would be used, in effect, to subsidize the diversion of scarce mobile broadband spectrum to allocation for competing unlicensed uses. Because licensed carriers will base their bids on the estimated net revenue effects of acquiring new 600 MHz spectrum, they will need to account for the revenue losses they will sustain as a consequence of subsidizing free inputs for the likes of Google and Microsoft. Of course, carriers would be less likely to bid aggressively for new 600 MHz spectrum if they know that a significant portion of those bids will be used to subsidize the clearing of unlicensed spectrum for these competing operations (beyond the minimum amounts

of unlicensed spectrum to protect licensed spectrum from interference).[40] Among other concerns, the new subsidized competitors would benefit from a much lower cost structure than conventional mobile licensees, precisely because they would not have to pay for their spectrum inputs.[41]

In sum, unnecessary reductions in the number of licensed spectrum blocks in the 600 MHz band would very likely lead to major reductions in aggregate auction revenues. Because this auction cannot close unless those revenues meet the statutory revenue requirement, any Commission decision that needlessly reduces the supply of licensed spectrum would increase the risk that no spectrum will be reallocated at all—not for licensed uses, and not for unlicensed uses either. That would be a regulatory failure of historic proportions.

4. Any Unlicensed Uses in Guard Bands Must Not Interfere with Licensed Operations and Must Accept Interference from Mobile Broadband Operations

Insofar as interference concerns in fact require guard bands (including a 10-12 megahertz duplex gap), AT&T does not oppose unlicensed uses in those guard bands.[42] Any such uses, however, must meet at least two criteria. First, as the Spectrum Act provides (§ 6407(e)), "[t]he

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[40] Katz et al. Reply Decl. ¶ 77. Indeed, carriers would be subsidizing competition to services they offer using their *existing* spectrum holdings and thereby reducing the value of those holdings as well.

[41] To be clear, AT&T's objection is *not* to facing competition from other providers that have obtained access to 600 MHz spectrum on fair and equal terms. If all the 600 MHz spectrum (other than guard bands) is auctioned as licensed spectrum, as AT&T advocates, and if AT&T purchases some of that spectrum, it will face post-auction competition from other providers who purchased all the rest of that licensed spectrum. AT&T welcomes that outcome insofar as those other providers, like AT&T, will have paid for the spectrum in a fair and efficient auction.

[42] In its opening comments, AT&T suggested that it might be technically feasible to place supplemental downlink blocks in the duplex gap but noted the need for additional study of that issue. AT&T Comments at 33-34. Based on that further analysis, AT&T no longer advocates placing supplemental downlink blocks in the duplex gap.

Commission may not permit any use of a guard band that the Commission determines would cause harmful interference to licensed services." Second, and conversely, such unlicensed uses must accept any interference from licensed mobile broadband operations.

Such protections are important for at least three reasons. First, if the Commission does not make clear that licensed spectrum will be protected from interference by unlicensed operations in the duplex gap and other guard bands, the risk of that interference would reduce the value of licensed spectrum and increase the risk of auction failure. Similarly, if licensed operations might be subject to restrictions in order to protect unlicensed uses, that too would reduce the value of licensed blocks.

Second, failure to establish such protections for licensed spectrum would undermine the Commission's goal of creating a band plan with fungible spectrum blocks. If operations in the duplex gap, for example, were not precluded from causing interference to licensed mobile operations, the blocks closest to the duplex gap would be subject to the risk of the greatest interference and would accordingly be less valuable than blocks further away from the duplex gap. Likewise, any restrictions to protect unlicensed operations from interference would fall most heavily on the blocks closest to the duplex gap, further reducing their relative value. Third, as discussed in greater detail below, subjecting licensed blocks adjacent to the duplex gap (or other guard bands) to interference from unlicensed operations would present handset-interoperability concerns by increasing the pressure on the international standards-setting process to assign those blocks to a different band class in order to protect the remaining spectrum blocks. Reed/Tripathi Reply at 25-26.

The Commission can straightforwardly establish by rule that unlicensed uses in the duplex gap and other guard bands are not entitled to any protection from interference from

licensed users. Designing rules to ensure that those unlicensed operations themselves do not cause interference to adjacent licensed operations is more complex. The appropriate limitations will depend on a number of characteristics of the potential unlicensed use, such as (1) whether it is uplink, downlink, or both; (2) where within the duplex gap or guard band the use will be located (*e.g.*, immediately adjacent to the licensed use or in the middle of the duplex gap, such that part of that gap functions as an internal guard band); (3) the power level of the unlicensed use; (4) the quality of the relevant filters; and (5) the nature of the likely real-world deployment of the unlicensed use (such as whether the unlicensed use will likely be physically proximate to licensed mobile equipment or, as in the case of wireless microphones, whether the unlicensed devices are likely to be confined to particular spaces). Reed/Tripathi Reply at 26. It is not possible at this stage to specify the precise restrictions to which unlicensed uses would have to be subject in order to satisfy the statutory requirement that they not interfere with licensed operations. Preliminary analysis suggests, however, that those restrictions are likely to be quite significant.

Finally, some commenters propose that the Commission permit unlicensed uses in spectrum blocks that have been awarded to a licensed operator, but in which the operator is not yet providing service.[43] Although AT&T does not necessarily oppose that outcome, this temporary-use regime would have to be subject to strict enforcement mechanisms, and any unlicensed user would have to commit unequivocally to clear the spectrum immediately once the licensed operator is ready to make use of it. As the history of wireless microphones

[43] Google/Microsoft Comments at 44-46; WhiteSpace Alliance Comments at 19-20.

demonstrates,[44] getting unlicensed operations to vacate once they have established themselves can be difficult, and the Commission should not allow unlicensed uses on spectrum that is otherwise licensed without clear, timely, and self-executing mechanisms under which those uses will be cleared so as to protect the rights of licensed users.

C. The Commission Should Design Its Band Plan to Promote Handset Interoperability but Should Reject Requests to Impose Interoperability Requirements on 600 MHz Handsets

As discussed in its opening comments, AT&T supports designing the *band plan* to enable market forces and private standards-setting initiatives to devise maximally efficient solutions to the use of this spectrum, including efficient interoperability among handsets. The Commission should not mandate that outcome by usurping the traditional role of standards-setting organizations; instead, it should take the steps noted above to reduce the threat of interference throughout the 600 MHz band. Two examples warrant repeating. First, the Commission should set effective limits on the power levels of devices operating in all guard bands, including the duplex gap, to avoid subjecting the immediately adjacent licensed blocks to disproportionate interference problems. Second, the Commission should avoid creating conditions in which TDD operations could ever be adjacent to FDD operations because these mutually incompatible technologies would create massive mutual interference, which again would affect some blocks more than others. Failing to take either step would almost certainly consign the 600 MHz band to a new generation of interference-created handset interoperability challenges.

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[44] *See* FCC, *Consumer Guide: Operation of Wireless Microphones*, at 1-2 (2013) (describing need to ban wireless microphone operations that had been squatting in unused portions of the 700 MHz band), http://transition.fcc.gov/cgb/consumerfacts/wirelessmic_advisory.pdf.

The Lower 700 MHz band presents a textbook example of the interoperability problems that can arise if the Commission does *not* manage such interference concerns through a carefully designed band plan. The interoperability challenges there stem from a severe defect in the Lower 700 MHz band plan: Lower A Block transmissions are vulnerable to interference from Channel 51 broadcasters and high-power Lower E Block broadcasts, and such interference degrades performance on handsets whose filters allow A Block transmissions, even when those handsets are operating on other 700 MHz frequencies. Led by Motorola and a host of companies in an open industry-wide proceeding, the international standards-setting community responded by defining separate bands with different filter solutions designed to protect non-A Block users against such interference.[45] All parties understood before the 700 MHz auction that the A Block spectrum would face these unique interference issues, and A Block licensees obtained this spectrum at auction at a reduced price that reflected those concerns.[46] That has not stopped those licensees, however, from seeking "interoperability" requirements that would subject *all* Lower 700 MHz spectrum licensees, including those that paid more to obtain less-interference-prone spectrum blocks, to the same interference problems that these A Block licensees voluntarily undertook for themselves.[47]

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[45] *See generally* Notice of Proposed Rulemaking, *Promoting Interoperability in the 700 MHz Commercial Spectrum*, 27 FCC Rcd 3521, 3523-29 ¶¶ 6-14 (2012); Comments of AT&T, *Promoting Interoperability in the 700 MHz Commercial Spectrum et al.*, WT Docket No. 12-69 *et al.* (filed June 1, 2012) ("AT&T 700 MHz Interoperability Comments").

[46] *See, e.g.*, Letter from Joseph P. Marx (AT&T) to Marlene H. Dortch (FCC), WT Docket No. 06-150; PS Docket No. 06-229; GN Docket No. 09-51; RM-11592, at 1, 4 (filed June 3, 2010).

[47] *See generally* AT&T 700 MHz Interoperability Comments at 3, 27-35.

AT&T mentions this 700 MHz experience not to relitigate that controversy in this forum, but simply to note that the Commission could have precluded that controversy altogether had its band plan avoided the sources of interference that ended up compromising wireless operations. Had it done that, there would have been less of a need for the international standards-setting community to cope with such interference by prescribing different band classes for the Lower 700 MHz spectrum. The Commission should take pains to avoid any similar problems here by minimizing the extent to which avoidable interference, including from unlicensed uses, will impair mobile operations in particular 600 MHz blocks.

Although the Commission *should* design a sound band plan in order to promote standards-based solutions to efficient interoperability, it should *not* short-circuit those solutions by requiring all devices that utilize 600 MHz spectrum to support all blocks in that band. Such a requirement would be unprecedented. Since the dawn of the digital era in mobile communications, the FCC has never regulated equipment manufacturers' choice of pass-band filters or other handset components. Instead, the international standards-setting community has always addressed those issues in a collaborative process that accounts for the diverse interests of providers, manufacturers, and consumers. That process is open, efficient, and unparalleled in its technological sophistication, and the Commission should allow it to work here as well.

In contrast, mandated one-size-fits-all 600 MHz handset components would substantially devalue this spectrum, both for forward-auction bidders and for the consumers who may someday use it (if the auction is successful). Although the Commission can reduce block-by-block disparities in interference risk, it cannot eliminate such disparities altogether, nor can it predict with certainty exactly what technological challenges will arise once this spectrum is auctioned and assigned. As noted in our opening comments (at 50-51), the standards-setting

process is designed to provide the flexibility needed to address those concerns as they arise, and the Commission should not foreclose that role by prescribing equipment standards.

In all events, it would be premature for the Commission even to consider imposing such mandates before it has even settled on a band plan that balances the objective of clearing as much spectrum as possible against the objective of minimizing interference concerns in cleared spectrum. In the absence of a band plan, the Commission cannot know what band-specific technological challenges the industry will face, and it therefore cannot rationally conclude that it would serve the public interest to supplant the traditional standards-setting process with regulatory mandates.

II. THE COMMISSION SHOULD MAXIMIZE FORWARD-AUCTION REVENUES AND THE ODDS OF AUCTION SUCCESS BY REJECTING PROPOSALS TO LIMIT AUCTION ELIGIBILITY

In this and other proceedings, some commenters ask the Commission to resurrect the functional equivalent of a hard spectrum cap, which the Commission rightly abandoned twelve years ago,[48] and apply that cap against AT&T and Verizon by limiting their participation in this auction.[49] Other commenters seek to achieve essentially the same outcome through a self-interested scheme of auction-distorting "bidding credits."[50] Although the details vary, these regulatory proposals all share a common theme: they are all aimed at keeping some providers—

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[48] Report and Order, *2000 Biennial Regulatory Review Spectrum Aggregation Limits for Commercial Mobile Radio Services*, 16 FCC Rcd 22668, 22693-94 ¶ 50 (2001); *see also* Notice of Proposed Rulemaking, *Service Rules for Advanced Wireless Services in the 2155-2175 MHz Band*, 22 FCC Rcd 17035, 17079 ¶ 101 (2007) (noting that the Commission eliminated the spectrum cap because it "found that the cap, by setting an *a priori* limit on spectrum aggregation without looking at the particular circumstances of specific proposed transactions, was unnecessarily inflexible and could be preventing beneficial arrangements that promote efficiency without undermining competition").

[49] Cellular South Comments at 5-6; Sprint Comments at 8-9; T-Mobile Comments at 27-31.

[50] Leap Comments at 6; MetroPCS Comments at 26-27.

and AT&T and Verizon in particular—from competing as effectively as possible to serve their customers as well as possible.

That outcome might benefit individual wireless companies, but it would thwart the public interest and radically increase the risk of auction failure. First, disparities in spectrum holdings are not a symptom of market failure; to the contrary, they can be—and are here—signs of market success and thus cannot justify limitations on auction participation. *See* Section II.A, *infra.* Second, even if there were some sound policy basis to force reductions in such disparities, AT&T does not have disproportionate spectrum holdings in the first place; indeed, it has far less spectrum than Sprint/Clearwire. Sprint and others seek to exclude AT&T and Verizon from this auction on the theory that they have too much "low-band" spectrum, but that argument is untenable as well. *See* Section II.B, *infra.* Third, restricting AT&T and Verizon from fully participating in this auction would dramatically increase the risk of auction failure, as potential broadcaster reverse-auction participants have explained. *See* Section II.C, *infra.* Fourth, the "bidding credits" schemes proposed by some advocates would suffer from the same defects as other restrictions on participation by AT&T and Verizon. *See* Section II.D, *infra*. Finally, section 6404 of the Spectrum Act prohibits the Commission from relying on spectrum-aggregation rules to exclude AT&T and Verizon from this auction, in whole or in part, given the alternative of allowing them to participate and then divest other spectrum, if necessary, to preserve compliance with those rules. *See* Section II.E, *infra.*

A. As Commission Precedent Recognizes, Sound Economic Considerations Foreclose Proposals to Limit Auction Participation on the Basis of Existing Spectrum Holdings

As AT&T has previously explained, the spectrum requirements of any given carrier depend on the number of the carrier's customers and the intensity of their bandwidth demands.[51] In general, carriers that best meet consumer needs are the ones that win the most customers, and carriers in the vanguard of the mobile broadband revolution, as AT&T has been, are the ones that win customers with the greatest bandwidth demands. Successful mobile-broadband-oriented providers are the providers that face the most pressing capacity challenges—and are thus the ones willing to invest most heavily in the spectrum resources needed to meet those challenges. In short, success drives carriers to increase their spectrum holdings, and it is thus no surprise that carriers with large spectrum holdings are also the ones with the greatest success-driven spectrum *needs*.

As Professor Katz et al. observe, however, holding large quantities of spectrum cannot itself make a carrier successful, let alone exclude other carriers from marketplace success. Katz et al. Reply Decl. ¶¶ 8-9. Nor, as they explain, do the market conditions exist in which any carrier today could possibly benefit from "hoarding" spectrum in order to disadvantage its rivals rather than to meet its own customers' needs. *Id.* ¶¶ 9-10. Indeed, that observation is not subject to serious dispute, even though several commenters persist in disputing it.[52] As Chairman Genachowski has emphasized, it is "just not true" that "wireless companies[] are just sitting on

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[51] *See* Comments of AT&T, *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, at 6-7, 14 (filed Nov. 28, 2012) ("AT&T Spectrum Aggregation Comments").

[52] *See, e.g.*, T-Mobile Comments at 30-31; Competitive Carriers Association Comments at 11.

top of, or 'hoarding,' unused spectrum . . . . The looming spectrum shortage is real—and it is the alleged hoarding that is illusory."[53]

Several commenters nonetheless urge the Commission to limit auction participation as a means of equalizing network assets and thereby keeping any given provider from becoming too big and successful.[54] But "[t]he Commission is not at liberty . . . to subordinate the public interest to the interest of 'equalizing competition among competitors.'"[55] In particular, the "big is bad" rationale championed by some smaller providers would affirmatively harm consumers. Again, larger providers by definition serve more customers than smaller providers and thus may approach spectrum exhaust more rapidly than smaller carriers, even though the larger carriers might hold more spectrum in absolute terms. It would serve no sensible purpose for the Commission to deny larger providers access to the resources they need to serve the bandwidth demands of their customers.

Consistent with these conclusions, the Commission has long recognized that the best means of efficiently allocating new spectrum for the benefit of consumers is to auction it to the highest bidder and facilitate a secondary marketplace where providers may purchase or sell

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[53] FCC Chairman Julius Genachowski, *The Clock Is Ticking*, Remarks on Broadband, at 7-8 (rel. Mar. 16, 2011), http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-305225A1.pdf.

[54] *See* Cellular South Comments at 5-6; T-Mobile Comments at 33; Competitive Carriers Association Comments at 7.

[55] *SBC Communications Inc. v. FCC*, 56 F.3d 1484, 1491 (D.C. Cir. 1995); *see also Competitive Telecomms. Ass'n v. FCC*, 87 F.3d 522, 531-32 (D.C. Cir. 1996) (striking down "interim" rule designed to protect smaller IXCs at expense of AT&T); *Western Union Tel. Co. v. FCC*, 665 F.2d 1112, 1122 (D.C. Cir. 1981); *Hawaiian Tel. Co. v. FCC*, 498 F.2d 771, 776 (D.C. Cir. 1974); *see also United States v. Western Elec. Co.*, 969 F.2d 1231, 1243 (D.C. Cir. 1992) (rejecting efforts to "aid the minnows against the trout").

spectrum rights.[56] For example, in adopting rules for the Upper 700 MHz Band, the Commission rejected proposed eligibility limitations because, it found, "opening this spectrum to as wide a range of applicants as possible will encourage entrepreneurial efforts to develop new technologies and services, while helping to ensure the most efficient use of the spectrum."[57] Two years later, when the Commission considered service rules for the Lower 700 MHz Band, it repeated that "open eligibility will enhance the opportunities for licensees to provide service in any market or combination of markets" and that "[a] policy of open eligibility for the Lower 700 MHz Band will best serve the public interest[.]"[58] And the Commission reaffirmed these conclusions in the *National Broadband Plan* (at 78) by stressing the importance of spectrum

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[56] *See, e.g.*, Report and Order and Further Notice of Proposed Rulemaking, *Service Rules for the 698-746, 747-762 and 777-792 MHz Bands*, 22 FCC Rcd 8064, 8150 ¶ 235 (2007) ("Congress and the Commission have determined that using competitive bidding mechanisms for assigning spectrum licenses offers significant public interest benefits. For example, the competitive bidding process ensures that spectrum licenses are assigned to those who place the highest value on the resource and will be suited to put the licenses to their most efficient use."); *see also* Third Report and Order, *Service Rules for the 746-764 and 776-794 MHz Bands, and Revisions to Part 27 of the Commission's Rules*, 16 FCC Rcd 2703, 2720 ¶ 42 (2001); Second Report and Order and Third Notice of Proposed Rulemaking, *Interconnection and Resale Obligations Pertaining to Commercial Mobile Radio Services*, 11 FCC Rcd 9462, 9477 ¶ 27 (1996); Policy Statement, *Principles for Reallocation of Spectrum to Encourage the Development of Telecommunications Technologies for the New Millennium*, 14 FCC Rcd 19868, 19870-72 ¶¶ 9-13 (1999); *accord* Gregory L. Rosston & Jeffrey S. Steinberg, *Using Market-Based Spectrum Policy to Promote the Public Interest*, 50 Fed. Comm. L.J. 87, 94-95 (1997).

[57] First Report and Order, *Service Rules for the 746-764 and 776-794 MHz Bands, and Revisions to Part 27 of the Commission's Rules*, 15 FCC Rcd 476, 497 ¶ 49 (2000) (footnote omitted).

[58] Report and Order, *Reallocation and Service Rules for the 698-746 MHz Spectrum Band (Television Channels 52-59)*, 17 FCC Rcd 1022, 1074 ¶ 134 (2002) (footnote omitted); *see also* Report and Order, *Service Rules for Advanced Wireless Services in the 1.7 GHz and 2.1 GHz Bands*, 18 FCC Rcd 25162, 25178 ¶ 42 (2003) (noting that carriers should be entitled "to tailor their acquisition of spectrum . . . to meet their individual business plans" and that "market forces rather than the Commission [will] ultimately determine how this spectrum is licensed").

flexibility and the need to remove—not erect—regulation that "impedes the free flow of spectrum to its most highly valued uses."

B. Distinctions Between "High Band" And "Low Band" Spectrum Cannot Justify Restrictions on Auction Participation

Even if it were otherwise reasonable to exclude some providers from this auction on the ground that they already have "too much" spectrum, AT&T would not qualify as such a provider in the first place. Indeed, AT&T has only about half as much spectrum as Sprint/Clearwire,[59] and it could therefore make no sense to exclude AT&T but *not* those more spectrum-rich corporate partners.

In response, Sprint and a variety of other carriers try to gerrymander comparative spectrum statistics to inflate the value of "low band" (below 1 GHz) spectrum, which they claim is far more valuable than "high band" (above 1 GHz) spectrum, which they have a great deal of.[60] And they conclude that AT&T and Verizon should be categorically excluded from obtaining more spectrum that would place them above some artificially designated quantum of "low-band" spectrum even where they have no particular advantage with respect to spectrum

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[59] *See* Fifteenth Report, *Implementation of Section 6002(B) of the Omnibus Budget Reconciliation Act of 1993*, 26 FCC Rcd 9664, 9832 Chart 38 (2011) ("*Fifteenth Report*") (showing that Sprint and Clearwire together account for approximately 52 billion MHz/pops, whereas Verizon and AT&T each have 25 billion MHz/pops or below). Even before Sprint and Clearwire announced plans to merge, the Commission properly viewed those two companies as a single entity for spectrum-aggregation purposes. It explained that Sprint "holds a 54 percent [economic] interest in Clearwire and has the ability to nominate seven of Clearwire's thirteen directors," and thus rightly decided to "attribute Clearwire to Sprint Nextel when discussing spectrum holdings and network coverage." *Id.* at 9682 n.19. Notably, even a 10 percent holding triggers the Commission's attribution rules. *See, e.g.*, Memorandum Opinion and Order, *Sprint Nextel Corp. and Clearwire Corp.*, 23 FCC Rcd 17570, 17601 ¶ 77 (2008).

[60] *See* Sprint Comments at 2; T-Mobile Comments at 25-27; Cellular South Comments at 5.

holdings generally. That position is untenable for reasons that AT&T has previously explained and will briefly summarize here.[61]

Low-band spectrum has certain *coverage* advantages: because of its propagation characteristics, it is technically possible to use lower-band spectrum to provide service over a larger geographic area with a single cell site.[62] That is why, as some commenters point out,[63] low-band spectrum, particularly in rural areas, tends to attract higher bids at auction: some carriers decide to pay more up front for low-band spectrum with wider coverage, while other carriers decide to build more cell sites in exchange for paying less up front for high-band spectrum. The higher "book value" of low-band spectrum simply reflects that economic trade-off (among many other variables), and it provides no basis for concluding that using low-band spectrum is any more or less expensive *on the whole* to meet any given level of consumer demand. Just as important, this "larger area" advantage is irrelevant in densely populated urban areas, where providers must deploy more and smaller cells simply to increase network capacity. Indeed, as the Commission has recognized, higher-band spectrum above 1 GHz can provide greater *capacity* in the geographic area it covers,[64] which can present advantages in urban and

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61 *See* AT&T Spectrum Aggregation Comments at 62-73; Reply Comments of AT&T, *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, at 22-37 (filed Jan. 7, 2013).

62 *Fifteenth Report*, 26 FCC Rcd at 9833-34 ¶ 292.

63 *See* T-Mobile Comments at 28-29 n.59; Competitive Carriers Association Comments at 2.

64 *Fifteenth Report*, 26 FCC Rcd at 9836-37 ¶ 296 ("[H]igher-frequency spectrum may be just as effective, or more effective [then lower-band spectrum], for providing significant capacity, or increasing capacity, within smaller geographic areas…. In addition, capacity enhancement technologies such as multiple-input and multiple-output (MIMO) may perform better at higher frequencies. … Thus, higher-frequency spectrum can be ideally suited for

suburban areas where demand is greatest. As the Commission has added, moreover, higher-band spectrum is also available in larger blocks, and there is more of it.[65]

Indeed, the parties that complain the loudest to *the Commission* about the "excessive concentration" of low-band spectrum routinely tell *the market* that their high-band spectrum holdings place them, in the words of Sprint CEO Dan Hesse, "in the strongest place for the future."[66] For example, in a presentation to investors, Clearwire Chairman John Stanton explained that his company's 2.5 GHz spectrum is "much" superior to low-band spectrum in high-density markets:

> Spectrum in the 2.5 gigahertz band is *ideally suited* for high-volume wireless data. *High-frequency spectrum is much more conducive than low- or mid-band spectrum to meeting the usage and speed requirements of heavy tonnage users in densely populated markets*. The 2.5 gigahertz band is also the sweet spot of global TDD LTE evolution. Earlier this year, Clearwire cofounded the GTI consortium with China Mobile, Vodafone, SoftBank and Bharti. Clearwire was the only American carrier included in the consortium. The members of this consortium serve more than 1.3 billion customers, representing 4x the population of the U.S. This means that this group will be driving the lowest possible cost and greatest variety of devices.[67]

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providing high capacity where it is needed, such as in high-traffic urban areas.") (footnotes omitted).

[65] *Id.* ("[T]here currently is significantly more spectrum above 1 GHz that is potentially available for use …, and, in many parts of these higher bands, spectrum is licensed in larger contiguous blocks[, which]… can enable operators to deploy wider channels and simplify device design.").

[66] Andrew Munchbach, *CTIA 2010's day two keynote with Sprint CEO Dan Hesse*, BGR (May 24, 2010), http://bgr.com/2010/03/24/live-from-ctia-2010s-day-one-keynote-with-sprints-dan-hesse/.

[67] *Clearwire's CEO Discusses Q2 2011 Results – Earnings Call Transcript*, Seeking Alpha (Aug. 4, 2011), http://seekingalpha.com/article/284461-clearwire-s-ceo-discusses-q2-2011-results-earnings-call-transcript (emphasis added).

In short, advocates of excluding AT&T and Verizon can point to no plausible rationale (beyond their own self-interest) for treating "low-band" spectrum differently for purposes of any spectrum-aggregation analysis or for excluding those companies from this auction, in whole or in part.

C. Restrictions on Auction Participation Would Dramatically Increase the Risk of Auction Failure

As AT&T has emphasized, the public policy consequences of imposing "aggregation"-oriented auction restrictions could easily undermine the Commission's plans to free up 600 MHz spectrum for any mobile provider. In particular, restricting well-capitalized carriers such as AT&T and Verizon from full participation in this auction would undermine forward-auction competition, suppress bid levels, and thus dramatically increase the risk that forward-auction revenues will be insufficient to meet the statutory closing conditions for any given spectrum-clearing target. Although some carriers have claimed that they would somehow end up bidding more if AT&T and Verizon were banished from this auction,[68] that claim defies economic logic, as Professor Katz et al. explain (at ¶¶ 31-36). In fact, these carriers know that excluding AT&T and Verizon would stifle competition for 600 MHz spectrum assets and would thus reduce pressure on those other carriers to bid at appropriately high levels for those assets. That outcome would succeed only in depressing forward-auction revenue results and reducing the total amount

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[68] T-Mobile Comments at 33. Shortly after the opening round of comments, a private consulting group issued a new paper purporting to show that bidding restrictions would not necessarily reduce auction issues. *See* Martyn Roetter & Alan Pearce, *The Impact of Bidding Eligibility Conditions on Spectrum Auction Revenues*, Information Age Economics (Feb. 2013), *available at* http://www.ccianet.org/CCIA/files/ccLibraryFiles/Filename/000000000750/IAE%20Report%20-%20Final.pdf. As Professor Katz et al. observe in their reply declaration (at ¶¶ 37-42), that paper suffers from numerous methodological flaws and is not credible.

of reallocated spectrum, and it would benefit no one other than the carriers seeking this regulatory favor.

This concern is hardly unique to the carriers that would be disadvantaged by this proposal; it is also a major concern of the very broadcasters who would otherwise be most interested in participating in the reverse auction and ceding spectrum rights. In the words of the Expanding Opportunities for Broadcasters Coalition ("EOBC"):

> ***The Coalition strongly opposes any efforts to exclude or otherwise restrict any wireless providers from participating in the forward auction.*** Simple truths can be stated succinctly. The potentially willing broadcast sellers, upon whom the FCC must rely for the success of the incentive auction, strongly and sincerely believe that the following would be the nearly certain consequences of restricting Verizon and/or AT&T from participating in the forward auction (including any requirement that they divest other spectrum as a condition of closing on spectrum purchased in the incentive auction):
>
> • *First*, the auction will not produce the revenues necessary to meet the expectations of the potentially willing broadcast sellers;
>
> • *Second*, the auction will fail;
>
> • *Third*, there will be no new spectrum allocated for consumer use of wireless devices;
>
> • *Fourth*, there will be no surplus to fund an interoperable network for public safety first responders; and
>
> • *Fifth*, there will be no surplus for deficit reduction.[69]

This passage is critical not only because it is objectively accurate, but also because it reflects the subjective expectations of the very broadcasters who would be among the most willing to participate in this auction proceeding. Such broadcasters need reassurance that the auction stands a great enough chance of success that they should follow through on their plans to place their stations on the block. As these broadcasters' lead economist explains, the auction

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[69] EOBC Comments at 13-14 (emphasis in original). EOBC adds: "The Coalition offers these observations as an independent assessment. No wireless carrier is a member of our Coalition. No wireless carrier has contributed a single penny to our Coalition." *Id.* at 14.

will succeed only if broadcasters have "confidence that they will face the full demand curve, and that demand will not be reduced by exclusion, or handicapping, of some potential buyers."[70] If the Commission denied broadcasters that confidence by "handicapping . . . potential buyers" such as AT&T and Verizon, it would undermine the odds of success not only in the forward auction, but also in the reverse auction.

D. Proposals for "Bidding Credits" Based on Existing Spectrum Holdings Are As Untenable As Other Restrictions on Auction Participation

Various commenters ask the Commission to bestow "bidding credits" on auction participants on the basis of their relative spectrum holdings.[71] Those proposals would suffer from all the defects of any of the other artificial means, discussed above, to exclude AT&T and Verizon from the forward auctions in various localities in whole or in part. *See* Katz et al. Reply Decl. ¶¶ 43-52. Among their other shortcomings, the proposed bidding-credit schemes would be purely and irrationally retrospective, in that they would consider only what spectrum a carrier has acquired in the past and would completely ignore the carrier's expected future need for additional spectrum to accommodate its growing customer base and usage patterns. Moreover, these bidding-credit proposals, if successful, would drive down auction revenues simply as a matter of arithmetic. The whole point of bidding credits is to alter the identities of the winning bidders. But if the regime succeeds in that goal, then the amounts those bidders will pay at

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[70] EOBC Comments, Exh. A (Decl. of Jeffrey Eisenach) at 12-13; Letter from Richard Bodorff (for EOBC) to Marlene Dortch (FCC), WT Docket No. 12-269, at 3 (filed Mar. 4, 2013) ("For an auction to allocate spectrum efficiently, sellers must enter the auction with confidence that they will face the full demand curve, and that demand will not be reduced by arbitrary exclusion of some potential buyers.").

[71] *See, e.g.*, Leap Comments at 6; MetroPCS Comments at 26-27; Competitive Carriers Comments at 11-12.

auction will necessarily be lower than the amounts that would otherwise be paid by the winning bidders in the *absence* of bidding credits. *See id.* ¶ 45. In other words, no bidding-credits regime can both serve its intended (and misguided) purpose of spectrum-equalization without reducing forward-auction revenues and therefore increasing the risk of auction failure.

Bidding credits would also distort the operation of secondary spectrum markets and give the beneficiaries multi-billion-dollar windfalls at the expense of forward-auction revenues and consumer welfare. Again, the Commission's current regime generally allocates spectrum assets to the highest bidder, which is then generally free to sell some or all of those assets to third parties in the secondary market. If the Commission maintains that regime, bidding credits would not keep spectrum out of the hands of the carriers that value it most highly, including large carriers with significant existing spectrum holdings. Instead, as Professor Katz et al. explain (at ¶¶ 49-51), bidding credits would simply add a wasteful new step in the process by initially assigning the spectrum to credit-assisted auction winners who would then monetize their credits by reselling the spectrum to less credit-eligible entities. In addition to reducing forward-auction revenues, *see id.* ¶ 47, that outcome would needlessly delay utilization of the affected spectrum, potentially by many years.

The Commission could avoid that outcome only by designing and administering a complex anti-alienation regime that would restrict credit-assisted winners from reselling their spectrum to willing buyers in the secondary market. But that approach would be even worse for consumers. By definition, restrictions on secondary-market transactions would keep auction winners from selling spectrum assets to other providers that can put those assets to uses more valued by consumers, such as alleviating severe network congestion in urban markets. In addition, any anti-alienation regime would also be susceptible to major implementation disputes.

The Commission has faced a similar set of controversies in administering its much more limited scheme of bidding credits for designated entities (*i.e.*, small businesses), and the result has been years of destabilizing litigation.[72] Creating a *new* bidding-credits scheme on the basis of existing spectrum holdings would succeed only in creating a new dimension of intractable implementation controversies.

E. The Spectrum Act Prohibits the Commission from Excluding AT&T and Verizon from this Auction on the Basis of Spectrum-Aggregation Policies, Given the Alternative of Allowing Them to Participate and Then Make Any Necessary Divestitures to Preserve Compliance with Those Policies

The Commission would violate section 6404 of the Spectrum Act if, on the basis of existing spectrum holdings, it excluded any carrier from participating in any auction for 600 MHz spectrum, whether in a particular locality or more generally. Codified as section 307(j)(17) of the Communications Act, section 6404 provides that "the Commission may not prevent" an otherwise qualified bidder "from participating in a system of competitive bidding" on the basis of its spectrum holdings (or for any other reason). Congress added that the Commission may exercise whatever authority it previously had "to adopt and enforce rules of general applicability, including rules concerning spectrum aggregation that promote competition." 47 U.S.C. § 309(j)(17).

These two provisions are easily harmonized. The Commission can "adopt and enforce" spectrum-aggregation "rules of general applicability" *without* "prevent[ing]" a carrier "from participating in a system of competitive bidding" simply by allowing the carrier, post-auction, to divest existing spectrum if necessary to keep itself in compliance with the rules while

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[72] *See, e.g.*, *Council Tree Commc'ns, Inc. v. FCC*, 619 F.3d 235 (3d Cir. 2010) (invalidating certain anti-alienation rules on APA grounds).

rationalizing its spectrum holdings across various markets. The availability of that option thus precludes the Commission from disqualifying carriers from bidding for spectrum in a given locality if they agree to make divestures that will keep them from ever coming into violation of any spectrum-aggregation policy. Excluding those carriers from such bidding would be unlawful precisely because the Commission has other—indeed, better tailored—means of "enforc[ing] rules of general applicability, including rules concerning spectrum aggregation that promote competition."

III. THE COMMISSION SHOULD DESIGN EFFICIENT AUCTION MECHANISMS—INCLUDING PACKAGE BIDDING—TO MAXIMIZE THE ODDS THAT FORWARD-AUCTION RESULTS WILL MEET THE STATUTORY REVENUE REQUIREMENTS

As discussed, this auction will succeed, and 600 MHz spectrum will be reallocated to mobile broadband, only if forward-auction bids meet the statutory revenue requirements. Whether the auction succeeds or fails will depend in large part on the decisions the Commission makes on the front end about auction participation and design. For example, as discussed in Sections I and II above, the Commission should maximize the prospective value of this spectrum to forward-auction bidders and avoid anticompetitive, revenue-reducing restrictions on who may participate in the forward auction. To increase the odds of success, the Commission should also design efficient auction mechanisms that (1) induce forward-auction participants to express the full value of this spectrum in the form of high winning bids and (2) structure the reverse-auction bidding and the repacking analysis to ensure attainable revenue requirements for meeting given spectrum-clearing targets.

AT&T addressed these auction-design issues in great detail in its opening comments and supporting declarations. As explained there, the Commission should (among other things):

- provide for "generic bidding" but carefully define the categories of generic licenses so that each category contains only truly interchangeable spectrum blocks of similar value;

- adopt a "clock package auction" format that, as proposed by Professors Che, Haile, and Kearns, will enable forward-auction participants to express the substantial value of geographic complementarities and will thereby avoid the bid-depressing consequences of the exposure problem;

- establish clear assignment rules that will provide winning bidders with geographically and spectrally contiguous spectrum to the maximum extent possible, thereby inducing forward-auction participants to express those complementarities in the form of higher bids for generic spectrum;

- hold a "single-pass reverse auction" that would ask broadcasters to indicate, *before* any forward-auction bidding is conducted, whether or not they would cede specified spectrum rights at progressively lower price levels; and

- establish mechanisms for eliciting additional bidding in *both* the forward *and* the reverse auction to maximize the odds of meeting the closing conditions for a given channel-clearing target if those conditions are not met when the descending reverse-auction clock has just eliminated excess supply and the ascending forward-auction clock has just eliminated excess demand.

Rather than repeat the rationales for all of these auction-design proposals here, we respectfully refer the Commission to our opening comments and to the opening and reply declarations of Professors Che, Haile, and Kearns. Nonetheless, the issue of package bidding is sufficiently important and controversial that we briefly respond to the claims of package-bidding opponents.

As discussed in our opening comments, package bidding is necessary to avoid a bid-suppressing *exposure problem* that is well-recognized both in Commission precedent and in the auction literature.[73] Understanding the exposure problem is key to understanding why package-

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[73] *E.g.*, Second Report and Order, *Service Rules for the 698-746, 747-762 and 777-792 MHz Bands et al.*, 22 FCC Rcd 15289, 15396-97 ¶¶ 287, 290 (2007) ("*700 MHz Order*"); Sang Won Kim *et al.*, *Measuring the Performance of Large-Scale Combinatorial Auctions: A Structural Estimation Approach*, at 1 (June 11, 2012), http://www.hss.caltech.edu/~mshum/gradio/papers/Weintraub2012.pdf. ("The main advantage of package bidding is that it allows bidders to express cost synergies in their bids. In contrast, if bidders were allowed only to

bidding options are essential, yet—tellingly—many opponents of package bidding *do not even mention* the exposure problem in their comments.[74] We thus briefly summarize the nature of the problem before returning to AT&T's proposed solution.

As the Commission has explained, a "bidder whose business plan is premised on realizing economies of scale may need to win a large number of licenses in order to justify the bid that it would make if it could win all of them. The risk of winning less than all the licenses needed to support the amount of the aggregate bid is sometimes known as the 'exposure problem.'"[75] A concrete example—a carrier's investment in particular handset technologies—helps illustrate the point. Because portability is the essence of mobile technology, a carrier with regional or nationwide operations does not typically sell its customers different handsets depending on where they live; in general, it offers every customer the same menu of handset options. The carrier must therefore make footprint-wide decisions about which components to install in its handsets. Those decisions present important trade-offs. For example, to optimize device performance and form factors, a carrier must limit the number of—and carefully select—the antennas and radio-frequency filters that it installs in its handsets.[76]

Carriers thus work hard to rationalize their spectrum holdings across different markets. If a carrier had licenses for Bands A and B in some cities, Bands C and D in other cities, and Bands E and F in yet other cities, its customers could not make use of all those bands when they travel

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submit bids for each unit separately they would face the risk of winning some units but not others. This phenomenon, known as the *exposure problem*, makes the bidders less aggressive[.]") (emphasis in original).

[74] *See* Leap Comments at 9; MetroPCS Comments at 13-14.

[75] *700 MHz Order*, 22 FCC Rcd at 15396 ¶ 287.

[76] *See* Qualcomm Comments at iii, 3 & n.5; RIM Comments at 10-11.

unless the carrier installs an inefficiently large number of handset components designed to process signals on all of those bands. Instead, the carrier would much prefer to have licenses simply for the same two bands in all, or at least most, of its geographic markets.

For these reasons, a carrier might well decide that it makes no economic sense to invest in 600 MHz technology *at all* if it does not win 600 MHz spectrum rights in most of the geographic areas within its footprint. And it might thus wish to avoid paying substantial sums for 600 MHz licenses in some areas if it does not win them throughout most of its footprint. Without package bidding, however, such a carrier might well get stuck "winning" unwanted licenses because it would have to bid separately for licenses in every geographic area within its footprint. For example, the forward auctions in a few cities might conclude early and leave the carrier as a high bidder, while the bidding proceeds to such high levels in other cities that the carrier can no longer afford to remain in those auctions. Faced with that risk, the carrier would have a strong incentive to exit the auction process inefficiently early in order to avoid paying for spectrum that later turns out to be much less valuable than it would have been as part of a multi-area package.

Because of that exposure problem, the absence of a package-bidding mechanism would reduce forward-auction revenues and increase the risk of auction failure. Some commenters seek to minimize this concern by noting that the Commission did not rely on package bidding in the AWS auction and permitted package bidding for only a single block in the 700 MHz auction.[77]

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[77] *See* US Cellular Comments at 55; MetroPCS Comments at 13-14. The 700 MHz block subject to package bidding was the Upper C Block, whose constituent licenses Verizon ultimately won throughout the continental United States. The winning bids for the C Block were relatively low, but only because the Commission imposed various "openness" conditions that encumbered C Block licenses and deterred other carriers from bidding aggressively for

That argument is unsound on two levels. First, the Commission assigned very large geographic areas to certain licenses sold in these auctions and thus established a rough (but quite imperfect) proxy for package bidding, likely alleviating the exposure problem to some degree.[78] Here, in contrast, the Commission proposes to assign licenses only to relatively small geographic units (EAs), thereby maximizing the exposure problem that would arise in the absence of a package-bidding mechanism. That approach would be unwise as a policy matter, and it would disregard the Commission's statutory mandate to "consider assigning licenses that cover geographic areas of a variety of different sizes." Spectrum Act § 6403(c)(3).

Second, and just as important, the Commission may well have forgone substantial auction revenues in the AWS and 700 MHz auctions precisely because it did *not* make adequate provision for package bidding there. Indeed, there is compelling evidence for that conclusion. In the half-dozen years following those two auctions, carriers have paid one another enormous sums on the secondary market to rationalize the hodgepodge of spectrum holdings that they won in these two auctions. The likelihood of having to incur the costs, delays, and uncertainties of such post-auction transactions almost certainly induced carriers to bid less in the AWS and 700 MHz auctions than they would have bid if only they could have rationalized their spectrum holdings up front, in the form of winning package bids in those auctions themselves. Of course, the auctions closed anyway, despite the lower revenues deposited into the U.S. Treasury, but

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them. *See* Comments of AT&T, *Framework for Broadband Internet Service*, GN Docket No. 10-127, at 111-12 & n.190 (filed July 15, 2010).

[78] *See 700 MHz Order*, 22 FCC Rcd at 15324 ¶¶ 81-82 (noting use of large regional licenses in AWS-1 auction and adopting similar areas for certain licenses in 700 MHz auction). Consistent with this observation, bids for REAG licenses in the AWS auction were on average 37 percent higher per MHz than those for EAs covering the same population. *See* Che/Haile Reply Analysis at 10.

only because the AWS and 700 MHz auctions were not subject to rigid revenue requirements. *This* auction for 600 MHz spectrum, however, *is* subject to a rigid revenue requirement, and the Commission should thus take all available steps, including the adoption of a package-bidding mechanism, to ensure that the requirement is met.

Some commenters further claim that package bidding would (1) add intractable complexity to the auction or (2) discriminate unfairly against smaller carriers.[79] The clock package auction proposed by Professors Che, Haile, and Kearns, however, is designed precisely to avoid both of those concerns. First, their proposal will efficiently manage computational complexity by specifying allowable package bids such that each pre-defined package is fully nested within the next-larger pre-defined package in a clear hierarchy (EAs, MEAs, and REAs).[80] This pre-defined hierarchy of permissible packages will avoid the severe computational challenges that, as the Commission has noted, *would* arise if bidders were simply allowed to define their own, partially overlapping packages.[81]

Second, the Che/Haile/Kearns proposal will not favor package bidders (such as national carriers) over auction participants that bid only on individual EAs. A package bidder could win licenses in all EAs within its geographic package only if the total price for that package exceeds

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[79] *See* MetroPCS Comments at 13-14; US Cellular Comments at 51-55; Leap Comments at 9.

[80] *See* Yeon-Koo Che, Phil Haile, and Michael Kearns, *Design of the FCC Incentive Auctions*, at 35, 37-39 (Jan. 25, 2013) ("CHK Analysis") (attached to AT&T's opening comments as Exh. B).

[81] *See* Che/Haile Reply Analysis at 3; Public Notice, *Mobility Fund Phase I Auction Scheduled for September 27, 2012; Comment Sought on Competitive Bidding Procedures for Auction 901 and Certain Program Requirements*, 27 FCC Rcd 530, 539 ¶ 32 (WTB & WCB 2012) (proposing to limit the number of package bids based on census blocks because selecting winning bidders "can be difficult . . . with large numbers of partially overlapping package bids").

the sum of the bids that would otherwise prevail, including all EA-specific bids. That mechanism will pick winners solely on the basis of which combination of bids expresses—and can be presumed to produce—the greatest economic value for consumers. In particular, by enabling bidders to express the substantial complementarities they can achieve through geographic packages, the proposal will promote consumer welfare while maximizing the odds of satisfying the closing conditions for a given spectrum-clearing target. If anything, the Che/Haile/Kearns framework would be preferable to the Auctionomics proposal from the perspective of small bidders. *See* Che/Haile Reply Analysis at 9-10. Among other considerations, it would correct the "overflow problem" inherent in the Auctionomics design, which tends to disadvantage bidders for single-EA licenses in various circumstances. *Id.* at 9.

Third, theoretical concerns about the "threshold problem" also cannot justify opposition to the proposed clock package auction.[82] The problem can arise "where bidders on individual licenses together have a higher valuation than the package bidder, but because of limited competition for the individual licenses, the sum of the bids on individual licenses is lower than the package bid. Each bidder would be willing to raise its own bid, but would prefer that other bidders do so to increase the sum of the bids on individual licenses."[83] This concern is particularly substantial in traditional SMR ("simultaneous multiple-round") auctions, but it could theoretically arise in a clock auction as well. *See* Che/Haile Reply Analysis at 4, 7.

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82 *See* MetroPCS Comments at 14; US Cellular Comments at 53-54.

83 *See* Gregory L. Rosston, *Implementing Package Bidding in the 700 MHz Band to Improve Consumer Welfare* at 11-12, attached to Letter From Kathleen Wallman (counsel to Pegasus Communications Corporation) and Ruth Milkman (counsel to Access Spectrum, LLC) to Marlene H. Dortch (FCC), WT Docket No. 06-150 (filed Feb. 5, 2007).

As Professors Che and Haile explain, however, the threshold problem does not arise from, and thus cannot be a basis for opposing, any well-designed mechanism for package bidding. *Id.* at 4-8. Instead, it arises from the market reality that—in any spectrum auction, with or without package bidding—some bidders will perceive complementarities in holding licenses in geographically adjacent regions, and they will place bids designed to capture those complementarities. *Id.* at 5. The Che/Haile/Kearns proposal for a clock package auction would not introduce any new threshold problem beyond what the Auctionomics proposal would present even without a package-bidding mechanism; indeed, if anything, the Auctionomics proposal would present the problem in more acute form. *Id.* at 5-8.

Finally, as Professors Che and Haile explain in their reply analysis, their proposed clock package auction presents no significant risk that bidders would engage in strategic bid manipulation by bidding up either component or package prices in order to induce inefficient undersell. *Id.* at 10-13. Concerns about any such risk appear to rest on a simple misunderstanding of how that auction would be structured. In any event, the prospect of supplementary bidding within the Che/Haile/Kearns framework greatly alleviates any undersell concern, whether arising from strategic manipulation or otherwise. *Id.*at 12-13; *see also* CHK Analysis at 54-57 (describing discretionary supplementary bid procedure).

IV. THE COMMISSION SHOULD REJECT PROPOSALS TO LIMIT ITS REPACKING DISCRETION

As discussed in our opening comments, this proceeding will succeed only if the Commission retains flexibility to repack remaining broadcast stations as efficiently as possible. Efficient repacking is the key to reducing the statutory revenue requirements by limiting the number of stations that must be paid compensation for ceding spectrum rights. The Commission should thus reject various broadcaster proposals to hamstring its own repacking discretion.

A. The Statute Requires Balancing Broadcaster Interests Against the Public Interest in Reallocating Additional Spectrum to Mobile Broadband

After prolonged legislative debate, Congress gave the Commission precisely the repacking flexibility that it needs to make this auction a success. In particular, the Spectrum Act gives the Commission broad discretion to "make such reassignments of television stations that the Commission considers appropriate" "[f]or purposes of making available spectrum to carry out the forward auction." Spectrum Act § 6403(b)(1), (b)(1)(B)(i). To this generalized mandate, Congress attached a single relevant qualification: the Commission must "make all *reasonable* efforts to preserve, as of the date of the enactment of this Act, the coverage area and population served of each broadcast television licensee, as determined using the methodology described in OET Bulletin 69 of the Office of Engineering and Technology of the Commission." *Id.* § 6403(b)(2) (emphasis added). As the NPRM recognizes, "all reasonable efforts" is a common statutory term; "its meaning depends on the circumstances involved, and comports with the common meaning of the word 'reasonable,'" which includes "[f]it and appropriate to the end in view."[84] Congress included this qualifier because it wished to grant the Commission very broad discretion to balance a range of objectives, including not only protections for broadcasters, but also the policy imperative to "[m]aximize[e] the amount of spectrum freed up" for mobile broadband.[85]

This open-ended statutory language flatly precludes arguments by some broadcasters that Congress somehow required the Commission to sacrifice all other objectives in order to "hold

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[84] NPRM ¶ 105 (citing, *inter alia*, Black's Law Dictionary 1265 (6th ed. 1990)); *see, e.g.*, *Capital Network Sys., Inc. v. FCC*, 28 F.3d 201, 204 (D.C. Cir. 1994).

[85] *See* NPRM, 27 FCC Rcd at 12547 (statement of Chairman Genachowski).

harmless" those broadcasters that do not participate in the auction and must be repacked.[86] The statutory language similarly forecloses NAB's argument (at 19) that the Commission must identify "extraordinary" or "truly exceptional" circumstances before altering a station's coverage area and population served. A mandate to make "reasonable efforts" to maintain coverage and population does not require or even permit the Commission to maintain coverage and population in all but "extraordinary circumstances" if such rigidity would risk decreasing the spectrum reallocated to mobile broadband uses.

Moreover, that conclusion follows no matter how the Commission resolves a secondary interpretive question: whether "preserv[ing] . . . the coverage area and population served" by a broadcaster means preserving coverage for *all the exact same people and places* as before or, instead, the same number of people and square mileage. *See, e.g.*, NAB Comments at 23-24. The statutory language is in fact ambiguous on that point, and the Commission should interpret it as needed to pursue its broader policy objectives. *See, e.g.*, Verizon Comments at 35-36. But even if this statutory language ("preserv[ing] . . . the coverage area and population served") compelled the broadcasters' preferred construction, that language would still be subject to the "reasonable efforts" standard. No matter how broadcasters' interests in the repacking process are defined, the Commission need make only "all *reasonable* efforts" to protect them. Again, the unqualified term "reasonable" means that those interests must sometimes yield to competing interests.

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[86] Affiliate Associations Comments at 32; *see also* NAB Comments at 18 (arguing that the statute "makes clear that … [broadcasters] who do not participate [in the auction] should not be harmed in any way").

To be clear: AT&T agrees that the Commission should try hard to protect broadcasters' interests in the repacking process, and it should give substantial weight to a broadcaster's interests in avoiding significant new interference or significant changes in signal contours. But the Commission should not attribute *infinite* value to those broadcaster interests or even a disproportionately large value. It should instead balance them as appropriate against the public's equally important interest in freeing up additional spectrum for mobile broadband. In conducting that balance, the Commission should also bear a key fact in mind. Fewer than 10% of U.S. television households still rely exclusively on over-the-air broadcast signals to receive TV programming.[87] The remaining 90% subscribe to cable, satellite, or other MVPD services and receive local broadcast signals that way. In short, the vast majority of television viewers will be unaffected by the details of this repacking process. Commenting broadcasters sometimes overlook that fact when they discuss the viewer impact of new interference or contour adjustments. *See, e.g.*, NAB Comments at 21 & n.33. If a station has 100,000 potential viewers and repacking would subject the station to one percent additional interference, that change could be expected to affect, on average, only about 100 viewers (10% of 1% of 100,000), not 1000.[88]

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[87] Fourteenth Report, *Annual Assessment of the Status of Competition in the Market for the Delivery of Video Programming*, 27 FCC Rcd 8610, 8705-06 ¶ 211 (2012) ("After a steady decline over the last few years, the percentage of television households relying exclusively on over-the-air broadcast service" stands at approximately "9.6 percent (10.97 million households) at the end of 2011.").

[88] Although ease of repacking should influence the selection of winners in the reverse auction, *see* AT&T Comments at 75-76, AT&T agrees with EOBC that "[a] station's enterprise value has no correlation to the value of recovering spectrum rights" and should not be a "scoring factor" in the selection of reverse-auction winners. EOBC Comments at 4.

B. The $1.75 Billion Cap on the Repacking Fund Does Not Limit the Commission to Repacking "400-500 Stations"

The major broadcaster associations contend that "the Commission should not plan on relocating more than 400 to 500 stations because otherwise relocation costs will exceed the amount of the [$1.75 billion] Fund Congress established to fully reimburse broadcasters." Affiliate Associations Comments at 47; *see also* NAB Comments at 49. In fact, the Commission might well need to repack more than 500 stations under a successful auction scenario. And any argument that the Commission is somehow limited to repacking "400 to 500 stations" is untenable as a matter of both law and accounting.

First, the argument misreads the Spectrum Act, which nowhere suggests that the $1.75 billion figure constrains the Commission's discretion to repack as many stations as it deems appropriate to reallocate spectrum for mobile broadband. Section 6402 provides that "$1,750,000,000 of the proceeds from the incentive auction . . . shall be deposited in the TV Broadcaster Relocation Fund," which is separately established in section 6403(d)(2). Section 6403 further provides that the auction can close only if forward-auction revenues exceed the sum of (1) winning reverse-auction bids, (2) certain administrative costs, and (3) "the estimated costs for which the Commission is required to make reimbursements under subsection (b)(4)(A)." *Id.* § 6403(c)(2)(B). Critically, the cross-referenced provision—section 6403(b)(4)(A)—directs the Commission merely to "reimburse costs reasonably incurred" by broadcasters and others "*from amounts made available under subsection (d)(2)*"—that is, from the Fund, which Congress capped at $1.75 billion. (Emphasis added.) As a result, the third variable in the auction-closing equation set forth in section 6403(c)(2)—"the estimated costs for which the Commission is required to make reimbursements"—can be *at most* $1.75 billion. Any repacking costs that

exceed $1.75 billion therefore cannot keep the auction from meeting the statutory closing conditions. Significantly, broadcasters lobbied Congress for a much larger Fund for these purposes, and Congress considered that request, but it ultimately decided to cap the amount at $1.75 billion.[89]

More important, this dispute is likely to have only academic significance because, even if the Commission repacks more than 500 stations, the costs "reasonably incurred" in any foreseeable scenario will likely remain well below $1.75 billion. For example, an economic analysis prepared on this issue in 2011 projected that full repacking costs for 629 stations would amount to only about $565 million.[90]

Of course, much of this discrepancy in repacking cost estimates stems from the broadcasters' expansive view of the "costs" for which they claim entitlement to reimbursement. For example, the Affiliate Associations criticize the NPRM's entirely reasonable proposal to borrow the standard from the 800 MHz rebanding proceeding and permit recovery of "costs that are reasonable, prudent, and the minimum necessary to provide facilities and services comparable to those presently in use." NPRM ¶ 343. According to the Affiliate Associations (at 50), the statutory language ("costs reasonably incurred") entitles them to recover *more* than the "minimum necessary" costs to maintain a comparable level of service.

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[89] *See* Kim McAvoy, *Levin: TV Spectrum Auctions Likely Doomed*, TVNewsCheck (Jan. 5, 2012) (describing House bill that included broadcaster-backed provisions, including a $3 billion relocation fund), http://www.tvnewscheck.com/article/56476/levin-tv-spectrum-auctions-likely-doomed.

[90] *See* CTIA & CEA, *Broadcast Spectrum Incentive Auctions*, at 6-7 (Feb. 15, 2011), attached to Letter from Christopher Guttman-McCabe (CTIA) and Julie Kearney (CEA) to Chairman Julius Genachowski and Commissioners (Feb. 15, 2011), http://cea.aristotle.com/Shared%20Documents/issuesSpectrum/CTIA_CEA_TV_Spectrum_Whitepaper-FINAL-021511.pdf.

That is implausible, and the Commission has clear authority to adopt its proposed standard. Congress did not define the "cost[s]" that may be recovered, and "without any better indication of meaning than the unadorned term, the word 'cost' . . . is a 'chameleon'" and a "'virtually meaningless' term." *Verizon Commc'ns, Inc. v. FCC*, 535 U.S. 467, 500 (2002). As the D.C. Circuit recently reaffirmed, Congress's use of that term in a statute "is open to a wide range of reasonable interpretations" and grants the Commission great discretion to accommodate its policy preferences. *American Elec. Power Serv. Corp. v. FCC*, No. 11-1146, 2013 WL 673501, at *6 (D.C. Cir. Feb. 26, 2013) (citing *Transmission Access Policy Study Group v. FERC*, 225 F.3d 667, 704 (D.C. Cir. 2000)). Indeed, the cost standard upheld in *Verizon*—total long run incremental cost, or TELRIC—assesses costs on the basis of what a hypothetical, most efficient provider would pay to replicate the functionality of a network element, not what any provider *actually* paid for that functionality.[91]

AT&T also supports Sprint's proposal (at 11) that, "as soon as practically possible . . . , all television broadcasters should be required to provide the Commission with an inventory of their equipment and facilities that would be impacted by repacking, along with a preliminary estimate of their repacking costs."[92] As Sprint explains, the Commission should "engage third party experts to evaluate these inventories and provide the Commission with independent estimates on the cost of broadcaster relocation . . . , extrapolating these figures to estimate total

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[91] *See AT&T Corp. v. Iowa Utilities Bd.*, 525 U.S. 366, 375 n.3 (1999) (TELRIC is "based upon the cost of operating a hypothetical network built with the most efficient technology available").

[92] As Sprint explains (at 12), this proposal is less burdensome than it might first appear, given that "as a result of the recent DTV transition, it is reasonable to assume that licensees have some level of system inventory already completed."

relocation costs under a variety of scenarios and in different markets." *Id.* AT&T also supports Sprint's suggestion that the Commission "adopt clear rules and policies" concerning reimbursable costs in advance "so that television broadcasters can make the most educated decisions possible" about whether to participate in the reverse auction. *Id.* Without such guidance, "a broadcaster may inadvertently make a poor decision on participating in the reverse auction based on an erroneous assumption that certain costs associated with its repacking plans would be fully reimbursed." *Id.*

Finally, the Commission should reject the Affiliate Associations' proposal (at 48) for rules "to ensure that involuntarily repacked stations have *the maximum possible amount of time* to construct their new facilities and still qualify for reimbursement from the Fund." (Emphasis added.) By permitting stations to remain in their existing channels as long as possible, this approach would greatly lengthen the interval between the date of the forward auction and the date on which forward-auction winners can make use of the relevant spectrum for the provision of mobile broadband services. Every additional month that goes by, however, is a month that those winners will have tied up billions of dollars of capital in prospective assets that are not yet producing any revenues for them. Given the time value of money, therefore, the broadcasters' proposal for the "maximum possible" delay would depress forward-auction bids and exacerbate the risk of auction failure.

CONCLUSION

The Commission should take the steps outlined above and in AT&T's opening comments to derive the greatest value from the 600 MHz band and ensure that as much of it as possible is reallocated to mobile broadband uses.

Respectfully submitted,

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THE 600 MHz SPECTRUM AUCTION: AN ANALYSIS OF THE BAND PLAN FRAMEWORK AND RESPONSE TO CERTAIN PROPOSALS

Professors Reed[1] and Tripathi[2]

Abstract

This is our second paper in response to the Commission's NPRM. Our first paper analyzed the lead band plan framework set forth in the NPRM and provided a set of core principles that, when adhered to, would significantly enhance that framework. In this paper, we focus on certain specific band plan-related issues about which there have been debates and discussions among the commenters in this proceeding. We begin by explaining why the Commission should reject proposals to permit LTE-TDD (also known as TD-LTE) systems to operate in the 600 MHz bands. We show that, compared to LTE-FDD systems, LTE-TDD systems are much less widely deployed, are more complicated to deploy, lead to relatively smaller cells to attain the same target cell-edge throughput as LTE-FDD systems, and cannot fully exploit certain LTE-Advanced features. We further show that, in a 600 MHz deployment, LTE-TDD systems would result in harmonics that interfere with other mobile bands (*e.g.*, a PCS band), would produce fewer spectrum blocks for mobile licensed use, and would interfere with LTE-FDD systems operating in the 600 MHz band. We next address several guard band (including duplex gap) issues. First, we explain why the duplex gap should be no smaller than 10-12 MHz and no larger than 15 MHz. Second, we discuss why unlicensed operations in the duplex gap should be permitted only if they would not cause interference to licensed spectrum and only if they are required to accept all interference from licensed users. Third, we explain that the size of the guard bands needed to protect licensed mobile services from interference due to television stations using adjacent frequencies depends on several factors, and that the licensed uplink spectrum will require a guard band of at least 6 MHz, and the licensed downlink spectrum will require a guard band ranging from at least 6 MHz (when located adjacent to television stations operating at 50 kW or less) up to 10-14 MHz (when located adjacent to television stations operating at or near 1 MW).

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1. EXECUTIVE SUMMARY.

In our initial paper[3] we analyzed the lead band plan framework set forth in the Federal Communications Commission's ("FCC") NPRM,[4] and we provided a set of core principles that, if adhered to, could dramatically improve that framework. Several other commenters, including, for example, the National Association of Broadcasters, Qualcomm, T-Mobile, Intel, and Verizon, agreed with these core principles.[5] In this paper, we provide further analyses related to four specific band plan-related issues.

1. *No LTE-TDD in 600 MHz.* As we show below, the Commission should not permit the 600 MHz spectrum to be repurposed for mobile wireless use. First, in bands where multiple providers are expected to be providing service, such as in the 600 MHz band, the use of LTE-TDD would necessitate substantial coordination among all of the network operators using those bands to avoid harmful interference that would otherwise occur. Such coordination would significantly increase the costs of deploying services and introduce substantial uncertainties as to the extent to which the repurposed spectrum will be impaired by interference. Second, LTE-TDD networks typically require relatively smaller cells to achieve the same target cell-edge throughput as LTE-FDD networks in coverage-driven deployments. Furthermore, for a given cell size of a macro cell or micro cell, the cell-edge throughput would be smaller for LTE-TDD than LTE-FDD. Third, deployment of LTE-TDD spectrum in the 600 MHz bands would result in harmonics that, as we discussed in our initial paper, can cause significant interference to PCS and other frequency bands. Fourth, due to the need for more guard bands for LTE-TDD systems, various likely auction scenarios would end up allocating significantly less spectrum for mobile use if LTE-TDD is permitted. Fifth, incorporating LTE-TDD into the 600 MHz bands would limit provider's ability to fully exploit certain LTE-Advanced features that can significantly enhance network performance and user experience. Sixth, a mixed LTE-FDD and LTE-TDD approach would not only have all of the problems summarized above, but it would require additional guard bands between TDD spectrum and FDD spectrum to ensure satisfactory network performance, and it would result in significant co-channel interference when some base stations or eNodeBs use LTE-TDD while nearby eNodeBs use LTE-FDD in the same spectrum block.

2. The size of the duplex gap. The duplex gap is a guard band between the paired uplink and downlink frequencies in a FDD network that is needed to prevent interference between uplink

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[3] *See* Jeffrey Reed and Nishith Tripathi, *The 600 MHz Spectrum Auction: An Analysis Of The Band Plan Framework*, attached as Exhibit A to Comments of AT&T Inc., *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268 (Jan. 25, 2013) ("Reed-Tripathi Initial Paper").

[4] *See* Notice of Proposed Rulemaking, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, 27 FCC Rcd. 12357 (rel. Oct. 2, 2012) ("NPRM").

[5] *See, e.g.,* Letter From AT&T, Intel, National Association of Broadcasters, Qualcomm, T-Mobile, & Verizon Wireless to FCC, GN Docket No. 12-268 (filed Jan. 24, 2013).

and downlink signals. Google and Microsoft have suggested that the duplex gap should be as large as 28 MHz.[6] As we show below, based on fundamental wireless engineering principles and significant input from AT&T and AT&T's vendors (including chipset and device manufacturers), the duplex gap should be at least 10-12 MHz wide, but it should not exceed 15 MHz. A smaller duplex gap would raise significant interference concerns and reduce achievable throughput, and a larger duplex gap would raise significant practical implementation concerns and could reduce the amount of paired spectrum available for licensed mobile broadband use.

3. *Unlicensed Services In The Duplex Gap.* The FCC should permit unlicensed services to be operated in the duplex gap only if two conditions are met: (1) the unlicensed users must operate in a manner that fully protects licensed users from interference and (2) unlicensed users must accept any interference that may occur from licensed operations. These conditions are necessary to avoid subjecting spectrum located near the duplex gap to impairments that would decrease its value to providers and consumers by reducing capacity and quality. These conditions are also necessary to facilitate the FCC's goal of creating fungible paired spectrum blocks, by ensuring that spectrum near the guard bands is not subject to more interference than spectrum located farther from the guard bands. The precise restrictions that would have to be placed on unlicensed users in the duplex gap will depend significantly on the specifics of any contemplated unlicensed services. Among other things, the appropriate restrictions will depend on whether the services are uplink or downlink or both, power levels, band size, geographic locations, and filter performance. Accordingly, whether any particular unlicensed service should be permitted to operate in the duplex gap, and the limitations on that service needed to protect licensed users, must be assessed after it is clear what services are being considered for operation in the duplex gap.

4. *The size of the guard bands.* The size of the guard bands needed to protect licensed mobile services from interference due to television transmissions operating in adjacent frequencies is different for uplink and downlink mobile spectrum. It will also vary depending on the power level of the adjacent television stations. For these reasons, until there is a more established band plan framework, it is not possible to predict with certainty the precise size that will be needed for the guard bands to protect against interference. However, based on past testing in the 700 MHz frequencies, and analyses conducted by AT&T and its vendors, we can provide some general guidelines. In particular, based on the tentative analyses that have been conducted by device manufacturers and equipment vendors, the guard band between the downlink of the mobile spectrum and full powered (*i.e.*, 1 MW) television channels should be at

[6] *See* Comments of Google Inc. And Microsoft Corporation, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 37 (Jan. 25, 2013) ("Google-Microsoft Comments").

least 10-14 MHz, and the guard band between the downlink of the mobile spectrum and lower powered television channels (*i.e.*, 50 kW and lower) should be at least 6 MHz.[7]

2. LTE-FDD Versus LTE-TDD Systems.

Long Term Evolution Frequency Division Duplex ("LTE-FDD") is by far the dominant LTE technology worldwide. 4G Americas reported in September 2012 that, of the 100 LTE deployments worldwide, only 9 are Time Division Duplex LTE ("LTE-TDD") systems.[8] In the U.S., all of the LTE networks that have been commercially deployed to date use FDD. The Commission has thus quite understandably focused its 600 MHz band plan on making additional spectrum available for LTE-FDD. It is our understanding, however, that Clearwire is planning to deploy an LTE-TDD system in the U.S. using Band 41 (2.5 GHz spectrum). Although Clearwire owns more than enough TDD Band 41 spectrum for such a deployment (more than 160 MHz in the top 100 markets),[9] Clearwire and its principal owner, Sprint, have asked the Commission to consider a band plan framework for 600 MHz spectrum that would allocate all or part of the spectrum for LTE-TDD. For the reasons set forth below, we believe that the Commission should not permit LTE-TDD use in the 600 MHz spectrum bands.

2.1 Significant And Costly Coordination Would Be Required For An LTE-TDD Band Plan In The U.S. 600 MHz Frequencies.

LTE-FDD systems allocate separate spectrum for uplink (*i.e.*, mobile device transmit and base station receive) and downlink (*i.e.*, base station transmit and mobile device receive). As a result, LTE-FDD band plans are designed to ensure that no two providers will be operating in a manner such that the base station (*i.e.*, "eNodeB") of one provider is transmitting in frequencies that are adjacent to the receive frequencies being used by another provider's eNodeB, thus avoiding adjacent channel interference ("ACI") between the two systems resulting from significantly different uplink and downlink power levels.

By contrast, in LTE-TDD systems, any spectrum within the licensed frequencies can, in general, be used for either transmitting or receiving signals at any given time. As a result, where two providers are operating LTE-TDD systems in the same geographic area using adjacent spectrum, there is significant potential for ACI between the two systems. That is, there is significant

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[7] In the scenarios where the uplink mobile spectrum is located next to the TV channel (*e.g.*, due to different markets clearing different amounts of spectrum), a minimum guard band of 6 MHz is recommended based on the experience with AT&T's 700 MHz Band 17 networks.

[8] Press Release, 4G Americas, 4G Americas Reports 100 Commercial LTE Networks in 49 Countries, http://www.marketwire.com/press-release/4g-americas-reports-100-commercial-lte-networks-in-49-countries-1699482.htm.

[9] Phil Goldstein, *Sprint's Hesse Looks Beyond Clearwire for Spectrum Purchases,* FierceWireless, Feb. 20, 2013, http://www.fiercewireless.com/story/sprints-hesse-looks-beyond-clearwire-spectrum-purchases/2013-02-20.

potential that the eNodeB of one LTE-TDD system will be transmitting in frequencies that are adjacent to the frequencies that a nearby eNodeB is using to receive signals at a given instant. In such circumstances, the signal from the transmitting LTE-TDD eNodeB will interfere with the other LTE-TDD eNodeB's ability to reliably receive the desired uplink signals, resulting in reduced throughput or lost connections.

Figure 1 illustrates the ACI between the eNodeBs of different TDD service providers operating in the same geographic area, where the operators have not synchronized timings and other LTE parameters.

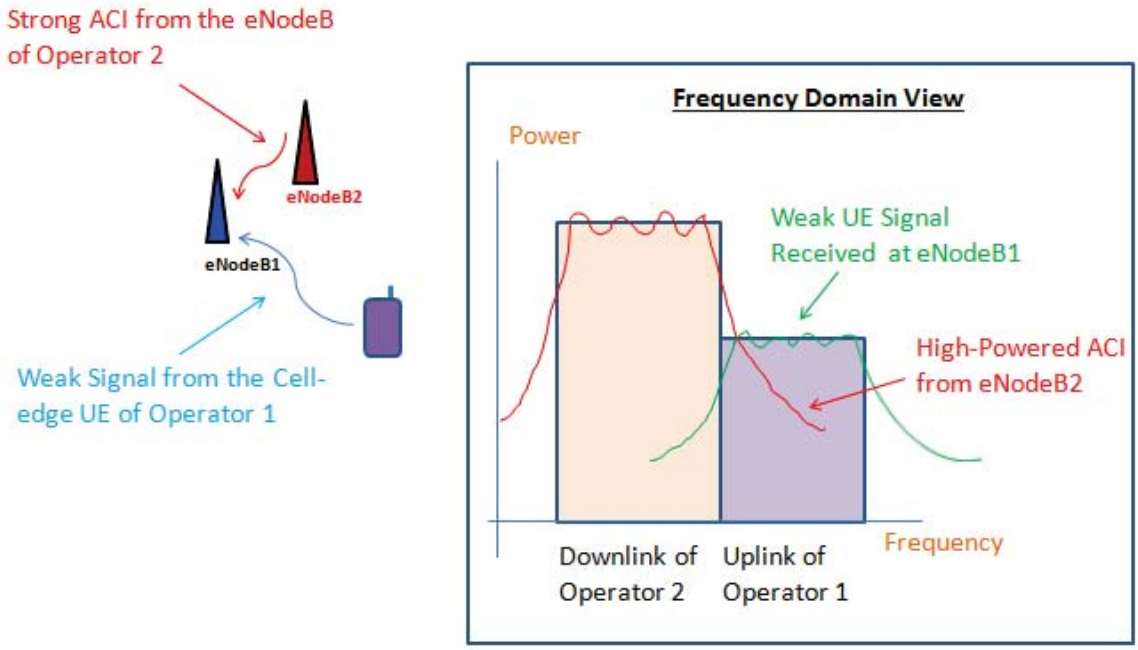

Figure 1. eNodeB-to-eNodeB Adjacent Channel Interference in LTE-TDD Systems

In Figure 1, the eNodeB1 of Operator 1 is trying to receive a weak signal from its customer's user equipment ("UE"). The eNodeB2 of another operator is located close to eNodeB1. Hence, the power level of the interfering signal is quite strong compared to the desired signal from the UE that the eNodeB1 is attempting to retrieve. At a given instant, Operator 1's uplink coincides with Operator 2's downlink, causing severe eNodeB-to-eNodeB ACI. As shown in the frequency domain view, the interfering signal could be quite high compared to the desired signal, especially when the UE is near the cell edge and the two eNodeBs are located close to each other.

This interference can be severe due to the wide disparity of the transmit power levels of the eNodeBs and the UEs. The maximum effective transmit power for an LTE UE is 23 dBm.[10] If

[10] LTE has defined Power Class 3 for traditional UEs. This power class corresponds to the maximum transmit power of 23 dBm. *See* 3GPP, TS 36.101, User Equipment (UE) Radio Transmission and Reception, Release 11, Version V11.2.0, September 2012.

there is another eNodeB nearby that is transmitting in frequencies that are adjacent to the frequency being used by the UE, significant ACI can occur because the eNodeB could easily be transmitting at effective power levels that exceed 45 dBm, far exceeding the 23 dBm of a UE. As a result, the interfering signal caused by the nearby transmitting eNodeB can easily overwhelm the signal of a UE at the receiving eNodeB, thus making it more difficult or impossible for such receiving eNodeB to retrieve the desired signal from the UE.

Figure 2 shows the ACI from one UE to another UE in case of different TDD service providers operating in the same geographic area, where the operators have not synchronized the timings and other parameters.

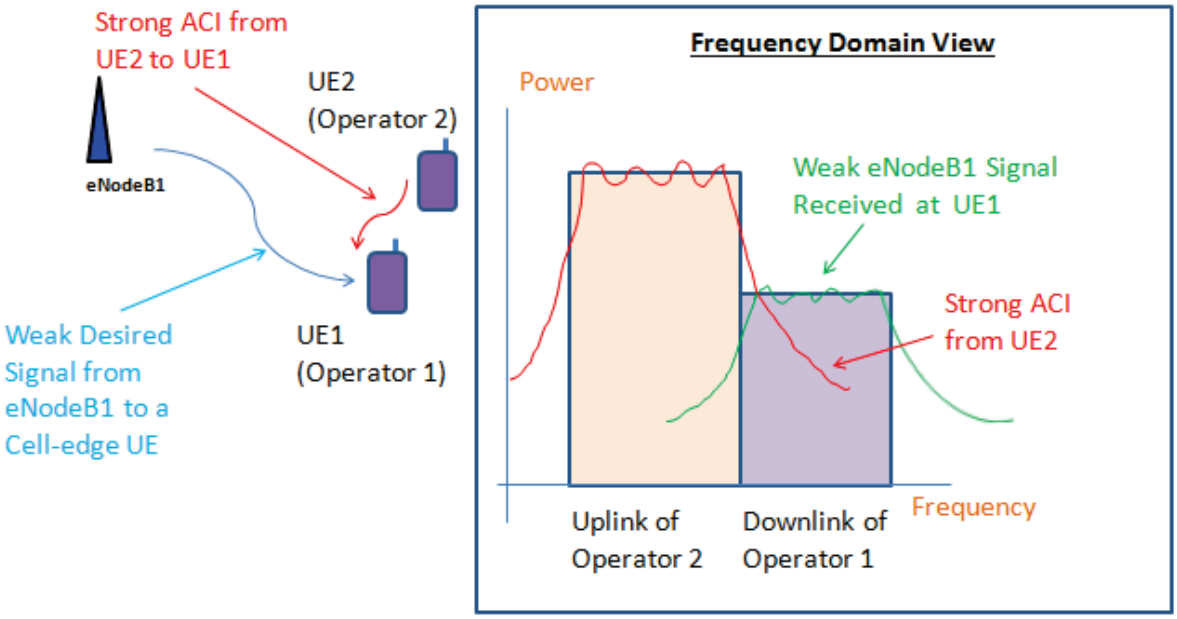

Figure 2. UE-to-UE Adjacent Channel Interference in LTE-TDD Systems

In Figure 2, the eNodeB1 of Operator 1 is sending the desired signal to its UE1. UE2 of another operator is located close to such UE1. Hence, the power level of the received interfering signal is quite strong compared to the received desired signal at UE1 that UE1 is attempting to retrieve. At a given instant, Operator 1's downlink coincides with Operator 2's uplink, causing severe UE-to-UE ACI. As shown in the frequency domain view for the received signals, the interfering signal could be quite strong compared to the desired signal, especially when the UEs are near the cell edge, because one UE's desired signal would be quite low and the interfering UE would be transmitting close to its maximum transmit power.

In areas where only one network operator is using an LTE-TDD system, that operator can design its network to avoid ACI among its own eNodeBs via a suitable timing configuration that is the same for all eNodeBs. However, where there are multiple operators using LTE-TDD systems in adjacent spectrum frequencies, each operator's LTE-TDD network would be subject to ACI from all other operators' LTE-TDD networks. As a result, a very significant level of coordination

among operators is necessary to avoid ACI. This difficulty is likely one reason why there are so few areas around the world where more than one LTE-TDD network is operating in a given frequency band.

It is our understanding that the U.S. 600 MHz spectrum is expected to be licensed to multiple network operators. Therefore, if the 600 MHz bands in the U.S. were allocated for LTE-TDD, significant coordination would be necessary among the 600 MHz spectrum licensees.

In such circumstances, there would essentially be two ways to mitigate the ACI among different LTE-TDD systems. The first approach would be to design an LTE-TDD band plan that places significant guard bands between the blocks of the LTE-TDD spectrum, thus minimizing the potential for ACI. But this approach is not practical because it would substantially reduce the overall amount of spectrum that could be put to use for mobile broadband services (a large part of the spectrum would have to be set aside as guard bands).[11]

The second approach would be for LTE-TDD operators to coordinate their networks in a manner that avoids ACI to and from other LTE-TDD networks using the adjacent spectrum. Before discussing how this coordination could be done, it is important to recognize, that this coordination must occur among all LTE-TDD providers using adjacent spectrum in a given area. If one LTE-TDD carrier does not participate in the coordination scheme, that carrier's system will interfere with (and be subject to interference from) the other LTE-TDD operators in the area.

To understand how operators in a multi-operator LTE-TDD environment must coordinate their systems, it is useful to begin by reviewing how LTE-TDD systems work in general. In TDD systems, transmissions are divided into time segments that are transmitted over a given frequency at specified times (measured in milliseconds). The receiver, by coordinating with the transmitter, knows which time segments contain the information it is attempting to receive, and the receiver is thus able to reconstitute the data that was transmitted to it. In Figure 3, below, we illustrate a simplified timing structure for an LTE-TDD system.

[11] *See also* Comments of Nokia Siemens Networks US LLC, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 12 (Jan. 25, 2013) ("Nokia Siemens Comments").

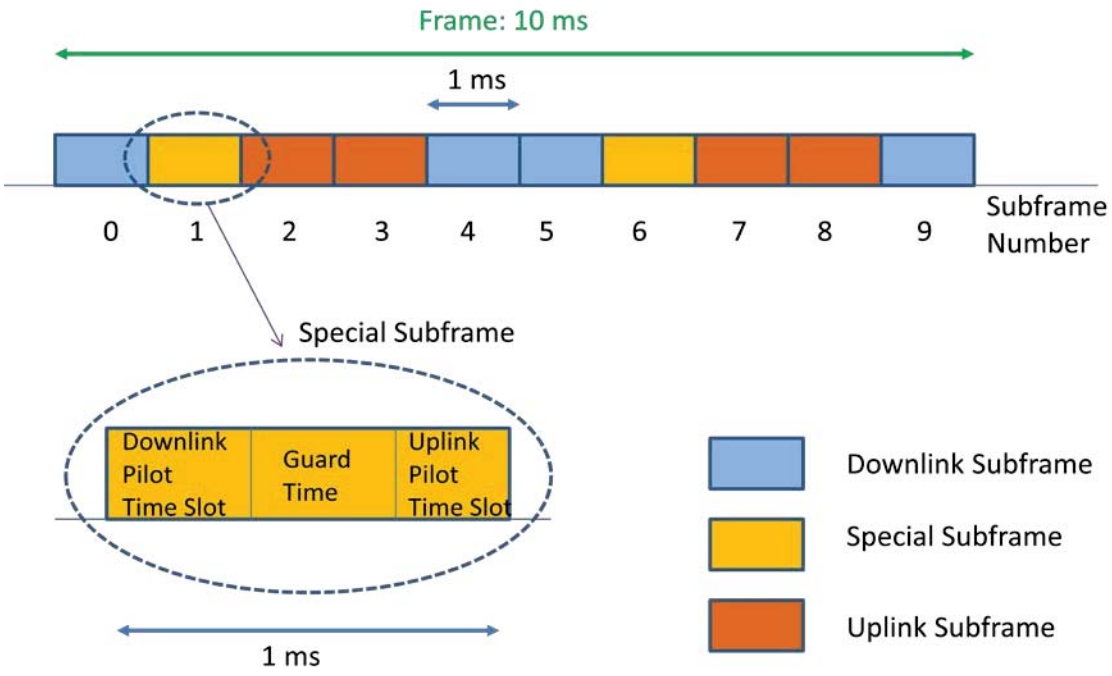

Figure 3. Example Timing Structure of an LTE-TDD System[12]

As Figure 3 illustrates, LTE-TDD systems use 10 millisecond (ms) time periods called "frames." Each frame is subdivided into ten 1 ms time periods called "subframes," and subframes are numbered from 0 to 9. A subframe could contain a downlink transmission, an uplink transmission, or a "special" transmission. A downlink subframe carries the downlink traffic and signaling messages from the eNodeB to the UE(s) and conveys both the downlink resource allocations and the uplink resource allocations. An uplink subframe carries the uplink traffic and uplink signaling messages from the UE(s) to the eNodeB.[13] A "special" subframe facilitates switching from downlink to uplink.[14]

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[12] The LTE standard allows several possible timing structures for TDD. Figure 3 shows one of the supported configurations (*i.e.*, the "subframe assignment 1"). The same principles apply to other configurations.

[13] The uplink subframe also allows the UE(s) that do not have a dedicated radio connection with an eNodeB to use a common random access channel to contact the eNodeB.

[14] As shown in Figure 3, the special subframe includes a downlink portion called the downlink pilot time slot, a guard time, and an uplink portion called the uplink pilot time slot. The downlink pilot time slot includes the primary synchronization signal to facilitate downlink synchronization by the UEs and allows the flexibility to carry downlink traffic and downlink signaling messages. The guard time enables an entity (*e.g.*, an eNodeB) to stop transmitting and to prepare to receive. The uplink pilot time slot may contain (i) reference signals that enable the eNodeB to estimate uplink channel conditions before the regular uplink

With this general understanding of LTE-TDD systems, it is easy to see how the ACI discussed above will occur. The subframes described above are transmitted in the frequencies used by the LTE-TDD network operator. Absent coordination, when two LTE-TDD network operators are using adjacent spectrum, one operator may allocate certain subframes to uplink, while the other system allocates the same subframes to downlink. In this situation, one carrier's eNodeB would be attempting to receive at the same time that the other carrier's eNodeB is attempting to transmit in an adjacent frequency, thus causing ACI.

To avoid this interference, the LTE-TDD operators must tightly coordinate their networks to ensure that they are always either all transmitting or all receiving at any given time.

This coordination is complex. To begin with, all of the LTE-TDD network operators must agree on a framework for determining the time to ensure that the timing of their 10 ms frames and 1 ms subframes are the same. A typical approach is for the operators to agree on the use of an accurate and common timing mechanism, such as a Global Positioning System ("GPS") and to agree when to start a given frame and subframe based on the GPS-based time.

Once the frame and subframe timings are agreed upon, the operators must ensure that they use the same settings for certain operational parameters. For example, the operators need to agree on which subframes to use as the downlink subframes and which subframes to use as the uplink subframes. In this regard, the operators must agree to use the same ratio of downlink subframes to uplink subframes so that the downlink (or uplink) subframes for all TDD operators occur at the same time. The TDD eNodeB advertizes the downlink/uplink ratios in a System Information Block 1 message via a parameter called "subframe assignment" or "sa." For example, in case of subframe assignment = 1, subframes 1 and 6 are special subframes, subframes 0, 4, 5, and 9 are downlink subframes, and subframes 2, 3, 7, and 8 are uplink subframes. Such a configuration corresponds to the downlink/uplink ratio of 6:4, where 6 is the effective number of downlink subframes (which is the sum of the number of regular downlink subframes and two special subframes) and 4 is the number of uplink subframes. Seven different downlink/uplink ratios or subframe assignments are supported in LTE-TDD.[15]

The need for all of this coordination to avoid ACI among LTE-TDD systems can significantly increase the cost and uncertainty associated with spectrum allocated for use in LTE-TDD systems as compared to spectrum allocated for use in LTE-FDD systems.

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transmissions start from the UE(s) or (ii) random access opportunities that are useful for small cells.

[15] Operators also have to agree upon common values for various special subframe parameters, including (1) the length of downlink pilot time slot; (2) the guard time; and (3) the length of the uplink pilot time slot. There are nine special subframe patterns that specify different durations for the downlink portion, the guard time, and the uplink portion. The TDD eNodeB advertizes the special subframe configuration in the System Information Block 1 message via a parameter called "special subframe pattern (ssp)."

There will likely be significant transaction costs associated with achieving the coordination that is necessary in LTE-TDD systems that are not required for LTE-FDD systems. As noted, if 600 MHz spectrum were allocated for use in LTE-TDD systems, each operator that uses 600 MHz spectrum will have to coordinate with all the other operators using 600 MHz spectrum to avoid ACI. Negotiating and attaining these agreements will require human resources, financial resources, and likely significant time. In addition, disputes may arise that may need to be resolved through actions by the FCC or in courts.

To further complicate matters, each provider may have to negotiate such coordination with different sets of other providers in each area. For example, "Provider A," may have to coordinate with "Provider B" and "Provider C" in New York, but with "Provider D" and "Provider E" in Chicago.

Furthermore, operators will have to frequently update their coordination arrangements to the extent they wish to alter the coordination parameters, including, for example, the downlink-to-uplink ratio.

The need to coordinate with multiple other providers and different sets of providers throughout the U.S. would also add significant uncertainty as to the actual amount of expected interference to any provider that purchases 600 MHz LTE-TDD spectrum. When assessing the value of 600 MHz spectrum allocated for LTE-TDD systems – and hence auction bids – potential bidders must account for the fact that they may not be able to reach coordination arrangements (or that it will take significant time and resources to reach coordination agreements) with other operators in at least some areas, thus significantly impairing the usefulness of the spectrum.

In addition, to reach coordination agreements with all other 600 MHz LTE-TDD operators in a given area, at least some operators will likely have to settle for sub-optimal coordination arrangements. As discussed above, any successful coordination arrangement must include agreement on the subframe downlink/uplink ratio, which effectively dictates the relative downlink/uplink capacity in a network. If one carrier desires substantially more downlink capacity in its network and another carrier desires significantly less downlink capacity (and correspondingly more uplink capacity), any coordination agreement will require one or both of the providers to agree to a sub-optimal uplink/downlink ratio for their network. Such a conflict of interest may arise due to the different traffic demands of different operators.

For all of these reasons, it is our view that operators would place substantially lower value on 600 MHz spectrum if it were allocated for use in LTE-TDD systems than if it were allocated for use in LTE-FDD systems.

We disagree with the assertions made by Sprint and Clearwire that LTE-TDD systems would not necessarily raise costs and uncertainty compared to LTE-FDD systems. Sprint, for example, states that in some instances even LTE-FDD operators must coordinate with each other to avoid interference. But neither Sprint nor any other commenter that addresses LTE-TDD systems

suggests that the level of LTE-FDD coordination comes even close to the level of coordination that is needed for LTE-TDD systems.

More fundamentally, Sprint's observation that even LTE-FDD providers may sometimes engage in some coordination is irrelevant to the 600 MHz spectrum at issue here. The Commission can, and should, adopt a 600 MHz LTE-FDD band plan that avoids potential inter-provider interference, and thus avoids the need for any significant coordination among providers. And particularly to the extent that package bidding and block assignment processes provide horizontal frequency contiguity, the LTE-FDD band plans proposed by the FCC and other parties to this proceeding obviate the need for any significant coordination among the FDD operators. By contrast, any LTE-TDD band plan would necessarily require the significant coordination described above (unless the FCC chooses to set aside very large amounts of spectrum as guard bands between each operator's licensed spectrum, which would lead to much less amount of usable licensed spectrum).

Sprint and Clearwire assert that LTE-TDD systems are typically more flexible than LTE-FDD systems. Sprint and Clearwire suggest that LTE-TDD operators can easily adjust the relative times being used for uplink and downlink – and hence relative uplink and downlink capacity – to account for changes in how consumers use mobile services. They state that LTE-FDD, by contrast, is inflexible in this regard due to the fact that specific spectrum is allocated for uplink and downlink.

This is simply not accurate in a multiple LTE-TDD operator environment. First, for practical deployments, it is not correct that an operator can dynamically change the uplink/downlink ratio in a particular eNodeB (or even a cell), to match consumer traffic patterns at that eNodeB. As we explained above, within any operator's network, all eNodeBs must use the same uplink/downlink ratios. Thus the uplink/downlink ratio must essentially be changed on all eNodeBs in an area or none of them. Furthermore, it is not true that an LTE-TDD operator would be able to easily and unilaterally alter the uplink/downlink ratio even for all of its own eNodeBs. As discussed above, each operator in an area must use the same uplink/downlink ratio. We note that Sprint expressly recognizes in a footnote that "TDD operators must agree on asymmetry ratios and synchronize their transmissions in order to avoid adjacent-channel interference in the absence of guard bands," which it concedes is a "disadvantage of TDD."[16] Therefore, if an operator seeks to change that ratio for its network, it must obtain the agreement of all other operators in the area(s) where it wishes to make that change. And there will always be uncertainty as to whether the other operators would agree to make that change, especially if other operators are experiencing different traffic patterns.

Sprint and Clearwire also overlook the fact that LTE-FDD networks are becoming increasingly flexible in terms of the relative amount of uplink and downlink capacity. Although commercial

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[16] Comments of Sprint Nextel Corporation, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 20 n.40 (Jan. 25, 2013).

LTE-FDD deployments typically use symmetric downlink channel bandwidth and uplink channel bandwidth today, the 3GPP standards have supported asymmetric channel bandwidths for the downlink and the uplink from the first LTE release (*i.e.*, Release 8). Carrier aggregation in LTE-Advanced further facilitates higher degrees of asymmetry by allowing different numbers of carrier frequencies and different amounts of channel bandwidths for the downlink and the uplink. In fact, asymmetric carrier aggregation with more resources in the downlink and fewer resources in the uplink would be quite common in practical LTE-Advanced deployments. LTE characteristics (applicable to both FDD and TDD) such as adaptive modulation and coding, fast feedback about channel conditions, multiple antenna techniques, fast scheduling, and hybrid automatic repeat request (H-ARQ) provide additional flexibility to meet the QoS requirements of different users and different applications in the downlink and the uplink.

Finally, we note that a TDD band plan would require more coordination effort for the LTE-TDD operators with TV broadcasters to manage co-channel interference in adjacent markets than an FDD band plan. In TDD operations, one would have to define exclusion zones based on acceptable levels of interference to both base stations and mobile devices, and in a typical deployment, the worst case scenario (*i.e.*, the larger exclusion zone) will dictate the network design. In an FDD band plan, the operator would be concerned with *either* protecting base station receiver (for uplink) or mobile receiver (downlink) but not both at the same location. Combined with the fact that different markets will clear different amounts of spectrum, the network design in an LTE-TDD band plan would be significantly more challenging compared to an LTE-FDD band plan.

2.2 LTE-TDD Systems Have Smaller Cells or Lower Cell-edge Throughput.

Another significant disadvantage of LTE-TDD systems compared to LTE-FDD systems is that LTE-TDD systems typically require smaller cells to attain the same target cell edge throughput.[17]

To understand why this is so, it is useful first to review the difference in the number of physical resource blocks ("PRBs") needed by LTE-FDD and LTE-TDD systems to transmit the same amount of data in the same amount of time. In an LTE system, each 5 MHz block of spectrum has 25 PRBs that can be used to transmit or receive data. All else being equal, the amount of data that can be transmitted in any given time increases with the number of PRBs allocated to the transmission.

Now, consider an LTE-FDD system that can complete a data file transmission in 10 seconds using 5 PRBs. All else being equal, a LTE-TDD system could not complete the same data file transmission in the same time using only 5 PRBs. To see this, consider a LTE-TDD system that is designed with a 50:50 uplink/downlink ratio, which means that, unlike the continuously transmitting LTE-FDD system, it uses only half of its time transmitting and the other half of its

[17] *See* Harri Holma and Antti Toskala, *LTE for UMTS: Evolution to LTE-Advanced* (2d ed. 2011); Angel Ivanov, *TD-LTE and LTE-FDD- A Basic Comparison*, Ascom Document: NT11-1036 (Jan. 12, 2012).

time receiving. Using 5 PRBs, this LTE-TDD system would require twice the time to transmit the same data file compared to the LTE-FDD system. Therefore, to achieve the same performance as an LTE-FDD system, the LTE-TDD system must allocate more PRBs to the transmission. In this example, the LTE-TDD system might need to allocate 10 PRBs (*i.e.*, twice the number of PRBs used by the LTE-FDD system) to achieve the same average data transfer rate as the LTE-FDD system. Since an LTE-TDD system has twice as many PRBs as an equivalent LTE-FDD system, both systems appear to have similar average throughput when the LTE-TDD has 50% downlink and 50% uplink.

With this backdrop, however, it is easy to see why an LTE-TDD system requires smaller cells to achieve the same cell edge throughput as an LTE-FDD system, all else being equal. Consider the uplink cell-edge throughput first. The maximum available transmit power for a UE is 23 dBm. This power is spread equally over each of the PRBs being used in a transmission. As a result, the greater the number of PRBs used in a transmission, the lower the transmission power levels per PRB. In other words, the power spectral density (*i.e.*, power per Hz) is lower when more resource blocks are used. Hence, to achieve the same reliability of successful packet retrieval, the propagation path loss between the eNodeB and the UE needs to be smaller when more PRBs are used. Thus, all else being equal, a UE that is transmitting over a larger number of PRBs must be closer to the base station to achieve the same throughput and reliability as a UE that is transmitting using fewer PRBs (and that is at a larger distance from the eNodeB).

LTE-TDD systems are likewise disadvantaged for downlink. Consider the downlink throughput near the cell-edge. For a given maximum power level at the eNodeB, the power per PRB is smaller for an LTE-TDD system because the LTE-TDD system requires more PRBs than an LTE-FDD system to achieve the same data-rate. The supportable throughput per PRB is thus smaller for the LTE-TDD system compared to the LTE-FDD system in areas farther away from the eNodeB. Hence, after accounting for the uplink/downlink ratios, the LTE-FDD system will generally yield higher cell-edge throughput in the downlink than the LTE-TDD system.

2.3 Harmonics.

An allocation of 600 MHz spectrum for LTE-TDD could also result in harmonics that interfere with mobile services using PCS spectrum, as well as other wireless services spectrum. As we explained in our first paper, transmissions in the frequency range from 643-665 MHz would create third order harmonics that fall within the receive bands for PCS spectrum, and thus would interfere with PCS mobile services. We note that Qualcomm's analysis of harmonics generated by transmissions in these frequencies supports our conclusions.[18]

Allocating these frequencies from 643-665 MHz to LTE-TDD, as Sprint proposes, would result in exactly this type of harmful interference. As noted, LTE-TDD can transmit or receive in any of

[18] Comments of Qualcomm Incorporated, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 6-7 (Jan. 25, 2013) ("Qualcomm Comments").

its allocated frequencies. Thus, when LTE-TDD systems transmit in the 643-665 MHz frequencies, it will result in harmonics that fall within the receive frequencies for the PCS spectrum. For this reason, Alcatel-Lucent states that "it is not recommended that TDD operate at 1/3 the PCS downlink band (643 to 665 MHz) . . ."[19] For these reasons, we proposed that the Commission's 600 MHz band plan framework avoid allocating these frequencies to the uplink.

Although the exact impact of this interference cannot be fully quantified without real-world testing across a multitude of devices, it is a significant risk. This harmonic interference can be problematic for a dual receiver or dual-transceiver UE supporting simultaneous operations on the 600 MHz band and the PCS band. For example, when a TDD UE is transmitting on a 600 MHz band, it may also be listening to a PCS band for a legacy network to receive an incoming page message from a 3G 1xRTT system or to make measurements of a 3G PCS system for an impending handover to the PCS band. Reception of the PCS band signal would be adversely affected by the 600 MHz transmission, leading to possibly missed page messages and delayed handover (increasing the likelihood of a call drop). Similarly, when a 600 MHz LTE-TDD UE is in close proximity to a PCS band UE, the harmonic transmission from the 600 MHz UE may cause significant interference to the PCS band UE. Alcatel Lucent has pointed out that a similar interference situation has been observed in the field, where a 700 MHz UE has caused harmonic interference to an AWS band UE.[20]

2.4 Less Overall Spectrum.

Allocating the 600 MHz spectrum in the U.S. to LTE-TDD would result in less overall spectrum being allocated for mobile broadband services. As Alcatel-Lucent points out, two significant guard bands of at least 10 MHz each on both sides of the TDD band (*e.g.*, a TV channel or Channel 37 on one side and the 700 MHz uplink on the other side) would be needed to protect the TDD systems and the systems adjacent to the TDD systems. These guard bands alone thus eliminate 20 MHz of spectrum from licensed mobile use. In addition, as noted, Alcatel-Lucent recommends not using spectrum in the 643-665 MHz range for uplink to avoid creating harmonics that interfere with PCS and other services.

Thus, for example, in areas where the auction clears all of the spectrum above Channel 37 for mobile broadband services, there would be 84 MHz of available spectrum. As we demonstrated in our prior paper, with appropriate guard bands, an FDD-system could efficiently allocate at least 70 MHz of this spectrum for mobile use. By contrast, as Alcatel-Lucent points out, an LTE-TDD system could allocate at most 64 MHz for mobile broadband use, due to the need for guard bands to protect Channel 37 and 700 MHz FDD systems.[21] Moreover,

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[19] Comments of Alcatel-Lucent, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 11 (Jan. 25, 2013) ("Alcatel-Lucent Comments"); *See also,* Nokia Siemens Comments, at 13.

[20] *See* Alcatel-Lucent Comments, at 13-14.

[21] *See id.* at 11.

if the Commission were to also avoid allocating frequencies from 643-665 MHz to LTE-TDD, that would further reduce the amount of usable licensed mobile spectrum under a LTE-TDD allocation to 42 MHz – far less than the 70 MHz that would be available under the LTE-FDD plan presented in our initial paper.[22]

2.5 Other Considerations: Implications for Upcoming Enhancements for LTE Networks and Ecosystems.

As the FCC has correctly pointed out in the NPRM, LTE is the expected technology of choice for the 600 MHz deployments. While LTE-Advanced allows carrier or spectrum aggregation of multiple channels across different frequency bands to significantly increase peak and average throughput, such aggregation is feasible (i) within FDD bands or (ii) within TDD bands but not for a hybrid TDD-FDD situation. In other words, the LTE-FDD networks will not be able to exploit the carrier aggregation capability offered by LTE-Advanced to combine the 600 MHz TDD band with an existing FDD band such as the PCS band or the AWS band, significantly limiting user and network throughput relative to networks that can take advantage of these technology advances and hence reducing the value of the band to bidders since they could not do carrier aggregation with that 600 MHz TDD band.

Heterogeneous Networks (HetNets) represent another area where LTE-Advanced can improve network performance and the user experience. HetNets combine the benefits of large macrocells and small cells and enable high cell-edge throughput via more frequent reuse of precious radio resources in small cells. Features such as enhanced inter cell interference coordination (eICIC)[23] and further enhanced ICIC (FeICIC)[24] facilitate deployment of HetNets. The deployment of small cells[25] would be much more challenging for TDD due to the need for strict timing requirements across all the cells. FDD can circumvent such deployment challenges by using one frequency channel for all macrocells and a separate frequency channel for all of the small cells (that do not need timing coordination).

Channel reciprocity is frequently cited as an advantage of TDD systems compared to FDD systems, where the eNodeB can simply observe the uplink to reliably predict the downlink

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[22] *See* Reed-Tripathi Initial Paper, at 29.

[23] eICIC facilitates coordination between the macrocells and small cells via time domain scheduling of resources to minimize interference between the macrocells and small cells when the same radio channel (*e.g.*, in time domain) is used in microcells and small cells. Another way to minimize interference between the macrocells and small cells is to use different radio channels (*i.e.*, one channel for a macrocell and a different channel for a small cell).

[24] FeICIC involves interference cancellation at the UE receiver based on the knowledge of the time-frequency location of the cell-specific reference signals.

[25] Smalls cells could be femtocells in homes or somewhat larger cells such as pico cells and micro cells that could cover one or more buildings. *See* Small Cell Forum, http://www.smallcellforum.org/.

channel conditions. Such channel reciprocity is possible in TDD systems because the same spectrum is used for the uplink and the downlink. FDD systems require feedback from the UE on the downlink channel conditions, while TDD systems could theoretically avoid the need for such feedback. However, with the use of multiple antenna techniques such as spatial multiplexing in the current and emerging LTE deployments, TDD systems no longer hold any significant channel reciprocity advantage compared to FDD systems, because the number of antennas at the eNodeB and the UE are different. For example, for (2x2) downlink MIMO to work properly, the UE needs to estimate downlink channel conditions on a total of four propagation paths. The UE in current deployments, however, transmits from only one antenna and the eNodeB receives signals on two antennas, leading to reliable estimation of channel conditions on only 2 propagation paths. Since the channel conditions on 2 uplink propagation paths are not adequate to estimate downlink channel conditions on four propagation paths, the claimed channel reciprocity advantage of TDD systems compared to FDD systems is essentially non-existent in modern deployments.[26] The asymmetry in the number of antennas at the eNodeB and the UE is expected to persist in future deployments as well, because LTE-Advanced also defines more transmit antennas at the eNodeB and fewer transmit antennas at the UE. Finally, limited space in the UE (compared to the eNodeB) would very likely result in more antennas at the eNodeB and fewer antennas at the UE.

2.6 Additional Interference & Coordination Challenges In A Mixed TDD/LTE-FDD Environment.

Clearwire states that 600 MHz spectrum should be allocated with maximum flexibility so that providers can choose whether to use it for LTE-FDD or LTE-TDD. We respectfully disagree with this approach. We recommend that the FCC limit the use of 600 MHz spectrum to LTE-FDD services because, in addition to the interference and coordination challenges associated with LTE-TDD deployments (discussed above), a mixed TDD and FDD environment would create additional significant interference concerns.[27]

First, a mixed TDD and FDD environment would create significant potential for co-channel interference. We explained co-channel interference in our initial paper. In short, co-channel interference occurs where the interfering wireless system is transmitting in the same frequencies in which the victim wireless system is attempting to receive. Because the interfering signal is using the same frequencies as the receiver and thus is inside the passband of the receive filter, the receiver is unable to filter (and thus attenuate) the interfering signal. In

[26] Even in the case of uplink switched time diversity, the random nature of fading would not make TDD much more efficient than FDD. Furthermore, although supported in the standard, typical UEs are not capable of switching the antenna to transmit a signal.

[27] *See, e.g.,* Nokia Siemens Comments, at 11 ("Interleaving of FDD and TDD blocks in a random manner is not recommended as it will require guard bands at each FDD/TDD frequency border").

these circumstances, the throughput for the receiver can be significantly impaired, and the receiver may even lose its radio connection.

In a mixed LTE-TDD/LTE-FDD environment, LTE-TDD and LTE-FDD networks could be deployed using the exact same frequencies in adjacent geographic areas. Because the LTE-TDD network can transmit at any given time in any given frequency, the LTE-TDD network will inevitably end up transmitting in the same frequencies that the LTE-FDD network in the adjoining geographic area uses to receive transmissions. In these circumstances, the LTE-FDD base station will not be able to filter the strong co-channel LTE-TDD signal, and will thus experience significant interference that can substantially reduce throughput and result in lost connections. It is also possible for the LTE-FDD system to cause interference to the LTE-TDD system.

This co-channel FDD-TDD interference is not a hypothetical concern. This is a problem that AT&T faces today in Kansas City. AT&T owns lower 700 MHz B and C block licenses in much of Kansas City. However, two other providers own 700 MHz C block licenses in certain parts of Kansas City. These other providers have deployed a WiMAX-TDD network. As a result, the TDD-WiMAX base stations used by these providers are transmitting in the lower 700 MHz C block spectrum in areas immediately adjacent to where AT&T is operating an LTE-FDD network using lower 700 MHz spectrum. As a result of the AT&T system's close geographic proximity to the TDD-WiMAX system, several AT&T base stations experienced crippling interference when attempting to use the lower 700 MHz C block for LTE-FDD. AT&T has thus been forced to operate only with 700 MHz B block spectrum in large portions of Kansas City, resulting in substantially lower capacity and throughput than would be achievable if AT&T's 700 MHz C block spectrum were not impaired by the nearby 700 MHz WiMAX-TDD transmissions. AT&T's experience in Kansas City provides an example of what would likely occur throughout the country if the FCC were to allow mixed FDD and TDD use in 600 MHz spectrum.

Our discussion in this section so far has focused on co-channel interference. But a mixed FDD and TDD 600 MHz band plan would also likely result in significant adjacent channel interference where FDD and TDD systems are operating in the same geographic area. If an FDD operator wins a block in the FDD portion of the mixed band, and a TDD operator wins the TDD portion of the mixed band in the same geographic area, there would be significant ACI between the FDD and TDD systems. Indeed, a 10 MHz guard band is recommended by Alcatel-Lucent between the TDD systems and the FDD systems to minimize interference. The overall amount of licensed spectrum would be much smaller when we account for such additional guard bands.[28]

3. Duplex Gap Size.

In LTE-FDD systems, it is important to have a guard band between the uplink and the downlink frequencies. The guard band between uplink and downlink frequencies in an FDD system is typically referred to as the "duplex gap."

[28] *See also, e.g., id.*

A sufficiently sized duplex gap in an LTE-FDD system is necessary to avoid different types of interference within the system. For example, transmissions from the transmit portion of the UE can cause severe ACI to the receive portion of the UE as shown in Figure 4. The duplexer's filters cannot provide adequate attenuation if the duplex gap is too small.

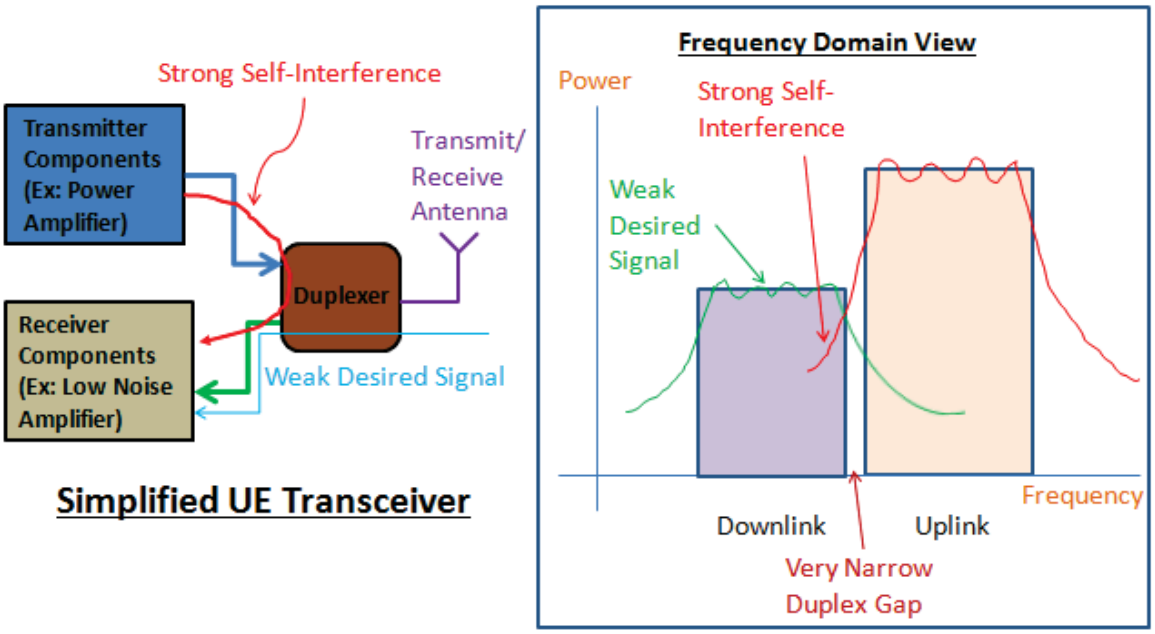

Figure 4. Self-Interference Inside a UE Transceiver due to Insufficient Duplex Gap

Another type of interference is eNodeB-to-eNodeB interference that the duplexer can mitigate. For example, if the duplex gap is too small, the downlink transmissions from an eNodeB could cause adjacent channel interference to nearby eNodeBs, adversely affecting the ability of these nearby eNodeBs to receive desired uplink transmissions from UEs. This type of interference is shown in Figure 5.

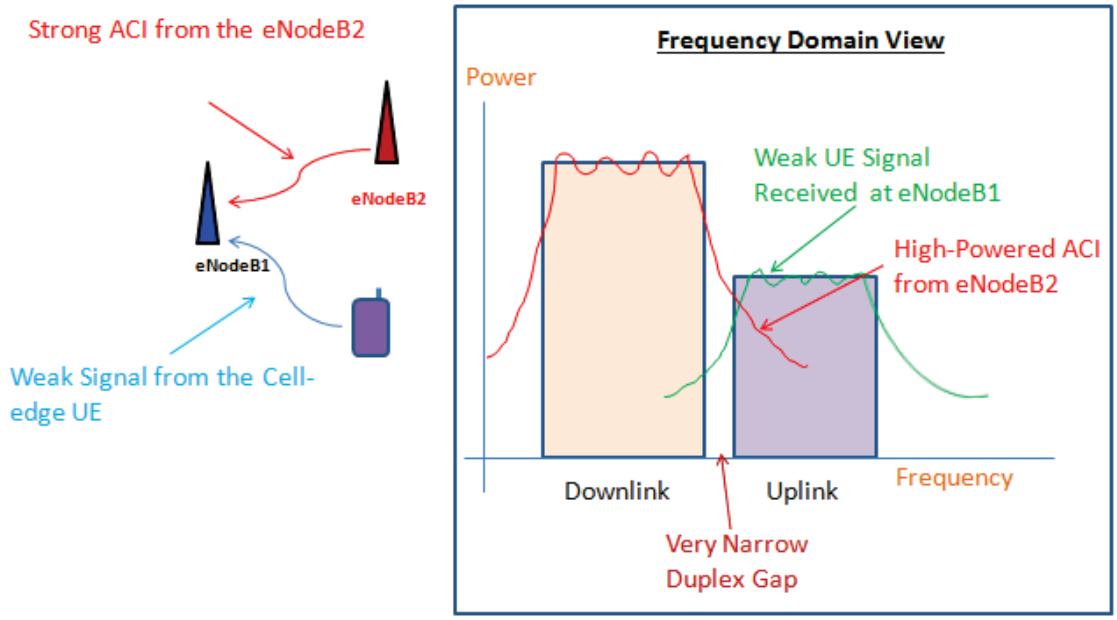

Figure 5. eNodeB-to-eNodeB Interference When Duplex Gap Is Too Small

As shown in Figure 5, eNodeB-to-eNodeB interference can be severe due to the wide disparity of the transmit power levels of the eNodeBs and the UEs. As noted, the maximum effective transmit power for an LTE UE is 23 dBm. If there is an eNodeB nearby that is transmitting in frequencies that are adjacent to the frequency being used by an eNodeB to receive the uplink signals from its UE, significant ACI can occur because the eNodeB could easily be transmitting at power levels that exceed 45 dBm, far exceeding the 23 dBm transmit power of a UE. As a result, the interfering signal caused by the nearby transmitting eNodeB could easily overwhelm the signal of a UE, thus making it quite difficult for the receiving eNodeB to retrieve the desired signal from the UE.

In addition to eNodeB-to-eNodeB interference, there can also be UE-to-UE interference. That is, the uplink transmissions from one UE would cause adjacent channel interference to nearby UEs, which impairs the ability of such UEs to receive desired downlink transmissions from their eNodeBs. This type of interference is shown in Figure 6.

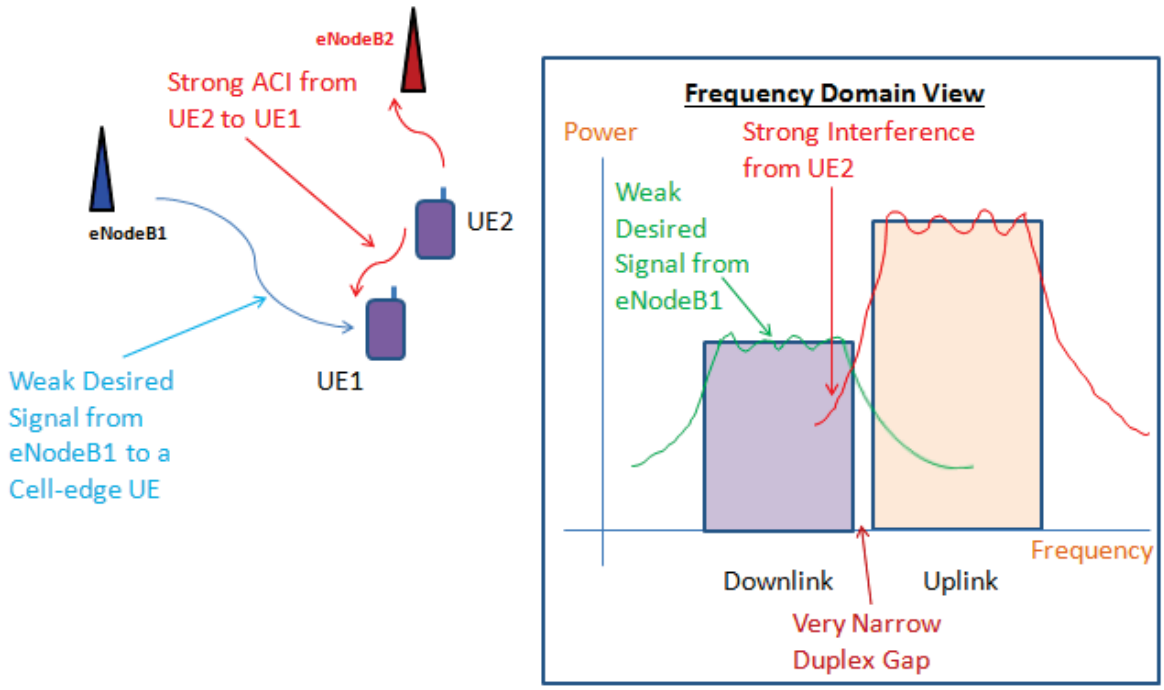

Figure 6. UE-to-UE Interference When Duplex Gap Is Too Small

The NPRM sought comment on the proper size of the duplex gap. At the time we filed our initial paper, the available analyses indicated that a duplex gap size for 600 MHz spectrum should be in the range of 10 MHz to 14 MHz. Upon further investigation by AT&T and its vendors, as well as the analyses of various other commenters in this proceeding, this range has been narrowed to 10-12 MHz. In addition, as we explain below, the maximum duplex gap should be no greater than about 15 MHz, because a larger duplex gap would either significantly reduce the available amount of paired spectrum, or force device manufactures to make design decisions that would result in larger or lower quality devices.

Minimum Duplex Gap Size Of 10-12 MHz. The minimum size of the duplex gap is driven by simple wireless engineering requirements needed to avoid interference between the uplink and the downlink in an LTE-FDD system. According to basic engineering principles, real world considerations, and analyses by AT&T and its vendors, the duplex gap in the 600 MHz bands should be no smaller than about 10-12 MHz.

There is a well-established engineering principle that the duplex gap should be greater than at least 1% to 1.5% of the center frequency in which the service is operating. For example, the IWPC, the international wireless consortium that includes the major filter manufacturers, has shown that a duplex gap below 1% can make it extremely challenging to design adequate filtering, and that even a duplex gap of 1.5% of the center frequency is generally "hard" to

accommodate.[29] The analysis presented by the IWPC shows that attempts to accommodate a smaller duplex gap would lead to unacceptable insertion loss that would significantly degrade performance.[30] These facts have been confirmed by Alcatel-Lucent and multiple terminal filter manufacturers.[31] This limitation has also been confirmed to AT&T and ourselves by various vendors. Based on these figures, an LTE-FDD band centered at about 650 MHz requires a duplex gap of at least between 6.5 MHz (1%) and 9.75 MHz (1.5%).

To accommodate real world production and environmental factors, however, the duplex gap needs to be even larger. For example, as explained by IWPC, there are significant variations in manufacturing processes for the acoustic filters that are widely used in mobile wireless devices, which can lead to about 0.15% variation in the filter response.[32] The manufacturing variation leads to 3 MHz bandwidth change at 2 GHz and 1 MHz bandwidth change at 650 MHz.[33] Variations also occur due the fact that different manufactures produce filters with different performance characteristics.[34]

Another factor causing variation in the filter response is variations in temperature.[35] The performance of a filter can vary substantially in hot weather compared to cold weather (or as the components in the device heat up and cool).[36] The change in the frequency response of a filter is referred to as temperature motion of the filter, which is defined by its temperature coefficient or "Tempco."[37] Tempco is specified in parts per million per degree C (*i.e.,* ppm/C). For a typical acoustic filter, Tempco is -30 ppm/C, and according to IWPC calculations, the frequency of a filter can shift by 6.9 MHz at 2 GHz center carrier frequency.[38] Calculations

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[29] *See* Presentation by the International Wireless Industry Consortium Mobile RF Filter Group, submitted in the FCC's GN Docket No. 12-268 on November 27, 2013 ("IWPC Presentation"). The IWPC is an organization of more than 140 Wireless and RF product manufacturers and suppliers including, for example, Avago Technologies, MuRata, TDK-EPC, and TriQuint Semiconductor, that together represent the majority market share of RF filtering solutions for mobile devices. *Id.* at 2.

[30] IWPC Presentation, at 10-11, 15.

[31] Alcatel-Lucent Comments, at 21-22 ("As detailed in the IWPC submission in this proceeding and confirmed by Alcatel-Lucent's discussions with terminal filter manufacturers, it is currently difficult to make terminal filters with duplex gaps narrower than about 1.5%.").

[32] *See* IWPC Presentation, at 12.

[33] *See id*.

[34] *See id*.

[35] *See id.* at 13.

[36] *See id*.

[37] *See id.*

[38] *See id*.

based on this methodology show that the frequency could shift by 2.2 MHz at the center carrier frequency of 650 MHz.[39]

Taken together, the variations in the filter response could lead to about (1 MHz due to manufacturing variations + 2.2 MHz due to temperature variations = 3.2 MHz) change in the frequency at 650 MHz. Using the 1% rule, the duplex gap needs to be (6.5 + 3.2= 9.7 or about 10 MHz). The use of 1.5% rule leads to (9.75 + 3.2 = 12.95 or 13 MHz).

There appears to be strong consensus within the industry that the minimum duplex gap that the filter can be designed for and that will protect against harmful self-interference in real-world deployments must be at least 10-12 MHz.[40]

Maximum Duplex Gap Size. If the goal of the auction is to maximize the amount of paired spectrum, the duplex gap should be no larger than the minimum needed to avoid interference (as described above, this minimum size is about 10-12 MHz). A simple example illustrates this point. Consider a device that can support a bandwidth of about 65 MHz (the bandwidth is the sum of the frequencies used for the uplink, downlink, and duplex gap). If that device has a duplex gap of 15 MHz, it will have 50 MHz left over for paired spectrum, resulting in five pairs of 5 MHz FDD spectrum blocks. A larger duplex gap would reduce the amount of spectrum available for FDD pairs. Thus, a duplex gap no larger than 15 MHz would maximize the available paired spectrum.

For these reasons, the proposal set forth by Google and Microsoft to include a guard band containing a 28 MHz duplex gap is not at all consistent with a band plan seeking to maximize paired spectrum and the efficient use of spectrum. In the example above, using 28 MHz of that spectrum for the duplex gap would leave only 37 MHz of spectrum for paired LTE-FDD blocks. As a result, the use of a 28 MHz guard band would reduce the amount of available paired spectrum to 30 MHz (3 paired blocks of 5 MHz) compared to 50 MHz (5 paired blocks of 5 MHz) if a 12 MHz duplex gap were used.[41]

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[39] According to IWPC, the frequency shift is given by (Tempco*(T2-T1)* f), where Tempco is the temperature coefficient, T2 is the upper limit on the temperature in degrees C, T1 is the lower limit on the temperature in degrees C, and f is the center carrier frequency. IWPC's calculations use Tempco= -30 ppm/C, T2= 85°C, and T1=-30°C. At 650 MHz, the frequency shift is -30((85-(-30)*650/1000000)= -2.2 MHz.

[40] Alcatel-Lucent Comments, at 21-22 (10 MHz to 12 MHz); Nokia Siemens Comments at 9 (at least 10 MHz); Qualcomm Comments, at ii (10 MHz to 14 MHz, with 11 MHz to 12 MHz ideal); Comments of Research in Motion Corporation, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 12-13 (Jan. 25, 2013) ("RIM Comments") (greater than 2% of 600 MHz frequency, or about 12 MHz to 13 MHz).

[41] We note that the Spectrum Act provides that "guard bands shall be no larger than is technically reasonable to prevent harmful interference between licensed services outside the

Prof. Borth, in a paper attached to the Google-Microsoft Comments, recommends a duplex gap greater than 20 MHz to help achieve a low-cost and high-performing receiver.[42] We agree with Prof. Borth that the duplex gap should be large enough to facilitate a low-cost and simpler filter design and to sufficiently manage insertion loss. However, based on the information that we and AT&T have received from the filter manufacturers, a duplex gap of about 10 to 12 MHz is adequate for the current state-of-the-art filter design to achieve the filter performance goals that Prof. Borth and the FCC have outlined. The duplex gap of 10 to 12 MHz does not cause any appreciable increase in the filter complexity or cost compared to a much larger duplex gap. In contrast, as explained earlier, a 28 MHz duplex gap would cause much larger drop in the effective antenna gain at the UE if antennas were forced to operate in a larger overall bandwidth (covering the downlink band, the duplex gap, and the uplink band).

We respectfully disagree with Prof. Borth's assertion that intermodulation (IM) interference concerns alone justify a larger duplex gap.[43] Effective and efficient methods to counteract intermodulation interference include (i) avoiding the TV channels in the duplex gap, (ii) using an adequate guard band between the licensed spectrum and the TV spectrum, and (iii) placing relatively low-powered TV stations adjacent to the licensed mobile broadband spectrum. The proposed AT&T band plan makes effective use of these methods. Using a large duplex gap to solve the intermodulation interference is neither effective nor efficient, because the bandwidths of the IM products are quite wide. Rather, methods that prevent the occurrence of IM interference in the first place and that lead to significantly weaker power levels of the generated IM products are most effective.

It is also important to recognize that with currently available antenna technology, a maximum duplex gap no greater than 15 MHz should be used to achieve a band that can support 2 x 25 MHz of paired spectrum in 600 MHz spectrum. To understand why this is so, it is necessary to examine the engineering limits of antenna design for modern small form factor mobile devices.

The total bandwidth that a device can cover while operating at a specified efficiency level is governed by the volume of the antenna in the mobile device. All else being equal, an antenna with a larger volume can support more bandwidth than a smaller antenna. Given the small form factors of modern mobile devices and the myriad components that must be included in those multi-band devices (*e.g.*, chipset, power supply, camera, memory, GPS receiver, and so on), there are significant limitations on the size and number of antennas that can be placed in a

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guard bands." Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, Tit. VI, § 6407(b), 126 Stat. 156, 227-228 (Feb. 22, 2012) (codified at 47 U.S.C. § 1454(b)).

[42] *See* Declaration of David Borth, at ¶¶ 4-5 (Jan. 25, 2013) ("Borth Decl."), attached to Google-Microsoft Comments.

[43] Borth Decl. ¶ 15.

mobile device, and hence the bandwidth they can cover. As Qualcomm states, "[i]t is fair to say that there is no spare space in today's smartphones."[44]

There are two types of antennas that could theoretically be used in devices to support 600 MHz spectrum: (1) a passive antenna and (2) a "tunable" antenna.

A passive antenna is designed to cover a particular frequency range with a specified level of efficiency. Stand-alone passive antennas are used primarily for receiving and transmitting only specific frequency ranges. A single passive antenna that covers higher frequencies at the target efficiency is relatively small and a single passive antenna covering lower frequencies at the same target efficiency is relatively large.

For these reasons, the use of passive antennas to cover lower frequencies can be much more challenging than for higher frequencies. Antennas for higher frequencies can be quite small, and it is therefore easier to fit multiple high frequency antennas in a device. Moreover, the smaller size of higher frequency antennas allows for relatively small passive antennas that cover multiple frequency bands, creating greater space saving efficiencies in device design.

By contrast, the passive antennas needed for the lower frequency bands, such as 700 MHz or 600 MHz must be much larger to meet given efficiency standards. Even a 600 MHz antenna must be substantially larger than a 700 MHz antenna to meet the same efficiency standards. Qualcomm explains that "an antenna that is designed exclusively to support 600 MHz operations could require approximately 60% more volume than current 700 MHz antennas, which would substantially challenge current smartphone form factors," and given that there is already little or no space available in mobile devices, we share Qualcomm's "concern[] that if the Commission's band plan requires use of a separate antenna system for 600 MHz, smartphones would have to become much larger in order to perform acceptably."[45]

This problem would only be amplified if 600 MHz passive antennas were required to cover more than about 65 MHz. The 700 MHz passive antennas are designed to cover about 10% of their center frequency. And Qualcomm has found that to achieve the same level of efficiency in the 600 MHz range, this antenna would have to be 60% larger. To achieve not only the same efficiency but *also* greater than a 10% frequency range, the antenna would have be larger still. There are thus enormous practical impediments to adding 600 MHz antennas to small form factor devices that can cover a bandwidth greater than about 65 MHz.

A "tunable" antenna system is another option. The operating center frequency of a tunable antenna is set by adjusting its resonant frequency. As such, a single tunable antenna can be used in a device to handle multiple low frequency ranges with one frequency range being active at a time. For example, if we tune a 700 MHz antenna to operate at 600 MHz, the device will

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[44] Qualcomm Comments, at 13.

[45] *Id*.

be active on 600 MHz but not on 700 MHz. Sharing of the antenna system between the 600 MHz band and the 700 MHz is highly desirable because it saves space.

But here too, there are limits as to the frequency range that a tunable antenna can cover. As a rule of thumb, a tunable mobile device antenna can typically cover a frequency range of about 10% of the center frequency with good efficiency.[46] AT&T's vendors have confirmed that this would apply to tunable antennas for 600 MHz devices. Qualcomm has also explained that a reasonably sized and efficient antenna in the 600 MHz bands could cover only about 62 MHz.[47] With a 10% constraint, an antenna operating in a frequency range centered at 650 MHz could support a bandwidth 65 MHz. Consequently, a 600 MHz band that includes 2 x 25 MHz of paired spectrum can accommodate a maximum duplex gap of 15 MHz to ensure that the total frequency range being covered by the antenna does not exceed the maximum 65 MHz that can be efficiently covered by the antenna.

4. Unlicensed Operations in the Duplex Gap.

The NPRM asks whether unlicensed users should be permitted to operate in the duplex gap. In our view, unlicensed operations in the duplex gap should be permitted only if two criteria are satisfied: (1) the unlicensed users operate in a manner that fully protects licensed users from interference, and (2) the unlicensed must accept any interference that may occur from licensed operations.

These protections are critically important for a successful band plan and auction. Most fundamentally, failure to protect the licensed paired spectrum from interference generated by unlicensed deployments in the duplex gap (or a mandate that required paired spectrum licensees to somehow protect unlicensed users in the duplex gap) would impair the licensed spectrum in a manner that would decrease its value to providers and consumers by reducing capacity and quality.

Moreover, failure to protect licensed spectrum from interference from operations in the duplex gap would undermine the FCC's goal of creating a band plan with fungible paired spectrum blocks. Interference caused by operations in the duplex gap would have a greater impact on spectrum nearer to the duplex gap, thus making spectrum blocks closer to the duplex gap less desirable than spectrum blocks farther away from the duplex gap. Similarly, any requirement that licensees of paired spectrum provide some sort of protection to unlicensed users in the duplex gap would inevitably have a greater impact on licensees of spectrum blocks closer to the duplex gap than on paired spectrum in frequencies that are farther from the duplex gap.

The Commission can easily ensure that the second criterion is satisfied – *i.e.*, that unlicensed users are not entitled to any protections from interference from licensed users, and thus must accept any interference that may occur from licensed operations.

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[46] Jeffrey H. Reed, *Software Defined Radio: A Modern Approach to Radio Design*, (1st ed. 2002).

[47] Qualcomm Comments, at 15.

The challenge is designing rules that ensure that the first criterion is satisfied – *i.e.*, that the unlicensed users operate in a manner that fully protects licensed users from excessive interference. The difficulty is that the limitations needed to protect licensed users depend significantly on the specifics of the unlicensed service at issue. The amount of protection that an unlicensed system can provide to the licensed system depends on the filters, power levels, locations, and numerous other factors for the service being operated. The protection also depends on the types of services – *e.g.*, downlink only, uplink only, or both downlink and uplink. It can depend on the nature of the services and the physical layer characteristics of the unlicensed device such as power and modulation. For example, some unlicensed uses may be expected to operate in closer physical proximity to licensed mobile equipment and may therefore require greater restrictions to protect licensed mobile services.

For these reasons, we do not at this stage in these proceedings suggest a specific approach to ensuring that any unlicensed devices in the duplex gap do not interfere with licensed operations. We note, however, that very significant restrictions on unlicensed devices may be necessary to prevent such interference, given that the spectrum in the duplex gap is, by definition, immediately adjacent to both the uplink and downlink frequencies for licensed mobile services.

5. Guard Band Sizes.

The size of the guard band needed to protect mobile spectrum that is adjacent to television from interference will vary for uplink and downlink mobile spectrum, and will vary depending on the power level of the television stations. It can also vary based on the type of potential interference that may occur. For example, where the main concern is both adjacent channel interference and intermodulation interference, the guard band may need to be larger than if adjacent channel interference were the only concern. For these reasons, until there is a more established band plan, it is not possible to predict with certainty the precise size that will be needed for the guard bands to protect against harmful interference. However, based on past testing in the 700 MHz frequencies, and analyses conducted by AT&T and its vendors, we can provide some general guidelines.

Mobile Uplink Adjacent To Television Station. Based on experience where mobile uplink frequencies are adjacent to full powered television stations, a 6 MHz guard band is generally sufficient to protect against adjacent channel interference and potential intermodulation interference. This conclusion is based on the fact that AT&T is currently operating in 700 MHz Band 17 which has 6 MHz of separation from television channel 51, which are authorized to operate at power levels up to 1 MW. We understand from AT&T that this effective 6 MHz guard band has been sufficient to protect against harmful interference and has been verified by testing labs.

Mobile Downlink Adjacent To Television Station. There is no real world data that can be relied upon to determine the appropriate guard band where mobile downlink spectrum is located adjacent to a television broadcast station. The closest scenario of which we are aware is the

proximity of AT&T's 700 MHz Band 17 downlink spectrum, which is about 12 MHz away from the D-Block, and 6 MHz away from the E-Block (where Dish is expecting to deploy a television broadcast service at power levels up to 50 kW).

According to analyses by AT&T and Qualcomm, a 6 MHz guard band should be sufficient to protect against interference from 50 kW broadcasts.[48] It follows that a 6 MHz guard band should be sufficient in the 600 MHz bands to protect mobile downlink frequencies from adjacent television stations that are operating at or below 50 kW.

Although we are unaware of any testing as to the size of the guard bands needed to in the 600 MHz frequencies to protect mobile services from full powered (1 MW) broadcasts, we note that analyses of filter performance and other factors by Alcatel-Lucent, Nokia Siemens, and RIM indicate that these guard bands will likely need to be at least 10-12 MHz.[49]

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[48] *See, e.g.,* Jeffrey H. Reed and Nishith D. Tripathi, *Analysis of the V-COMM Report Estimating the Impact of Channel 51 and E Block Interference on Band 12 and Band 17 User Equipment Receivers*, at 6-7, 10-11, and 19-21 (Oct. 3, 2012), attached to Letter from David L. Lawson (AT&T) to Marlene H. Dortch (FCC), WT Docket No. 12-69 (Oct. 3, 2012) (presenting testing conducted by PCTest and 7Layers); Jeffrey H. Reed and Nishith D. Tripathi, *Supplemental Analysis: Impact of Channel 51 and E block Interference on Band 12 and Band 17 User Equipment Receivers*, at 9-13 (July 16, 2012), attached to Reply Comments of AT&T Services Inc., WT Docket No. 12-69 (July 16, 2012) (describing the testing conducted by PCTest and 7Layers); Comments of Qualcomm Incorporated, *Promoting Interoperability in the 700 MHz Commercial Spectrum*, WT Docket No. 12-69, at 6-29 (June 1, 2012).

[49] *See* Alcatel-Lucent Comments, at 23; Nokia Siemens Comments, at 15-19; RIM Comments, at 11.

Spectrum Aggregation Policy, Spectrum-Holdings-Based Bidding Credits, and Unlicensed Spectrum

Reply Declaration of

Michael L. Katz, Philip A. Haile,
Mark A. Israel, and Andres V. Lerner

March 12, 2013

CONTENTS

I. INTRODUCTION.....1

II. COMPETITION AND CONSUMERS WOULD BE HARMED BY RULES THAT LIMITED AUCTION PARTICIPATION IN ORDER TO LIMIT SPECTRUM AGGREGATION 7

A. RIGID LIMITS ON SPECTRUM AGGREGATION HARM COMPETITION AND CONSUMERS.....9

B. RESTRICTIONS ON PARTICIPATION IN THE FORWARD AUCTION FOR 600 MHZ SPECTRUM WOULD HARM COMPETITION AND CONSUMERS.....15

1. Limits on participation in the 600 MHz auctions would very likely harm consumers of mobile wireless services.....16

2. Limits on participation in the 600 MHz auctions would very likely reduce revenues. 20

III. A POLICY OF PROVIDING CREDITS TO BIDDERS BASED ON THEIR CURRENT LICENSE HOLDINGS WOULD BE FUNDAMENTALLY UNSOUND AND UNWORKABLE 28

A. BIDDING CREDITS WOULD VERY LIKELY LOWER AUCTION REVENUES. 29

B. BIDDING CREDITS FOR FIRMS WITH RELATIVELY SMALL CURRENT LICENSE HOLDINGS WOULD EITHER BE INEFFECTIVE OR THE COMMISSION WOULD HAVE TO SEVERELY RESTRICT SECONDARY MARKETS, THUS HARMING CONSUMERS.....31

C. USE OF SPECTRUM-HOLDINGS-BASED BIDDING CREDITS RISKS DISTORTING COMPETITION IN MOBILE WIRELESS SERVICES MARKETS RATHER THAN PROMOTING IT. 33

IV. PROPONENTS OF INCREASED ALLOCATION OF SPECTRUM FOR UNLICENSED USES FAIL TO ADDRESS THE FUNDAMENTAL ISSUES AND PROVIDE RELEVANT FACTS 33

A. GOOGLE AND MICROSOFT OFFER NO SOUND BASIS FOR THE CLAIM THAT ALLOCATING SPECTRUM TO UNLICENSED USES WOULD GENERATE GREATER CONSUMER BENEFITS THAN ALLOCATING IT TO LICENSED USES 34

1. Google and Microsoft ignore opportunity cost.....35

2. Google and Microsoft confuse the value of Wi-Fi and other technologies with the value of unlicensed access. 38

B. GOOGLE AND MICROSOFT OFFER NO SOUND BASIS FOR THE CLAIM THAT INCREASED ALLOCATION OF SPECTRUM TO UNLICENSED USES WOULD INCREASE AUCTION REVENUES. 40

1. The reduced supply of spectrum available at auction is likely to reduce auction revenues. 41

2. Unlicensed spectrum can be a substitute for licensed spectrum.....46

V. CONCLUSION 50

VI. APPENDIX A: REVENUE SIMULATIONS.....51

I. INTRODUCTION

1. In 2012, Congress directed the Federal Communications Commission (Commission) to design and conduct auctions to repurpose for mobile wireless use 600 MHz spectrum currently used for broadcast television operations.[1] In the present proceeding, the Commission sought comment on a band plan and auction framework for this spectrum.[2] More than one hundred comments were filed. We have been asked by counsel for AT&T to assess two sets of economic arguments and policy proposals made in those comments: (1) proposals by smaller wireless service providers that the Commission limit participation in the auction by larger providers or boost the auction prospects of the smaller providers by giving them bidding credits, and (2) proposals by Google and Microsoft that the Commission take a substantial portion of the 600 MHz spectrum that the Commission proposes to auction for licensed mobile wireless use and instead make it available for free for unlicensed use.

2. As we explain below, each of these proposals would harm competition, reduce consumer welfare, increase the risk of auction failure, and distort the reallocation of spectrum from broadcast television to mobile wireless services. Implementation of those proposals would benefit some wireless service providers by providing them with subsidies and/or constraining the ability of other wireless service providers to compete against them. But these policies would harm competition and consumers in mobile wireless service markets.

3. Turning to specific policy proposals, our findings are the following:

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1 Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. 112-96 (Feb. 22, 2012).

2 Federal Communications Commission, *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, Notice of Proposed Rulemaking, rel. October 12, 2012 (hereinafter, *NPRM*).

- Several commenters call for the imposition of general or auction-specific spectrum caps designed to restrain the abilities of the most successful mobile wireless service providers, AT&T and Verizon Wireless, to obtain additional spectrum licenses at auction. In doing so, these parties largely repeat arguments we have discredited elsewhere.[3] The ultimate objective of Commission policy is to protect competition in downstream markets for mobile wireless services. These proposals run directly counter to this objective: If implemented, their principal effect in downstream markets would be to harm consumers by weakening and distorting competition. Their principal effects in the upstream market for spectrum licenses would be to reduce expected auction revenues and increase the likelihood the 600 MHz auctions fail or result in inefficiently low reallocation of spectrum from TV to higher valued mobile wireless use.
    - Rigid caps on spectrum holdings limit the ability of those service providers most successful at satisfying consumer desires from expanding to offer consumers even more of the services they desire. By doing so, caps punish success, limit the realization of economies of scale, distort market outcomes, and weaken the competitive pressures faced by rival service providers. Over the longer term, spectrum caps attenuate innovation and investment incentives. Spectrum caps would not give rise to public-interest benefits that could offset these costs. Specifically, caps are not needed to prevent foreclosure because industry

[3] Mark A. Israel and Michael L. Katz, Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings, November 28, 2012 (hereinafter, *Israel and Katz Initial Declaration*), Attachment A to Comments of AT&T Inc., *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269; Mark A. Israel and Michael L. Katz, Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings (Reply Declaration), January 7, 2013 (hereinafter, *Israel and Katz Reply Declaration*), Attachment B to Reply Comments of AT&T Inc., WT Docket No. 12-269.

conditions make anticompetitive foreclosure unlikely and, even if there were a credible risk of foreclosure, such a risk would better be handled by a spectrum screen safe harbor and case-by-case analysis of those instances identified by the screen as potentially problematic.

- Even less justification exists for caps based on holdings of only a subset of all available spectrum (*e.g.*, all spectrum bands below 1 GHz or the 600 MHz spectrum band in particular). Contrary to what proponents of low-frequency spectrum caps claim, lower-frequency spectrum is not always better. Moreover, to the extent that higher-frequency spectrum has lower value than lower-frequency spectrum in some geographical areas under some conditions— because high-frequency spectrum necessitates greater facilities investments to achieve a certain degree of coverage—this lower value can be expected to be reflected in lower license prices, thus *offsetting* the higher investment cost. The higher value of lower-frequency spectrum, therefore, does not take on special competitive significance: Even if spectrum differs in quality, a potential entrant or expanding incumbent can buy less-expensive, high-frequency spectrum and invest more in infrastructure. As should be expected given these facts, market data demonstrate that service providers can and do succeed relying on high-frequency spectrum.

- Proposals that would limit participation in the 600 MHz forward auction directly make no economic sense for several reasons. First, the focus on low-frequency spectrum is misplaced for the reasons summarized in the previous bullet point. Second, and relatedly, the licenses in the 600 MHz auction comprise only a small

portion of overall spectrum holdings and their acquisition could not plausibly support a successful foreclosure strategy. Third, attempts to regulate primary auctions in isolation will very likely be undone by secondary-market transactions, so that the principal effect of the auction restraints is to trigger administrative costs and delay the inauguration of service.

  - Proposals that would directly or indirectly restrict auction participation would, if implemented, also threaten to reduce both auction revenues and the amount of spectrum allocated to mobile wireless services. The argument put forth by T-Mobile and Professor Cramton—that limiting auction participation could raise auction revenues because smaller bidders would stay out of the auction if AT&T and Verizon Wireless were to participate—is based on several critical assumptions that do not appear to be met in the current context, is highly speculative, and is a theory without a limiting principle. In contrast to the theoretical suppositions of T-Mobile and Professor Cramton, market experience indicates that smaller bidders are not deterred from participating in license auctions.

- Leap Wireless International, Inc., Cricket Communications, Inc., and MetroPCS Communications, Inc., advocate a policy under which firms with smaller relative spectrum holdings would be given very substantial bidding credits. Such a scheme would harm consumer welfare because:

  - To the extent the bidding credits have the effect of altering the final spectrum allocation, they would limit the realization of economies of scale and distort

competition in mobile wireless services markets by serving as a form of success tax.

  - Any change in the winner of the auction induced by the bidding credits would likely be undone in secondary markets. The net effect of bidding credits thus would be: delay, while spectrum found its way to the highest-value user; likely loss in auction revenues, which is of particular concern in the forward auction due to the net-revenue requirement that will determine the quantity of spectrum reallocated from broadcast television to mobile wireless use; and potential windfall gains to the credit recipients.
  - Restrictions on secondary markets sufficient to prevent recipients of bidding credits from reselling spectrum to higher-valued users would risk enormous market inefficiencies, create risk for auction bidders that could deter auction participation, likely lead to a reduction in forward-auction revenue, and be extremely difficult to administer.

- Google and Microsoft urge the Commission to exclude from the forward auction a large portion of the spectrum offered by broadcasters in the reverse auction and instead to make it available for free as unlicensed spectrum rights that would facilitate the business models of Google and Microsoft. Google and Microsoft base their claim of consumer benefits on the assertion that Wi-Fi, Bluetooth, and other technologies using unlicensed spectrum have generated significant benefits for consumers to date. There are two fundamental flaws with this line of reasoning.

- First, it ignores the opportunity cost of the spectrum. The relevant question for a public-interest assessment of spectrum allocation is whether the uses enabled by an incremental allocation to unlicensed uses would generate greater benefits than would an incremental allocation to licensed uses, taking into account both the direct consumer benefits of each and the consumer benefits of any resulting auction revenues. As noted already, revenues are of particular concern in the incentive auctions due to the role they play in determining the extent to which efficient reallocations of spectrum from broadcast TV can take place.
- Second, Google and Microsoft confuse the value of Wi-Fi and other technologies with the value of unlicensed access. The two are not equivalent. For example, the "Super" Wi-Fi or other wireless uses Google and Microsoft may have in mind could be offered under a licensed model. Consequently, even if the services Google and Microsoft contemplate were the highest-value use of spectrum at the margin, it would not follow that the Commission should allocate more spectrum to unlicensed uses.

- Lastly, Google and Microsoft claim that allocating substantial amounts of 600 MHz spectrum to unlicensed uses would not threaten the loss of auction revenues and might even raise revenues. They base this prediction on unsupported assertions that: (a) the aggregate demand for licensed spectrum is inelastic, and (b) that unlicensed use is complementary, and not a substitute for, licensed use. We demonstrate that neither assertion is well founded.

- Although we know of no reliable estimates of the elasticity of demand for spectrum, the available studies that have attempted to estimate it suggest that demand is elastic. The existence of infrastructure and technology substitutes to spectrum use rights for the purpose of increasing network capacity suggests that it is likely that the demand for spectrum from each auction participant is elastic. This is supported by Monte Carlo simulations, which suggest that revenue losses are likely under a wide range of valuation distributions.
- An evaluation of both current uses of unlicensed spectrum and potential future uses suggests that it is much more likely that these uses are substitutes rather than complements to licensed spectrum. The greater the extent to which licensed and unlicensed uses are substitutes, the higher the probability that additional allocation of spectrum to unlicensed uses would lead to lower auction revenues even if the demand for licensed spectrum were inelastic.

4. The remainder of this declaration explains these findings in greater depth and provides details of the facts and analysis that underlie them.

II. COMPETITION AND CONSUMERS WOULD BE HARMED BY RULES THAT LIMITED AUCTION PARTICIPATION IN ORDER TO LIMIT SPECTRUM AGGREGATION

5. Many of the comments filed in this proceeding are based on the unfounded claim that acquisition of additional spectrum by wireless providers that already have relatively large spectrum holdings is inherently harmful to consumers.[4] Some commenters go further and argue

[4] See, *e.g.*, Comments of T-Mobile USA, Inc., *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-268, January 25, 2013 (hereinafter, *T-Mobile Comments*) at 23-35; Comments of Competitive Carriers

that aggregation of licenses for spectrum below 1 GHz is particularly harmful.[5] Building on this claim, several commenters assert that limiting the ability of certain wireless service providers to acquire spectrum licenses in the upcoming 600 MHz auctions would promote mobile wireless services competition and consumer welfare.[6] Some commenters go so far as to conclude that such limits would promote competition *in the auctions themselves* and, thus, increase expected auction revenue and raise the probability that the auctions will succeed.[7]

6. In this section, we first summarize points that two of us have made in the Commission's closely related spectrum holdings proceeding, explaining why rigid limits on spectrum holdings—either overall or for frequencies below 1 GHz in particular—are harmful to consumer welfare.[8] We then apply and extend our analysis to the specific case of limits on the ability of certain providers to acquire spectrum in the 600 MHz auctions. We demonstrate that consumers would be harmed if such proposals were adopted, and we refute claims that restricting participation in the 600 MHz auction would be expected to generate higher auction revenues.

Association, *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-268, January 25, 2013 (hereinafter, *CCA Comments*) at 8-12.

5 Comments of Competitive Public Interest Spectrum Coalition, *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-268, January 25, 2013 (hereinafter, *PISC Comments*) at 67-68; Comments of Sprint Nextel Corporation, *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-268, January 25, 2013 (hereinafter, *Sprint Nextel Comments*) at 9-10; *CCA Comments* at 8-10; *T-Mobile Comments* at 23-35.

6 Comments of Cellular South Inc., *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-268, January 25, 2013 (hereinafter, *Cellular South Comments*) at 5-6; Comments of United States Cellular Corporation, *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-268, January 25, 2013 (hereinafter, *US Cellular Comments*) at 30-34; *Sprint Nextel Comments* at 9-10; *PISC Comments* at 66.

7 *T-Mobile Comments* at 33.

8 *Israel and Katz Initial Declaration*; *Israel and Katz Reply Declaration*.

A. RIGID LIMITS ON SPECTRUM AGGREGATION HARM COMPETITION AND CONSUMERS

7. As the Commission has repeatedly stated, its objective is to promote consumer welfare, not the well-being of particular competitors. Consumer welfare is driven by the performance of markets for mobile wireless services. The Commission's concern for consumer welfare thus dictates that Commission policies should be assessed based on their effects on these downstream markets, not their effects on spectrum markets *per se*.[9] As the Commission has long recognized, it can best promote consumer welfare in mobile wireless services markets by protecting undistorted competition in those markets. Among other things, this fact implies that initial spectrum assignments generally should go to the highest-value users through a competitive bidding process, and that a freely functioning secondary market should facilitate license reassignment (transfer).

8. By their very nature, rigid spectrum-aggregation limits (caps) block the working of the market and can harm consumers by making expansion more costly for those firms that best meet consumer needs. Although spectrum is an important input, there are many other important drivers of commercial success in mobile wireless markets, including investments in network infrastructure, customer service, and marketing. Some service providers are more successful than others at providing products, customer service, marketing, and other activities that

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[9] The Commission, itself, has made this point explicitly. For example, in its order sunsetting the spectrum cap, the Commission stated,

> Again, we emphasize that the markets with which we are principally concerned are the output markets for services, and that conditions in the input markets provide only a partial proxy measure of competition in the output markets.

(*2000 Biennial Regulatory Review – Spectrum Aggregation Limits for Commercial Mobile Radio Services*, WT Docket No. 01-14, Report and Order, 16 FCC Rcd 22668 (2001) (hereinafter, *Second Biennial Review Order*), ¶ 27.)

consumers find attractive. Generally, those service providers that are most successful in offering services and products that consumers desire are the providers that will have the greatest demands for spectrum use rights. The claim that large spectrum license holdings trigger competitive success is exactly backward in markets where competitive success triggers a service provider's demand for additional spectrum rights.[10] The harm from following such backward logic and imposing rigid spectrum caps is that doing so effectively punishes success, by making it more difficult and costly for successful firms to expand. As a result, the firms for which consumers have revealed a preference are restricted from growing to meet consumer demand. Moreover, by reducing the incentive and ability of firms offering attractive services to expand, spectrum caps reduce the competitive pressures felt by other suppliers in mobile wireless service markets. Finally, over the longer term, the incentive to innovate to become a successful firm is undermined when regulators announce *ex ante* that the company would be limited in how many customers it could serve.[11]

9. Consumer interests are served when public policy allows service providers to obtain additional spectrum rights unless obtaining those rights would foreclose rivals from competing in one or more markets for mobile wireless services.[12] In the present context, the risk of such

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[10] Note that the success does not always have to predate the spectrum acquisition for this logic to hold. Given the long-term nature of network planning, a firm (Clearwire, for example) may see a competitive opportunity and purchase spectrum as a step in pursuing that opportunity. Even when the timing is reversed in this way, the same logic holds: Capping spectrum holdings prevents (or at least limits) such firms from pursuing innovative new offerings.

[11] Indeed, it can be shown algebraically that a policy mandating equal market shares can induce service providers to behave like a monopoly or perfect cartel.

[12] There is a well-established antitrust framework generally used to identify situations in which large holdings of particular inputs (*e.g.*, spectrum use rights) may pose a threat to competition in downstream markets. The central logic of this framework is that, to raise a competitive concern, there must be a high risk of "foreclosure" in downstream markets. For foreclosure to be a valid competitive concern, two conditions must hold. First, the firm holding the inputs allegedly used

foreclosure is extremely low for several reasons.[13] First, in supporting its 2001 decision to sunset the imposition of spectrum caps, the Commission pointed to the number mobile telephony providers available to American consumers.[14] Today, consumers have even more competitive options.[15] Second, a foreclosure strategy based on "warehousing" spectrum would be enormously costly to an incumbent. One reason is that a service provider may need only a small fraction of the available spectrum in order to be a viable competitor. As the Commission recently recognized, more than 600 MHz of suitable spectrum has already been allocated to mobile wireless services,[16] and providers have attained substantial market shares in many markets with less than five percent of the total available spectrum.[17] When there are competitors that need only a small share of available spectrum to be viable, an incumbent firm seeking to

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to foreclose rivals must have the ability profitably to withhold the inputs from other firms (or raise the price of the inputs) and thereby raise the costs facing those other firms by an amount sufficient to have a *significant* effect on downstream competition. Second, the efficiencies created by the firm's use of this spectrum must not increase consumer welfare by an amount that outweighs any loss of consumer welfare due to harm to competition

13 For additional analysis of this point, see *Israel and Katz Initial Declaration* and *Israel and Katz Reply Declaration*.

14 *Second Biennial Review Order*, ¶31. (See also, ¶¶ 5-6 and 30.)

15 Compare *Second Biennial Review Order*, ¶ 31, with *In the Matter of Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993 Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services*, WT Docket No. 10-133, Fifteenth Report, rel. June 27, 2011 (hereinafter, *Fifteenth CMRS Competition Report*), Table 6.

16 See Federal Communications Commission Wireless Telecommunications Bureau, Office of Engineering & Technology, *The Mobile Broadband Spectrum Challenge: International Comparisons*, February 26, 2013, Table 1.

17 Metro PCS has achieved an estimated market share of at least ten percent in 17 CMAs where it has 20 MHz or less spectrum. Similarly, Leap has achieved at least ten-percent estimated market share in 14 CMAs where it has no more than 20 MHz of spectrum; in three of those CMAs, Leap's estimated market share is in excess of 20 percent. (Calculations based on *AT&T market share estimates* and data downloaded from the Commission's "Spectrum Dashboard," *available at* http://reboot.fcc.gov/reform/systems/spectrum-dashboard, *data downloaded* October 18, 2012, (hereinafter, *Spectrum Dashboard*).)

pursue a foreclosure strategy based on spectrum warehousing would have to purchase licenses for all of the blocks of spectrum that the entrant might potentially utilize, while the entrant need obtain only licenses sufficient to offer viable service. Third, to sustain a foreclosure strategy based on warehousing 600 MHz spectrum, for example, a firm would not only have to obtain almost all of that spectrum, but would also need to contend with the likely release of AWS-3 (2155-2175 MHz) spectrum and the possible reallocation of 90 MHz of mobile satellite service (MSS) spectrum for terrestrial broadband services.[18] The firm also would have to ensure that no other spectrum holder sells spectrum to a potential entrant (or facilitates entry via spectrum leases, the lease of wholesale network capacity, an MVNO resale arrangement, or other alternative transactions). Lastly, while these costs all would be incurred by the foreclosing firm, the *benefits* of a warehousing strategy would accrue to all non-foreclosed firms in the marketplace, making it unlikely the foreclosure would be profitable.

10. Although several commenters argue for regulatory limits that apply specifically to the aggregation of use rights for spectrum below 1 GHz—which would have the effect of severely constraining the ability of AT&T and Verizon Wireless to participate in the 600 MHz auctions—there is no credible case for foreclosure based on aggregation of spectrum below 1 GHz on its own.[19] Most fundamentally, far less than a third of the available mobile wireless spectrum is below 1 GHz, and many firms can and do compete using spectrum above 1 GHz. Even if a

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[18] *Fifteenth CMRS Competition Report*, ¶ 267 and note 764. More generally, the *National Broadband Plan* calls for an additional 300 MHz of spectrum to be allocated to mobile wireless by 2015 and for a total of 500 MHz to be added by 2020. (Federal Communications Commission, "Connecting America: The National Broadband Plan," March 2010, at 75, *available at* http://www.broadband.gov/download-plan/, site visited November 26, 2012.)

[19] *T-Mobile Comments* at 23-25; *PISC Comments* at 67-68; *Sprint Nextel Comments* at 9-10; *CCA Comments* at 8-10.

service provider were to acquire 100 percent of the licenses for spectrum below 1 GHz, rivals firms would not be foreclosed from competing. In fact, carriers have entered and competed effectively using *only* spectrum above 1 GHz. An obvious example is T-Mobile USA, which competes almost entirely with PCS (1900 MHz) and AWS (1700/2100 MHz) spectrum, yet has market share in particular CMAs as high as 50 percent and a nationwide subscriber share of 11.8 percent.[20] Both the Commission staff and the U.S. Department of Justice have argued that T-Mobile USA is an effective and important competitor.[21] Other examples include Leap Wireless, Metro PCS, and Clearwire.[22]

11. The fact that, due to its propagation characteristics, low-frequency spectrum is more valuable in some areas than is high-frequency spectrum *does not* imply that control of low-frequency spectrum alone can serve as the basis for a foreclosure strategy or that this spectrum is particularly important for competition. Some proponents of low-frequency caps have claimed that carriers using high-frequency spectrum may be foreclosed from competing due to high costs associated with building required network infrastructure. But this argument fails to recognize that, to the extent that high-frequency spectrum necessitates greater additional facilities investment to achieve a certain degree of coverage, the equilibrium market price of that spectrum

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[20] The Commission's *Spectrum Dashboard* lists T-Mobile as the holder of a Cellular license in one CMA and as the holder of a 700 MHz license in one other CMA. Otherwise, all of T-Mobile's spectrum holdings are in the PCS and AWS bands. In CMA 304, Joliet, IL, T-Mobile has an estimated market share of 49.5 percent. (*AT&T Market Share Estimates*.) National share of subscribers is from *Fifteenth CMRS Competition Report*, Table 4.

[21] Second Amended Complaint, *United States, et al. v. AT&T, Inc. and T-Mobile USA, Inc.*, Civil Action No. 11-01560 (ESH), September 30, 2011, ¶¶ 33 and 35; *Applications of AT&T Inc. and Deutsche Telekom AG for Consent To Transfer Control of the Licenses and Authorizations Held by T-Mobile USA, Inc. and Its Subsidiaries*, Staff Analysis and Findings, WT Docket No. 11-65, November 29, 2011, ¶¶ 21 and 22.

[22] See *Israel and Katz Initial Declaration*, ¶ 61and *Israel and Katz Reply Declaration*, ¶¶ 50-54 and references cited therein.

can be expected to be lower, thus *offsetting* the higher cost of expansion.[23] Consequently, even if spectrum differs in quality, a potential entrant or expanding incumbent can either: (a) buy expensive, "good" spectrum and then pay less in additional investment to reach a given capacity level, or (b) buy less-expensive, "bad" spectrum and then pay more in additional investment.

12. In order to demonstrate a credible threat of foreclosure based on low-frequency spectrum alone, one would need, as a starting point, to establish the following necessary (but not sufficient) condition: that there exists a tight linkage between concentration of low frequency spectrum holdings and market concentration in downstream mobile wireless markets.[24] Absent demonstration of such a linkage, the entire enterprise of regulating low-frequency spectrum aggregation lacks a sound rationale. However, an examination of data for concentration of spectrum holdings below 1 GHz and concentration of estimated market shares shows no evidence for any strong positive correlation between the two.[25]

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[23] For this reason, data examined by Information Age Economics and others showing that low-frequency spectrum licenses sell for more per MHz-POP than high-frequency licenses, at most, demonstrate that spectrum markets function efficiently. (Martyn Roetter and Alan Pearce, "The Impact of Bidding Eligibility Conditions on Spectrum Auction Revenues," Information Age Economics, February 2013.)

[24] It is important to recognize that, although a necessary condition, establishing the existence of such a linkage is *not* a sufficient condition for the existence of foreclosure concerns. There are many reasons for this conclusion, including the facts that: (a) the causality underlying such a linkage might run in the reverse direction, and (b) greater market concentration is not necessarily bad for consumer welfare (*e.g.*, if concentration has increased because one company has done an exceptionally good job at satisfying consumer desires or if concentration promotes economies of scale).

[25] *Israel and Katz Reply Declaration*, ¶ 47. Despite the data, a proponent of the spectrum screen might argue that such a relationship would emerge if one were to examine much higher levels of concentration of spectrum holdings than have been observed to date. Although the emergence of such a relationship is a theoretical possibility, the fact remains that the available data do not suggest such a finding.

13. Lastly, if there were any concern about a risk of foreclosure—as we have shown there should not be—it would be better identified and addressed through public policies other than caps or other rigid spectrum-aggregation limits. Specifically, competition, consumers, and, thus, the public interest would be best served by a reinvigorated commitment to use of a spectrum screen (set at a level equal to at least one-third of suitable spectrum, counting all suitable frequencies equally) as a true safe harbor. The screen should be coupled with case-by-case review of instances where spectrum holdings exceed the screen in local markets, with that review utilizing clear principles transparently applied. In those situations where case-by-case review is undertaken, remedial action should be taken only when principled analysis demonstrates likely harm to competition in one or more local markets for mobile wireless services. Moreover, any remedies should be carefully targeted to just the specific competitive harms triggered by the transaction in the market or markets in which those harms occur.

14. In summary, viewed against the benchmark of a tailored policy, spectrum caps have no public-interest benefits. Combined with the fact that rigid caps on spectrum aggregation or limits on auction participation would distort competition in both upstream and downstream markets, by far the most likely effects of such caps and limits would be to harm consumers.

B. RESTRICTIONS ON PARTICIPATION IN THE FORWARD AUCTION FOR 600 MHZ SPECTRUM WOULD HARM COMPETITION AND CONSUMERS

15. Several commenters advocate limits that would apply specifically to spectrum acquired in the 600 MHz auctions.[26] Public Interest Spectrum Coalition and United States Cellular Corporation, for instance, propose that no bidder in the 600 MHz auction should be allowed to

[26] *PISC Comments* at 66; *US Cellular Comments* at 30-34; *Sprint Nextel Comments* at 9-10; *Cellular South Comments* at 5-6.

acquire more than a given percentage of 600 MHz spectrum in a given market area.[27] Sprint proposes that limits on the amount of spectrum that an applicant could acquire in the 600 MHz auctions apply only to applicants with more than one-third of available spectrum below 1 GHz.[28]

16. In this part, we analyze the effects of limits on auction participation—whether structured as general spectrum caps or auction-specific participation limits—and find that they would harm competition and consumers in mobile wireless services markets and would also run a significant risk of reducing auction revenues and, thus, the reallocation of spectrum from broadcasting to mobile wireless services, further harming consumers of mobile wireless services.

1. Limits on participation in the 600 MHz auctions would very likely harm consumers of mobile wireless services.

17. The logic that, except in cases of clear market failure, the competitive process should be relied on to allocate assets applies with equal force to spectrum auctions (in the primary market) as to other transactions (in the secondary market). As such, initial spectrum rights assignments should generally go to the highest-value users through a competitive bidding process in an auction, and a freely functioning secondary market should facilitate license reassignment. Industry participants now have sufficient experience with auctions, license transfers, and

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[27] US Cellular proposes that no applicant should be "allowed to acquire more than 25 percent of the repurposed broadcast spectrum made available for auction in any licensed market area." (*US Cellular Comments* at 32.) Public Interest Spectrum Coalition claims that a limit equal to one-third of the 600 MHz spectrum available at auction would be "too high considering the unique propagation characteristics of 600 MHz spectrum…" (*PISC Comments* at 66.)

[28] *Sprint Nextel Comments* at 9-10. Sprint does not specify the limit it proposes, but states that the limits "require tailoring based on the type of band plan (TDD, FDD, technology neutral, or a combination) and the specific amount of spectrum made available for mobile broadband." In addition, it proposes to "prohibit any operator with more than one-third of the spectrum below 1 GHz from acquiring more than one 5x5 megahertz license in the higher-frequency pairing if the amount of spectrum made available requires implementation of two frequency-pairing blocks." (*Id*.)

Commission policies that there is no need for a hard spectrum cap that places *ex ante* limits on the abilities of firms to bid for spectrum licenses at auction. Instead, *ex ante* guidelines, coupled with *ex post* review and (where appropriate) remedies, will better protect competition and promote consumer welfare.

18. Commenters including T-Mobile USA acknowledge the benefit of case-by-case analysis for secondary-market spectrum transactions, but argue that a hard cap should apply to auctions.[29] This proposal defies economic logic for several reasons.

19. First, the arguments against rigid limits on spectrum holdings summarized above apply to any transaction, whether in a primary auction or a secondary market. The goal of aggregation policy should be to permit pro-competitive outcomes and prevent only those outcomes that create a real risk of foreclosure, regardless of the institutional form of the transaction. No rigid spectrum aggregation limit, whether applied to auctions or secondary-market transactions, can accomplish this goal.

20. We note that, even if a regulator sought to influence competitive market outcomes in a manner that went beyond simply preventing foreclosure—which would be misguided for the reasons discussed above and in our previous declarations—restricting participation in auctions for 600 MHz spectrum alone would be a particularly poor way to do so. Sensible competition policy cannot focus on ownership of a small subset of available inputs while ignoring the fact that many firms compete effectively using spectrum in other bands. Moreover, the threat of foreclosure is especially weak in the case of auctions for newly released spectrum because such

[29] *T-Mobile Comments* at 27-33.

auctions necessarily increase the amount of spectrum in the market without reducing the spectrum holdings of any firm.

21. To the extent that analysis of the outcome of a particular auction reveals that spectrum holdings are excessive, a remedy can be applied after the auction has closed. The Commission and U.S. Department of Justice now have extensive experience dealing with a wide range of transactions involving spectrum licenses. A firm bidding in a primary auction would understand the regulatory risk associated with license acquisitions (particularly large ones) that push it above the safe harbor screen. But such a firm would also know that it would have the right to defend its acquisitions in a regulatory or judicial proceeding and, thus, could choose to make the acquisition if it viewed the pro-competitive case for the acquisition as sufficiently strong. A firm might also purchase spectrum knowing that it would have to divest other spectrum in order to obtain regulatory approval. Such a strategy could be economically rational and pro-competitive if it allowed the firm to obtain spectrum that better fit with its business and network strategies than did its existing holdings.

22. Finally, applying one set of rules to auctions and another to secondary markets creates arbitrage opportunities. Economic forces generally lead to assets being held by the users who value them most. If the highest-value user of a particular spectrum license were prevented from acquiring the license in an initial spectrum license auction, it should be expected to eventually acquire the license (or at least the ability to make use of the associated spectrum rights) from the auction winner through a later, secondary-market transaction. Thus, attempts to regulate primary auctions in isolation will very likely be undone by secondary-market transactions.

23. However, secondary markets are subject to delays and transaction costs. Efforts by excluded firms to assemble multiple complementary licenses won by different bidders in the secondary market will be especially burdensome. Thus, restrictions on auction participation could induce delays in the use of spectrum and trigger transaction costs because of the need for licenses first to go through the initial assignment process and then to be reassigned through secondary-market transactions.

24. The Commission could attempt to block secondary-market transactions, but doing so would raise difficult and important issues. Specifically, if an eligible bidder has won one or more licenses in an auction, what restrictions—if any—should it face with respect to secondary-market transactions? For example, could it sell its licenses to any willing buyer, or would the buyer have to be an entity that would have been eligible to bid for the license in the primary auction? Alternatively, would a winning bidder for a particular spectrum license be allowed to sell capacity on its network to an ineligible entity or enter into some other sort of network-sharing arrangement?

25. The Commission could ban or limit resale and sharing arrangements with entities that were not themselves eligible to bid for the licenses in the primary auction, but that would not be a sound policy. Entry and expansion are uncertain propositions. For example, entrants frequently learn through experience that they do not have attractive business models and seek to exit the market. The most attractive exit option may be to sell spectrum licenses (and possibly other assets) to incumbent service providers. From a social welfare point of view, selling spectrum licenses to an incumbent through a secondary-market transaction would redirect spectrum to a higher-value use and, thus, generate social benefits. Moreover, by reducing an

entrant's exit options, a ban on resale transactions could discourage initial entry (or expansion) attempts. A new firm could be discouraged from attempting to enter the market if it knew that it did not have the option of selling its assets to others, including incumbents, if the entrant's business plans did not pan out.

2. Limits on participation in the 600 MHz auctions would very likely reduce revenues.

26. Restricting auction participation would also threaten to reduce both auction revenues and the amount of spectrum allocated to mobile wireless services. If high-value bidders are excluded from the auction, the winning bid in the auction will be driven by the value the non-excluded bidders believe they can receive in the secondary market. If there were no asymmetric information or other frictions interfering with the secondary market, one might expect that restrictions applied solely to a primary auction would have no effect on either the ultimate user of the spectrum rights or the price paid at auction: All bidders would bid up to the secondary-market value of the spectrum, where the highest-value user would acquire the spectrum use rights.

27. However, the intuition that revenues would not decrease from excluding the high-value bidders assumes that the seller in the secondary market can obtain the same price as would have been achieved in an unrestricted primary auction. This is unlikely to be the case for various reasons. Consider a simple example in which there is one license for sale, two large bidders, and many small bidders. Bidder valuations are

$$v_1 = 8$$
$$v_2 = 7$$
$$v_3 = 5$$

where the large bidders have valuations v_1 and v_2, respectively, and we all small bidders have the same valuation v_3 (this assumption is for simplicity and is not essential). In an unrestricted auction, the license would sell for a price of $7.

28. Now suppose that the two large bidders are excluded from the auction, but may buy in the secondary market. Suppose the secondary market is fully efficient and the buyer and seller equally split the gains from trade. Each small bidder anticipates that, if it wins the auction, it will be able to sell at a price of $6.5 (splitting the total gains from trade, which equal $8 – $5). Auction revenues thus fall to $6.5. Whether the assumption that the buyer and seller equally split the gains from trade in a secondary market is reasonable depends on the relative bargaining position of large and small bidders. However, auction revenue would increase only if the small bidder can obtain a price in the secondary market that is higher than the price of $7 that an unrestricted primary auction would have produced. This outcome seems highly implausible. At best, there might be circumstances in which the reseller could obtain as much revenue as the auction would generate.[30] Even this seems unlikely. Resale of spectrum takes place primarily through bilateral negotiations, which typically do not permit the seller to extract as large a share of the gains from trade as would be achieved in an auction. In summary, auction revenue will very likely fall even in the absence of delays and distortions in the secondary market.

29. The reduction in auction revenues from participation restrictions would be even greater because the secondary market is not frictionless. Secondary markets are subject to delays and

[30] For example, if bidders 1 and 2 would still value the license at $8 and $7, respectively, in the secondary market after having been excluded from the primary auction (*i.e.,* being excluded did not cause the bidders to pursue different spectrum aggregation strategies), then by holding an auction in the secondary resale market the seller would achieve a price of $7.

transaction costs. There may also be considerable uncertainty regarding the price that a seller can obtain in a secondary market, including uncertainty regarding whether regulatory authorities will permit a secondary-market transfer to excluded bidders. These frictions reduce the gains from trade realized in the secondary market. Anticipating these distortions, the bidder's willingness to pay in the primary auction will be reduced as well, harming auction revenues. For instance, in the numerical example above, if frictions in the secondary market destroy $1 of surplus, the willingness to pay of bidder 3 in the auction (and thus the auction revenue) would decline from $6.5 to $6.

30. In addition, auction-only caps can lead to windfall profits for private entities that submit winning bids on spectrum licenses at auctions, then turn around, and sell them for a profit to excluded bidders. This can arise, for example, if one of the non-excluded bidders is in a better bargaining position than other bidders to extract rents from the buyers in the secondary market. The firm with superior ability to extract rents in the secondary market would pay less in the primary auction than the price it can obtain in the secondary market, thereby generating windfall profits. These windfall gains would come at the expense of forward-auction revenue, risking inefficient reduction in the quantity of spectrum reallocated to mobile wireless services.

31. T-Mobile USA argues that limiting auction participation by the largest wireless providers (via a "market-based spectrum cap") might encourage participation by other, smaller providers and, thus, might actually *increase* auction revenue.[31] In support of this counterintuitive claim, T-Mobile cites to 2000 Senate testimony by Professor Cramton, in which he outlines a theory that smaller "non-incumbents" may be unwilling to participate in an auction if they think they

[31] *T-Mobile Comments* at 33.

have little chance of winning, enabling incumbents to obtain spectrum at low prices.[32] However, as we will discuss below, such a theory depends on several critical assumptions that do not appear to be met in the current context.

32. Absent satisfaction of the assumptions underlying T-Mobile's theory, basic economic theory indicates that greater auction participation, particularly by firms having high valuations of the licensees being auctioned, is likely to increase auction revenue. Indeed, the testimony by Professor Cramton, to which T-Mobile cites, states that "[t]ypically, spectrum caps lower auction revenues…".[33] Consistent with this conclusion, an analysis of 2008's Auction 73 of 700 MHz spectrum found that "given the low valuations the small players were willing to pay, the auction would have raised less than half the amount it actually raised if AT&T and Verizon Wireless had been excluded from the 700 MHz auction."[34]

33. The central premise of T-Mobile's and Professor Cramton's theory is that most potential bidders would stay out of the auction because the costs of participating in the auction would be large relative to the expected benefits of participation.[35] For this to be the case, firms other than AT&T and Verizon Wireless would have to be so certain that they would win no spectrum from

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32 Peter Cramton, "Lessons from the United States Spectrum Auctions," Before the United States Senate Budget Committee, February 10, 2000 (hereinafter, *Cramton Testimony*).

33 *Cramton Testimony* at 3.

34 Anna-Maria Kovacs, "The merits of open and competitive spectrum auctions," *Fierce Wireless*, March 13, 2012, *available at* http://www.fiercewireless.com/story/merits-open-and-competitive-spectrum-auctions/2012-03-13, site visited February 24, 2013 (hereinafter *Kovacs Auction Analysis*).

35 In this Senate testimony, Professor Cramton makes vague reference to the "incentive and ability to secure the needed financing from capital markets." (*Cramton Testimony* at 3.) However, this is not a plausible argument for the existence of fixed costs sufficient to deter auction participation by small providers. The costs of reaching out to investors appears low relative to the value of spectrum and, because providers always have the option of re-selling spectrum on secondary markets, investors should be willing to finance purchase of spectrum at any price up to the highest value that any user is expected to have for the spectrum.

the auction that, despite the enormous value of the spectrum rights at auction, auction participation costs would dominate the expected benefits of winning. Perhaps one could consider such a theory as plausible if one or a small number of licenses for which AT&T or Verizon Wireless were known with certainty to have this highest value were up for bid. But in the present case, with many licenses up for bid in many different regions, the logic fails. As long as there is a reasonable chance that a smaller service provider will win *some* of the licenses it desires, the value of those licenses very likely outweighs the costs of auction participation. Bidder participation is especially likely under the proposed clock auction design with generic licenses because these features of the auction design greatly simplify bidding and eliminate many opportunities for strategic bid manipulation that existed in the Simultaneous Multi-Round auction design used in prior FCC spectrum auctions. Once a provider is in the auction, the provider is free to bid on licenses everywhere—even if only later to lease or re-sell them to another provider in the secondary market. These facts make it highly unlikely that AT&T or Verizon Wireless could get the licenses "on the cheap."

34. In evaluating the plausibility of Professor Cramton's theory, it is essential to avoid confusing average and marginal valuations. Even if AT&T and Verizon Wireless were to place the highest value on spectrum licenses on average, it is highly unlikely that they will have the highest marginal valuations for all the licenses that will be up for bid. Given the enormous value of the spectrum to be auctioned, even a reasonable chance that a given bidder will have the highest marginal valuation for some of the licenses it desires—and thus have a reasonable chance of winning those licenses—is likely to be sufficient to encourage that provider to enter the auction.

35. In contrast to the theoretical suppositions of T-Mobile and Professor Cramton, market experience indicates that smaller bidders are not deterred from license auctions. For example, in Auction 73, the 2008 auction of 700 MHz spectrum:[36]

> Small players were not crowded out of the market. They not only won more than their proportionate share, they paid far less for it. In fact, 28 percent of the spectrum was sold to companies that collectively represented less than 10 percent of the subscribers in the market at the time and paid only 14 percent of the auction proceeds."

36. Finally, T-Mobile's and Professor Cramton's argument is notably lacking a limiting principle. Where does this logic end? If AT&T and Verizon Wireless were excluded from the auction, does that leave T-Mobile and Sprint as the most obvious winners? So, at that point, should they also be excluded from participation? How much uncertainty in values does there need to be before one would stop eliminating high-valuation bidders from an auction? And how would the Commission determine the degree to which industry participants were uncertain about one another's valuations of the licenses? Such a policy of fine-tuning who may participate in an auction in hopes of maximizing revenue is dangerous enough when the risk is simply lower forward-auction revenue. In the current context, when reducing revenue may cause the entire auction to fail or to clear less spectrum for mobile wireless use, the gamble of removing high-valuation bidders in hopes that the rest will more than make up the gap seems especially ill advised.

37. Information Age Economics (IAE) cites data that it claims demonstrate that bidding restrictions do not lower auction revenues.[37] Data analysis can in principle be an important tool

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[36] *Kovacs Auction Analysis*, note 34, at 2.

[37] Martyn Roetter and Alan Pearce, "The Impact of Bidding Eligibility Conditions on Spectrum Auction Revenues," Information Age Economics, February 2013 (hereinafter, *IAE Study*).

for resolving theoretical ambiguities and guiding policy, and there is a large tradition of using empirical analysis to asses and predict market outcomes, both the in the academic economics literature and in the practice of competition policy. However, the IAE study ignores even the most basic principles of this tradition and suffers from numerous significant flaws as a result. Comparisons of outcomes in different settings must account for all relevant variation in these settings to avoid attributing variation in outcomes to the wrong features. This is among the most elementary lessons of econometrics and statistical analysis. The IAE study repeatedly fails to do this.

38. One example of IAE's flawed research methodology is its comparison of prices in auctions with bidder eligibility restrictions to prices paid by Verizon Wireless for the Upper C Block in the 700 MHz auctions.[38] The study neglects entirely the open-access requirements imposed on that license, which alone may easily account for the observed differences in the value of the spectrum.

39. Another example of the flawed methodology used in the IAE study is the repeated attempts to draw lessons from cross-country price comparisons without adequate controls for cross-country differences.[39] As the study's authors themselves concede, many different factors affect equilibrium auction prices.[40] This includes auction design, the scale, population density and topography of the market (*e.g.*, the entire U.S. versus a single European country), the existing stock of spectrum, the past technological choices of carriers in deployment, consumer demand, local industry structure, the local regulatory environment, and the availability of

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38 *IAE Study* at 7-8.

39 *IAE Study* at 8-20.

40 *IAE Study* at footnote 18.

substitute and complementary services. The IAE study controls for none of these factors, instead arguing informally that some of these features are not too different across countries and asserting that comparisons without formal controls for heterogeneity are valid.[41] This assertion is not credible and is inconsistent with standard practice in cross-market comparisons of policy outcomes.

40. A second fundamental lesson of modern econometric policy analysis is the need to control for "endogeneity," which here is the fact that observed variation in policy toward bidder eligibility is not assigned randomly but is instead based on local factors, including regulators' beliefs about the likely effects on the competitiveness of the auction. The IAE study completely fails to address endogeneity and, thus, the study's findings are not reliable.

41. Lastly, the IAE study compares license prices under spectrum caps based on only holdings of newly licensed spectrum to license prices under caps based on all of a bidder's spectrum holdings, presumably to show that caps that apply to providers with large existing spectrum holdings had a positive impact on auction revenues.[42] But again, the study does not control for exogenous differences between the auctions or for potential endogeneity of the auction policies. Moreover, it is evident that caps applied to newly-licensed spectrum can depress the winning bids by limiting the ability of high-valuation auction participants to bid on some of the licenses that they would otherwise wish to obtain. Thus, the comparison does not show that auction revenues did not decline when caps are based on existing spectrum holdings.

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[41] *IAE Study* at 11 ("Given the similarities between the U.S. and Europe, the results of digital dividend auctions in Europe are relevant to an evaluation of the potential use of BECs in the U.S.") However, the authors also recognize that there are "several factors in addition to BECs that influence and may have a greater impact in some cases than BECs on the prices of spectrum licenses." (*Id.*)

[42] *IAE Study* at 12 and footnote 19.

42. In fact, the data cited by IAE demonstrates that bidding restrictions can have significant, adverse effects on auction revenues. For instance, the study reports that, in the 2010 Mexican AWS auction, a "cap effectively disqualified all but one entity (Nextel International)" from bidding on the license offered on a national basis and that, "not surprisingly, this national AWS license was awarded at the reserve price that was set."[43]

III. A POLICY OF PROVIDING CREDITS TO BIDDERS BASED ON THEIR CURRENT LICENSE HOLDINGS WOULD BE FUNDAMENTALLY UNSOUND AND UNWORKABLE

43. MetroPCS Communications, Inc., Leap Wireless International, Inc., and Cricket Communications, Inc. advocate a policy under which firms with relatively small current license holdings would be given bidding credits.[44] MetroPCS proposes that "credits should be given to applicants in inverse proportion to the amount of attributable spectrum that the applicant holds in the auctioned license territory": Applicants with 0 to 35 MHz of attributable spectrum would receive a 60 percent credit; applicants with 35 to 70 MHz would receive a 40 percent credit; and applicants with 70 to 105 MHz would receive a 20 percent credit.[45] Leap Wireless and Cricket Communications similarly propose that credits should be awarded "in inverse proportion to the

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43 *IAE Study* at 5-6.

44 Comments of MetroPCS Communications, Inc., *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-268, January 25, 2013 (hereinafter, *MetroPCS Comments*) at 26-27; Comments of Leap Wireless International, Inc. and Cricket Communications, Inc., *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-268, January 25, 2013 (hereinafter, *Leap Wireless/Cricket Comments*) at 6.

45 *MetroPCS Comments* at 26-27.

amount of spectrum that an applicant holds in a geographic area," but do not provide a specific schedule of proposed credits.[46]

44. Such a scheme would harm consumers and competition in several ways, which we discuss in turn.

A. BIDDING CREDITS WOULD VERY LIKELY LOWER AUCTION REVENUES.

45. Offering bidding credits to firms with smaller current license holdings is very likely to reduce auction revenue. First, suppose that resale is prohibited. Holding auction participation constant, it is not possible for bidding credits to change the allocation of a license without lowering the revenue the license generates: If the credits lead to a different winner than would occur absent the credits, then it must be that the winner in the presence of credits had a willingness to pay (after netting out the credits) below what would have been the winning bid in an auction where no bidder received credits.[47] But if, when credits are granted, the winning bidder's net willingness to pay is less than the alternative equilibrium price, then it must be the case that the auction revenues net of the bidding credits are lower as well.[48]

46. Arguments that bidder preferences might not harm auction revenues are based on the speculation that revenue losses will be offset by licenses for which the allocation does not

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46 *Leap Wireless/Cricket Comments* at 6.

47 One could argue that, in theory, smaller providers would not participate in the auction without bidding credits because they believe they have little chance of winning some spectrum, enabling AT&T and Verizon Wireless to obtain spectrum at low prices. Such a theory is analogous to the claims that T-Mobile makes in the context of participation limits. As described in detail above, such a theory is based on several critical assumptions that do not appear to be met in practice.

48 Moreover, there would be a loss in auction revenues if one bidder were eligible for larger subsidies than others. That bidder would enjoy windfall profits by outbidding rivals (while paying less than rivals offered) and then turning around to sell the licenses for a profit to the service provider with the highest unsubsidized valuation.

change, but the more-aggressive bids of preferred bidders lead to higher prices. The existence of such offsetting licenses is a theoretical possibility but one that requires there to be: (1) insufficient competition between high valuation bidders, and (2) a seller who can identify low-valuation bidders.[49] Further, "knowing the magnitude of the difference in reservation prices between strong and weak bidders is critical to calculating the size of the subsidy necessary to increase expected revenue."[50] Empirical observation suggests that this combination of requirements is quite rare. For example, as Ayers and Cramton point out, professional auction houses do not subsidize weak bidders.[51] More important, these conditions seem especially unlikely to apply in the 600 MHz forward auction. For instance, there is significant competition for spectrum between high-value bidders (including AT&T, Verizon Wireless, and other providers that have won licenses in previous auctions). Moreover, it seems unlikely that it would be feasible to identify low-value bidders. For instance, small carriers such as Metro PCS and Leap Wireless have won licenses in previous auctions, indicating that they were the highest-value bidders for that spectrum. And, in any case, there are no data that would enable the Commission to determine the bidding credit levels necessary to raise revenues rather than lower them.

47. If resale of licenses is permitted, then the conditions that can enable bidding credits to enhance revenue are especially unlikely to hold. To see this point, begin with an example. Consider a setting in which there is one high-valuation bidder and many low-valuation bidders. Let bidder 1 have valuation 9 while, for simplicity, all other bidders have valuation 3. This is the

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[49] Ian Ayres and Peter Cramton (1996) "Deficit Reduction Through Diversity: How Affirmative Action at the FCC Increased Auction Competition," *Stanford Law Review*, **48**(4): 761-815.

[50] *Id.* at 769.

[51] *Id.*

type of setting in which it is often imagined that bidding credits, while not changing the ultimate allocation, could enhance revenues by creating more intense competition against the high-valuation bidder. Suppose that the resale market is efficient and that any gains to resale trade are split equally between buyer and seller (neither simplification is essential). This means that if a low-valuation bidder wins the auction, resale will occur at a price of 6. Anticipating this, all bidders are willing to pay a price of 6, so the auction revenue is 6. Now consider giving the low valuation bidders a 25 percent bidding credit. Here this policy changes the bidding behavior only of the low-valuation bidders: each is willing to pay up to 6 from its own funds, which means it is willing to bid up to 8. Now the auction ends at the price of 8, with the net revenue (accounting for the 25 percent discount) of 6.[52]

48. Thus, when resale is possible, even the configuration of valuations typically used to show how bidding credits could sometimes enhance revenue fails to do so

B. BIDDING CREDITS FOR FIRMS WITH RELATIVELY SMALL CURRENT LICENSE HOLDINGS WOULD EITHER BE INEFFECTIVE OR THE COMMISSION WOULD HAVE TO SEVERELY RESTRICT SECONDARY MARKETS, THUS HARMING CONSUMERS

49. As illustrated above, with an efficient secondary market, the service provider with the highest unsubsidized valuation will eventually obtain rights to the spectrum through the secondary market but only after significant inefficiencies in the form of transaction costs and delays.[53]

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[52] One can even construct examples in which auction revenues would strictly fall when some firms receive larger bidding credits than others or there are other asymmetries among firms receiving bidding credits.

[53] See Section II.B above.

50. Concerns that the introduction of additional bidding credits would lead to inefficiency, revenue losses, and windfall profits are not mere speculation. The Commission has a long history of favoring certain bidders in ways that do not affect the ultimate use of the spectrum, but that do create various windfalls and short- to medium-term distortions in spectrum use. For example, in response to Congressional legislation, the Commission set aside the C and F blocks in the 1995-1996 auctions of Personal Communications Service spectrum licenses for small, entrepreneurial firms known as "designated entities." The Commission also implemented spectrum set-asides in Auction 35, which were designed to encourage the entry of new wireless network operators. In each of these cases, the set-aside process generated significant administrative and transaction costs, delayed the utilization of valuable spectrum, and very likely reduced auction revenues. Indeed, an analysis conducted by Verizon Wireless conservatively found that, measured on a MHz-per-POP basis, approximately two-thirds of the C- and F-block licenses are held today by entities that would have been ineligible to participate in the original auctions.[54]

51. For the reasons identified in above, restrictions on secondary markets to prevent the resale and sharing arrangements with entities that were not themselves eligible for bidding credits in the primary auction would not be sound policy.[55] The Commission itself has recognized the value of secondary-market transactions between the owners of licenses that were

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[54] Verizon Wireless analysis of data from Regular and Active, Radio Service Code: CW – PCS Broadband, Market Based License Search, *available at* http://wireless2.fcc.gov/UlsApp/UlsSearch/searchMarket.jsp, site visited May 17, 2012. The study is conservative in that it assumes only AT&T, Sprint Nextel, T-Mobile, U.S. Cellular, and Verizon Wireless would have been ineligible to bid.

[55] See Section II.B above.

obtained through special treatment and incumbent carriers that were not eligible for that treatment.[56]

C. USE OF SPECTRUM-HOLDINGS-BASED BIDDING CREDITS RISKS DISTORTING COMPETITION IN MOBILE WIRELESS SERVICES MARKETS RATHER THAN PROMOTING IT.

52. Proponents of spectrum-based bidding credits argue they will help establish new service providers or strengthen smaller incumbents (*e.g.*, by providing additional spectrum depth in markets already served or by extending service to new markets). These proponents argue that credits are needed because entrants and smaller incumbents allegedly would be unable to win in bidding against larger incumbents due to the latter's greater valuations or incentive to engage in spectrum warehousing. But bidding credits run counter to the objective of enhancing competition in wireless services markets. Similar to restrictions on auction participation, bidding credits would distort and weaken competition in downstream markets by limiting the ability of those service providers most successful at satisfying consumer desires to expand, limiting the realization of economies of scale, and reducing innovation and investment incentives over the long term. There is no evidence that such bidding credits would generate public-interest benefits that could offset these market distortions.

IV. PROPONENTS OF INCREASED ALLOCATION OF SPECTRUM FOR UNLICENSED USES FAIL TO ADDRESS THE FUNDAMENTAL ISSUES AND PROVIDE RELEVANT FACTS

53. Google and Microsoft assert that a large portion of the repurposed 600 MHz spectrum should be removed from auction and made available free of charge for unlicensed uses.[57] They

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[56] For example, as mentioned above, the Commission eased its restrictions on the transfer of C- and F-block licenses won by designated entities to incumbent wireless carriers and other firms that were not eligible to bid for these licenses in the primary auctions. (*See Sixth Report and Order*, § III.G.)

claim that doing so would create significant consumer benefits and would not threaten auction revenues. In this section, we examine these assertions and find that neither is well founded.

A. GOOGLE AND MICROSOFT OFFER NO SOUND BASIS FOR THE CLAIM THAT ALLOCATING SPECTRUM TO UNLICENSED USES WOULD GENERATE GREATER CONSUMER BENEFITS THAN ALLOCATING IT TO LICENSED USES

54. According to Google and Microsoft, additional 600 MHz spectrum should be allocated to unlicensed uses because doing so would create significant consumer benefits.[58] They base their claim of additional benefits on the assertion that Wi-Fi, Bluetooth, and other technologies using unlicensed spectrum have generated significant benefits for consumers.[59] There are two fundamental flaws with this line of reasoning. First is that it ignores the opportunity cost of the spectrum. The relevant question for a public-interest assessment of spectrum allocation is not whether unlicensed uses generate considerable consumer benefits—they plainly do—but whether the uses enabled by an *incremental* unlicensed allocation of *600 MHz spectrum* would generate greater benefits than would allocation of that spectrum to licensed uses, taking into account both the direct consumer benefits of each and the consumer benefits of any resulting auction revenues. The second flaw in Google and Microsoft's line of reasoning is that it confuses the value of Wi-Fi and other technologies with the value of unlicensed access. The two are not equivalent. For example, "Super" Wi-Fi or whatever other services Google and Microsoft may contemplate could be offered under a licensed model. Consequently, even if such services were the highest-

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57 Comments of Google Inc. and Microsoft Corporation, *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-268, January 25, 2013 (hereinafter, *Google-Microsoft Comments*).

58 *Google-Microsoft Comments* at 28 ("designating spectrum for unlicensed use from reclaimed spectrum in the 600 MHz band will generate enormous economic value for the national economy.").

59 *Google-Microsoft Comments* at 4-8.

value use of spectrum at the margin, it would not follow that the Commission should allocate more spectrum to unlicensed uses. In the remainder of this part, we discuss both flaws in more detail.

1. Google and Microsoft ignore opportunity cost.

55. Google and Microsoft support their request of additional unlicensed spectrum by stating that "[r]ecent studies calculate the annual contribution of the unlicensed wireless sector to be between $50 and $100 billion per year."[60] Google and Microsoft also refer to a paper commissioned by Google in which Paul Milgrom, Jonathan Levin, and Assaf Eliat discuss estimates of the "value created by current applications of unlicensed spectrum [of] $16-37 billion dollars a year in the United States alone."[61]

56. We note, in passing that, if total value created were the appropriate metric, then one clearly would conclude that all 600 MHz spectrum should be allocated to licensed uses: The value of licensed spectrum far exceeds the value of unlicensed uses. For example, according to a widely-cited study, wireless services in the U.S. generated $502.7 billion in consumer surplus in 2010.[62]

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60 *Google-Microsoft Comments* at 7.

61 Paul Milgrom, Jonathan Levin, and Assaf Eliat, "The Case for Unlicensed Spectrum," Stanford Institute for Economic Policy Research, Policy Paper No. 10-036, October 12, 2011 (hereinafter, *Milgrom et. al*) at 2, citing Richard Thanki, "The Economic Value Generated by Current and Future Allocations of Unlicensed Spectrum," Final Report, Perspective Associates, September 8, 2009, at 4.

62 Roger Entner, "The Wireless Industry: The Essential Engine of U.S. Economic Growth," Recon Analytics, May 2012, *available at* http://reconanalytics.com/wp-content/uploads/2012/04/Wireless-The-Ubiquitous-Engine-by-Recon-Analytics-1.pdf, site visited February 27, 2013.

57. More important, the total value derived from current uses of Wi-Fi is largely irrelevant to the question at hand. The relevant issue is the *net, incremental* value from allocating a certain amount of 600 MHz spectrum to unlicensed uses. Increased allocation of unlicensed spectrum may create consumer benefits, but these incremental benefits must be assessed in relation to the opportunity cost of such spectrum, which is driven by the consumer benefits that the spectrum would create if licensed. The key question is which spectrum allocation would yield the greatest benefits at the margin. Google and Microsoft fail to address the relevant question.

58. The opportunity cost of allocating 600 MHz spectrum to unlicensed uses is likely to be very large. Spectrum for licensed uses will undoubtedly create significant consumer benefits. It is undisputable that wireless carriers will face significant spectrum shortages, as new access devices and applications have dramatically increased demands on mobile wireless networks. The dramatic growth in demand will require mobile wireless providers to make significant investments in network infrastructure and technological advances in the spectral efficiency of their "core" networks (*i.e.*, the number of bits that can be communicated over a given amount of bandwidth). Additional spectrum use rights reduce the costs to providers of meeting the growth in consumer demand for wireless networks and thereby are expected to lead to less expensive rate plans and/or higher quality services for consumers.

59. The opportunity cost of allocating additional unlicensed spectrum is likely to be especially significant in the context of spectrum in the 300 MHz to 3 GHz range, which has propagation characteristics that make it particularly well-suited for licensed wide area network

applications.[63] We understand that there is other spectrum that is well suited to unlicensed, local area network uses, and which has a lower opportunity cost in terms of the forgone value from licensed uses. For instance, the Commission recently announced a "significant increase" in high-band spectrum available for unlicensed wireless devices in the 5 GHz band, which is better suited for short-range, high-speed wireless connections such Wi-Fi.[64] The availability of alternative, lower-opportunity cost sources of spectrum that are suitable for unlicensed uses such as Wi-Fi, indicate that the value of allocating 600 MHz spectrum to unlicensed uses is highly unlikely to be greater than the opportunity cost of doing so.

60. The fundamental error in the arguments made by Google and Microsoft in support of their proposal to increase the allocation of 600 MHz spectrum to unlicensed uses becomes especially evident when evaluating the value of Wi-Fi in offloading traffic from mobile wireless networks. Google and Microsoft (as well as *Milgrom et al*.) argue that an important benefit of unlicensed spectrum is the offloading of traffic from wireless mobile networks and that, as those networks become more and more congested, the benefits of offloading through Wi-Fi networks will increase.[65] This observation is correct, but it provides no support for their conclusion that

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63 Jeffrey H. Reed and Nishith D. Tripathi, "Comparative Analysis of Suitability of Lower and Higher Frequency Bands for Cellular Network Deployments," attached as Exhibit to Joint Opposition of AT&T Mobility Spectrum LLC and Qualcomm Incorporated To Petitions To Deny Or To Condition Consent And Reply To Comments, Application of AT&T Mobility Spectrum LLC and Qualcomm Incorporated for Consent to Assignment of Licenses and Authorizations, WT Docket No. 11-18, March 21, 2011.

64 Federal Communications Commission Press Release, "FCC Acts to Significantly Increase Spectrum Available for Unlicensed Devices in the 5 GHz Band," February 20, 2013.

65 *Google-Microsoft Comments* at 13-16. Google and Microsoft claim that "Today over one-third of the Internet-bound mobile data traffic carried by the CMRS carriers is offloaded to unlicensed bands. That percentage is expected to rise over the next decade. According to ComScore, by mid-2011, 37 percent of smartphone traffic was offloaded by cellular carriers to Wi-Fi networks." (*Google-Microsoft Comments* at 14.) However, this claim conflates Wi-Fi offloading by wireless carriers with use of Wi-Fi networks by end-users themselves. Traffic from use of Wi-Fi networks

more 600 MHz spectrum should be allocated to unlicensed use. The question is whether additional spectrum allocated to Wi-Fi is more efficient in alleviating congestion in wireless networks than is additional spectrum dedicated to networks themselves. We are unaware of any evidence that it is. Certainly, Google and Microsoft do not provide any.

2. Google and Microsoft confuse the value of Wi-Fi and other technologies with the value of unlicensed access.

61. Now, consider the second fundamental flaw in Google and Microsoft's argument. Even if Wi-Fi, "Super Wi-Fi" or some other technology contemplated by Google and Microsoft were the most valuable use of spectrum at the margin, it does not follow that more spectrum should be allocated to unlicensed uses. The reason is that a wireless provider (or third party) could (and would have incentives to) utilize these technologies to offload traffic using *licensed* spectrum. Google and Microsoft make the flawed assumption that Wi-Fi or other technologies they contemplate necessarily must use unlicensed spectrum. But Wi-Fi is not synonymous with unlicensed spectrum. If Google, Microsoft, or another company believed it could generate more value by implementing Wi-Fi, Super Wi-Fi or some other technology networks, it could bid for spectrum licenses and offer services that use that spectrum.[66] Thus, the key issue is not whether

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by end-users makes up the vast majority of Wi-Fi traffic. Thus, the claim that 37 percent of smartphone traffic "was offloaded by cellular carriers to Wi-Fi networks" is incorrect and grossly exaggerates the amount of wireless traffic that is offloaded.

66 *Milgrom et al.* argue that is infeasible to have an auction to determine allocation of spectrum for licensed uses versus Wi-Fi because "too many of the beneficiaries—future innovators and consumers in the case of unlicensed spectrum—are difficult or impossible to identify at the time of the auction." (*Milgrom et al*. at 3.) However, large players such as Google and Microsoft have business models that could benefit from providing Wi-Fi services (which could be monetized, for example, by selling advertising space). Google, Microsoft, or another company also could profit from the spectrum by providing offloading services to wireless carriers. And, Google and Microsoft are certainly not short of the funds necessary bid in an auction for licensed spectrum. Thus, Google and Microsoft have the ability and incentive to bid for licensed spectrum, as evidenced by the multi-billion dollar bid by Google in the 700 MHz auction for C Block spectrum

more spectrum should be allocated to Wi-Fi versus wireless networks, but rather, the economic benefits and potential shortcomings of licensed versus unlicensed regimes for 600 MHz spectrum.[67]

62. *Licensed spectrum* refers to frequency bands that are licensed exclusively to one party for a set period of time, while *unlicensed spectrum* refers to the bands on which unlicensed users may operate wireless devices without specific authorization. That is, unlicensed spectrum refers to the absence of private property rights to the spectrum, not a specific wireless technology.[68] Establishing that allocating additional spectrum to unlicensed uses is beneficial requires a showing that the lack of private property rights is a superior organization structure for 600 MHz spectrum than assigning private usage rights.

63. As *Milgrom et al.* recognize, there are important efficiencies of assigning property rights by licensing spectrum to one party.[69] Radio spectrum is a common pool resource, which suffers from the typical "tragedy of the commons" problem where individuals overuse the resource[70] (in

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that Verizon Wireless ultimately won. The standard argument that the values of "masses" of users who would use unlicensed spectrum cannot be aggregated therefore does not seem to apply in this case.

67 It also is important to be note that even licensed spectrum is heavily shared. Indeed, a modern cellular network makes it possible for millions of users to share spectrum, and the network is open to many third party providers of devices and applications.

68 However, it is important to recognize that unlicensed does not mean unrestricted, open access. Access is regulated by the government, and conditions are imposed on particular types of uses (for instance, power requirements) in order to limit conflicts between different uses of spectrum. Thus, the tradeoff between unlicensed and licensed spectrum is not about private control versus open access, but about private versus regulated access. Regulations on devices that use unlicensed spectrum (such as power limits and other technology mandates) protect some uses at the expense of others.

69 *Milgrom et al*. at 2, 6.

70 Garret Hardin (1968) "The Tragedy of the Commons," *Science*, 162: 1243–1248. Each user, acting independently, rationally over-consumes because she does not take into account of the cost

the context of Wi-Fi, signal interference, which leads to degradation of performance in terms of throughput and capacity of the wireless network).[71] A common solution to the "tragedy of the commons" problem is the assignment of private property rights. Property rights over the spectrum provide the licensee incentives to maximize the value of the spectrum by managing use of the spectrum and making complementary investments in improving the network. The "tragedy of the commons" problem is more significant with 600 MHz spectrum, which is well-suited for licensed wide area network applications, compared to the current spectrum used for Wi-Fi and other unlicensed spectrum uses. The limitations that allow use by many types of short-range devices (such as power limits, which restrict the range of such devices) would be much more difficult to implement in a wide area network and would diminish the value of a wide area network. In fact, the same benefits that Google and Microsoft expound for using 600 MHz for Wi-Fi—the long range and ability to transmit through walls—are also the source of inefficiencies from the lack of private property rights over such spectrum.[72]

B. GOOGLE AND MICROSOFT OFFER NO SOUND BASIS FOR THE CLAIM THAT INCREASED ALLOCATION OF SPECTRUM TO UNLICENSED USES WOULD INCREASE AUCTION REVENUES.

64. Google and Microsoft argue that allocating 600 MHz spectrum to unlicensed uses would not threaten the loss of auction revenues.[73] Indeed, they claim that allocating spectrum for unlicensed uses would likely increase auction revenues by creating scarcity and driving up the

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of her consumption in terms of depletion of the common resource, which is borne by all users collectively. The classic example is an open parcel of land that is overgrazed by cattle owners.

[71] See, *e.g.*, Cisco, "20 Myths of Wi-Fi Interference," *available at* http://www.cisco.com/en/US/prod/collateral/wireless/ps9391/ps9393/ps9394/prod_white_paper0900aecd807395a9_ns736_Networking_Solutions_White_Paper.html, site visited March 11, 2013.

[72] *Google-Microsoft Comments* at 26.

[73] *Google-Microsoft Comments* at 29.

price of the remaining spectrum rights that are auctioned.[74] *Milgrom et al.* make a similar, although more cautious, claim.[75] They offer two reasons why the reduction in the amount of spectrum auctioned off likely would increase revenues. First, they argue that, to the extent aggregate demand for licensed spectrum is inelastic, a "reduction in the available spectrum would, by itself, actually increase the revenue that can be expected from a given auction."[76] Second, they argue that allocating additional spectrum for unlicensed use will increase the value of licensed spectrum by increasing the value to consumers of mobile wireless networks and devices—or, in economic terms, Wi-Fi and other unlicensed uses of spectrum are more like complements than substitutes to licensed wireless spectrum.[77] Neither of these arguments holds up to scrutiny.

1. The reduced supply of spectrum available at auction is likely to reduce auction revenues.

65. Even under the assumptions most favorable to the Google/Microsoft auction-revenue argument, it is theoretically possible that reducing the amount of spectrum rights sold at auction may raise total revenues *only* if demand is inelastic—that is, if the elasticity of demand is less than one. If demand is elastic, auction revenues would decrease. *Milgrom et al.* provide no evidence that the demand for 600 MHz spectrum is inelastic. In fact, they explicitly state that they "are not aware of convincing estimates of the aggregate demand for licensed spectrum."[78]

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74 *Id.*

75 *Milgrom et al*. at 29 ("Is it costly, in terms of auction revenues, to set aside some spectrum for unlicensed uses? The surprise for many will be that economic theory provides no clear answer, but we believe that the most likely answer is no.").

76 *Id.* at 23. See also, *Google-Microsoft Comments* at 29.

77 *Google-Microsoft Comments* at 30-31.

78 *Milgrom et al*. at 23.

Thus, *Milgrom et al.* make only the theoretical observation that *if* the demand for licensed spectrum were inelastic, then a reduction in the quantity of spectrum available to be auctioned would increase auction revenues.[79] This theoretical observation does not provide a reasonable economic basis for a proposal to allocate significant amounts of 600 MHz spectrum to unlicensed uses, particularly in the light of the significant risks and potential consumer harms from doing so.

66. In fact, the demand for spectrum from each auction participant is likely to be elastic because there are substitutes to additional spectrum use rights for purposes of increasing the capacity of a wireless mobile network.[80] Most notably, carriers can make infrastructure investments to decrease cell sizes, allowing existing spectrum to be "reused" to a greater extent. We understand, for example, that doubling the amount of spectrum and doubling the number of cell sites in a given area are very roughly equivalent in terms of the resulting network capacity increase. Alternatively, the carrier may accelerate the rollout of more spectrally efficient technologies or take other measures designed to improve efficiency given existing network

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79 *Id.* at 23.

80 Although we also are not aware of convincing estimates of the aggregate demand for licensed spectrum, the available studies that have attempted to estimate it suggest that demand is elastic (*i.e.*, less than -1). These studies estimate the demand for wireless services by consumers rather than the demand for spectrum by wireless carriers. For instance, Bazelon (2009) and Bazelon (2011) conclude that the elasticity of demand for wireless broadband services is -1.2. (Coleman Bazelon, "The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations," The Brattle Group, October 23, 2009, *available at* www.brattle.com/_documents/uploadlibrary/upload809.pdf, site visited February 28, 2013; Coleman Bazelon, "Expected Receipts from Proposed Spectrum Auctions," The Brattle Group, July 28, 2011, *available at* www.brattle.com/_documents/UploadLibrary/Upload964.pdf, site visited February 28, 2013.) Similarly, Ingraham and Sidak estimate that the elasticity of demand for wireless services is -1.29 to -1.12. (Allan T. Ingraham and Gregory Sidak (2004) "Do States Tax Wireless Services Inefficiently? Evidence on the Price Elasticity of Demand," *Virginia Tax Review*, **24**(2): 249-261.) These elasticities would imply that withholding spectrum from auctions would *decrease* revenues, not increase them, as Google and Microsoft assume.

architecture and technology (*e.g.*, engineering optimization measures designed to reduce interference between adjacent cells). The demand for spectrum is, in large part, driven by the cost of these alternative means of increasing wireless network capacity. In addition, wireless providers can obtain additional spectrum from the secondary market, or from other spectrum coming online in future auctions or repurposing (*e.g.*, such as spectrum allocated to MSS). These alternative sources of spectrum also tend to make demand for 600 MHz spectrum available in the forward auction more elastic.

67. Because there are no credible estimates of the relevant demand elasticity, we have performed Monte Carlo simulations in order to assess the possible effects of reducing the supply of spectrum available at auction on auction revenues. In particular, we simulate an auction of a "representative" license by drawing random numbers for bidder valuations of the license.[81] Auction revenues are then calculated, assuming straightforward bidding, first based on a full set of licenses (treated here as either 7 or 10 10-MHz licenses) being available for auction. We then consider revenues when reducing the available licenses by either one or two units (between 10 and 29 percent of the spectrum available).[82] We perform these simulations based on many different lognormal distributions of bidder valuations. For each distribution, we repeat the simulation process 1000 times in order to examine the distribution of revenue effects. Our

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81 These random numbers are generated from a multivariate lognormal distribution.

82 For example, if bidders together seek up to 14 licenses and 10 are available, we treat the marginal valuation, $v^{(4:14)}$, as the market clearing price. We then compare the resulting revenue, $10v^{(4:14)}$, to the revenue that would have been obtained by selling 9 units at the higher price, $v^{(5:14)}$.

simulations provide upper bounds on the revenue gains that might be achieved (and lower bounds on the revenue losses) for a wide range of valuation distributions.[83]

68. These simulations indicate that revenue gains from the reduction of spectrum available at auction are possible but unlikely, and that there is substantial risk of lowering revenues. In particular, for most distributions of bidder valuations, reducing supply tends to reduce auction revenue. We find that a 1-unit reduction in supply (a 10 or 14 percent reduction) typically leads to a revenue loss of at least 3 to 7 percent. For only 2 of the 72 different parameter combinations considered we find a possibility that a revenue gain is more likely than a revenue loss. A 2-unit reduction in supply (a 20 or 28 percent reduction) leads to broadly similar results, although with considerably more variance (risk). We provide additional detail and a full presentation of results in Appendix A.

69. Although *Milgrom et al*. do not offer any estimates of the elasticity of demand for licensed spectrum, they argue that bidders have fixed budgets and that, consequently, the elasticity of demand is exactly equal to one.[84] In particular, they cite a paper by Bulow, Levin, and Milgrom, which provides a descriptive empirical analysis of the 2006 FCC AWS spectrum auctions.[85] According to *Bulow et al*., as prices rise during the auction, bidders bid for fewer

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83 The mathematical results underlying this claim are given in the appendix.

84 Milgrom *et al*. at 23:

> Bulow, Levin and Milgrom (2009), however, have pointed out that, in large spectrum auctions, the overall auction revenue tends to reflect the aggregate budgets of the participants. To the extent that telecommunications firms allocate budgets for spectrum purchases that are relatively insensitive to changes in the available spectrum, and tend to spend their budget at auction, changes in the available spectrum will have only modest effects, if any, on government revenue."

85 Jeremy Bulow, Jonathan Levin, and Paul Milgrom, "Winning Play in Spectrum Auctions," Working Paper, February 2009 (hereinafter, *Bulow et al*.).

licenses but often made little adjustment to the total value of their bids.[86] *Bulow et al*. observe that this is broadly consistent with binding budget constraints.[87]

70. Google and Microsoft incorrectly conclude from these results that reducing the quantity of spectrum available does not affect spectrum auction revenues. The contention that budgets do not depend on the amount of spectrum available is both implausible on logical grounds and inconsistent with our knowledge of the budgeting process at major wireless carriers. Although bidding teams may face budget constraints for a particular auction (while having considerable freedom in deciding which licenses to buy within their fixed budgets), this does not mean that budgets do not depend on the quantity of spectrum that is being offered at the auction. Taken to its logical extreme, the argument that providers have fixed budget irrespective of how much spectrum is available would imply that the government could auction a nationwide license for 1 MHz of spectrum for tens of billions of dollars. Neither the evidence in *Bulow et al*. nor those authors' own interpretation leads to the conclusion Google and Microsoft reach. Google and Microsoft repeatedly cite the paper by *Milgrom et al.* to support their argument. However, those authors are themselves careful to stop short of the claim Google and Microsoft make. The authors merely say that[88]

> "*[t]o the extent* that telecommunication firms allocate budgets for spectrum purchases that are relatively insensitive to changes in the available spectrum, and tend to spend their budget at auction, changes in the available spectrum will have

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86 They show that the total value of all bids at a given point in the auction increases fairly quickly as the auction proceeds, and then remains nearly constant until the end of the auction, both for the auction as a whole and for many bidders individually.

87 *Bulow et al*. do not attempt to provide a full explanation of the observed bidding pattern or to develop empirical tests of their hypotheses, nor do they discuss which features of the SMR auction design used in the AWS spectrum auctions might lead to the patterns of behavior they found.

88 *Milgrom et al*. at 23.

only modest effects, if any on government revenue. [Emphasis added.]

2. Unlicensed spectrum can be a substitute for licensed spectrum.

71. Even if the demand for licensed spectrum were inelastic, auction revenues nevertheless could decline if 600 MHz spectrum were allocated to unlicensed uses. The argument that auction revenues will increase if demand for spectrum is inelastic would apply if a certain quantity of spectrum were *eliminated* from the market. However, allocating spectrum to unlicensed uses does not eliminate spectrum from the market. To the extent that unlicensed spectrum will be used to provide services that are at least, in part, substitutes for licensed spectrum, demand for licensed spectrum would decrease. All else equal, a decrease in demand for spectrum would have the effect of decreasing auction revenues. Wi-Fi is often a substitute for wireless mobile networks. This is true in both upstream and downstream markets.

72. In upstream input markets, the offloading benefit of Wi-Fi unambiguously makes Wi-Fi a substitute to wireless networks from the perspective of wireless carriers: Both are means of meeting increasing demand for mobile wireless services and reducing congestion on mobile wireless service provider networks. In their comments, Google and Microsoft (and *Milgrom et al.*) describe at length how offloading wireless traffic through Wi-Fi networks is a substitute for adding spectrum.[89] In fact, they seem to argue that offloading through Wi-Fi networks is a superior means of increasing network capacity compared to adding spectrum to the wireless mobile networks themselves. If Wi-Fi is a close (or superior) substitute for licensed spectrum, then giving away for free spectrum for unlicensed uses would reduce demand for licensed spectrum and thereby reduce auction revenue even if the demand for spectrum were inelastic.

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[89] *Google-Microsoft Comments* at 13; *Milgrom et al.* at 11.

This fact highlights an important inconsistency in the arguments made by Google and Microsoft: They claim that unlicensed spectrum is more valuable than licensed spectrum for purposes of alleviating traffic congestion in wireless networks, but at the same time assume that such an allocation will not decrease demand for licensed spectrum. These claims cannot both be correct. If spectrum is given away free of charge as unlicensed spectrum, and unlicensed spectrum is an effective substitute to licensed spectrum for adding capacity to wireless networks, then demand for licensed spectrum and auction revenues will surely decrease. And, if Wi-Fi were not an adequate substitute to adding spectrum to wireless networks, then consumers of mobile wireless services would be harmed by the resulting increase in wireless provider costs and retail prices due to spectrum scarcity.

73. In downstream markets for wireless services, Wi-Fi services using unlicensed spectrum and wireless services using licensed spectrum are also likely to be substitutes from the perspective of consumers. Consumers can use Wi-Fi instead of a mobile wireless network in many situations, such as in using Wi-Fi hotspots inside or outside their homes. *Milgrom et al.* recognize that "services that operate on unlicensed spectrum increasingly compete with services offered by operators that rely on licensed spectrum" from the perspective of consumers.[90] However, they also argue that Wi-Fi and mobile wireless networks are complements and that, as a result, allocating additional spectrum for unlicensed uses would increase demand by consumers for services provided by mobile networks, increase the value of licensed spectrum, and therefore increase auction revenues. Empirical support for this claim is notably lacking.

[90] *Milgrom et al*. at 15.

74. Although it is possible that some unlicensed uses of spectrum would be complementary to licensed ones,[91] the opposite may also be true. The availability of Wi-Fi networks can reduce both the number of consumers who purchase wireless services, as well as the quantity of wireless services used by each consumer. *Milgrom et al*. argue that the iPad[92]

> illustrates how Wi-Fi can complement licensed data services. In one typical pattern, an iPad owner uses Wi-Fi when it is available, but switches to 3G mobile to operate outside of Wi-Fi hotspots. … In this example, the availability of unlicensed spectrum applications helps create more consumer demand for licensed spectrum services.

However, the majority of iPads are Wi-Fi only, which indicates that, at least with respect to iPads, the substitute effect is likely much greater than the complementarity effect.

75. The substitution effect likely would be even stronger if unlicensed 600 MHz spectrum were deployed in higher-power, wide-area, unlicensed networks, as Google and Microsoft suggest it could be used, as compared to higher-band, unlicensed spectrum that is today used for local area networks.

76. One argument that has been made in support of the contention that Wi-Fi and licensed spectrum are complements is that usage of Wi-Fi and licensed spectrum have grown in tandem over time.[93] But this fact does not mean that Wi-Fi and licensed spectrum are complements. Increased demand for use of wireless mobile devices has increased demand for both types of

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91 For example, the availability of Wi-Fi in airports and coffee shops might enhance demand for wireless cellular devices, and increase demand for licensed spectrum as a result. The availability of Wi-Fi and other unlicensed uses also might increase innovation in applications and mobile devices that take advantage of those technologies in ways that make mobile wireless services packaged with Wi-Fi-capable devices more valuable to consumers.

92 *Milgrom et al*. at 17.

93 See, *e.g.*, Mark Cooper, "Efficiency Gains and Consumer Benefits of Unlicensed Access to the Public Airwaves," January 2012, at 7. Google and Microsoft cite this paper frequently in their comments.

spectrum. But demand for two inputs can grow in tandem, but nevertheless be substitutes. For instance, as demand for a product increases, a manufacturer may use more of two inputs in manufacturing the product (*e.g.*, capital and labor). But the firm may be able to substitute more labor for capital, or vice-versa, in the manufacturing of the product. The relevant question to whether the inputs are substitutes or complements is whether demand for one increases or decreases when the price of the other rises, not whether demand for both rises as demand for the downstream product increases.

77. Thus, on net, it seems more likely that competition from Wi-Fi, Super Wi-Fi, or other unlicensed uses contemplated by Microsoft and Google would lower demand for licensed spectrum, thereby lowering bidder valuations and suppressing auction revenues. This view is consistent with the fact that support for withholding spectrum for unlicensed use is not coming from wireless carriers but from firms like Google and Microsoft, who would likely profit from offering Internet-based services without having to purchase spectrum or invest in the same infrastructure that mobile wireless carriers do. Allowing these firms to compete in the auction would provide a way to determine the highest-value uses of the spectrum. Setting aside spectrum for the uses desired by these firms would not.

78. Moreover, even if the uses of licensed and unlicensed spectrum were complements, it would not follow that the positive effect on the demand for spectrum licenses from the increase in unlicensed spectrum would outweigh the negative effect on auction revenues from the reduction in the quantity of spectrum rights sold. Google and Microsoft offer no evidence to support their claim.

79. In short, it is highly speculative, at best, to suggest that reducing mobile wireless spectrum allocations would increase (or not reduce) forward-auction revenues. Given the extraordinary costs of being wrong, it is short-sighted to take such a gamble given the lack of supporting evidence.

V. CONCLUSION

80. The Commission should not manipulate the 600 MHz auction in an attempt to skew the results in favor certain firms at the expense of mobile wireless services consumers.

VI. APPENDIX A: REVENUE SIMULATIONS

81. These auction simulations examine the likely impact of reducing the supply of spectrum on auction revenues. We will look at this in a simplified setup in which there is just one object (but many units) for sale.

82. Let $v^{(1:n)}, v^{(2:n)}, \ldots, v^{(n:n)}$ denote the realized order statistics (in increasing order) of the n valuations of the units. Because bidders may demand more than one unit each, these should be interpreted as the set of all marginal valuations across all bidders. Under straightforward bidding, auction revenue when k units are available is

$$kv^{(n-k:n)}.$$

To look at possible revenue effects of reducing supply to $k - t$ units ($t > 0$), we will look at the ratio

$$\delta(k, t, n) \equiv \frac{(k - t)\, v^{(n-k+t:n)}}{kv^{(n-k:n)}}. \tag{1}$$

When $\delta(k,t,n) > 1$, reducing supply enhances auction revenue.

83. We use simulation to examine how often this happens under plausible specifications of valuations. We draw valuations at random, construct the sample of order statistics $v^{(1:n)}, v^{(2:n)}, \ldots, v^{(n:n)}$, and check the value of $\delta(k,t,n)$. Repeating this many times, we assess possible effects of reducing supply on auction revenue.

84. We draw valuations from a lognormal distribution. Let the random vector $Z \in \mathrm{R}^n$ have a multivariate normal distribution, mean 0 and covariance matrix, Σ, where for $\rho \in [0,1]$

$$\Sigma = \begin{bmatrix} 1 & \rho & \dots & \rho \\ \rho & \ddots & \rho & \vdots \\ \vdots & \rho & \ddots & \rho \\ \rho & \dots & \rho & 1 \end{bmatrix}.$$

We then specify valuations as

$$V_i = \lambda + \exp(\mu + \beta Z_i) \quad i = 1,2,...n \ ,$$

where $\lambda \in \mathrm{R}_+$, $\mu \in \mathrm{R}$, and $\beta \in \mathrm{R}_{++}$ are scalar parameters.

85. With this specification, valuations have mean and variance

$$E\left[V_i\right] = \lambda + e^{\mu + \frac{\beta^2}{2}} \tag{2}$$

$$Var\left[V_i\right] = e^{2\mu + \beta^2}\left(e^{\beta^2} - 1\right). \tag{3}$$

The covariance between V_i and V_j ($j \neq i$) is

$$e^{2\mu + \beta^2}\left(e^{\rho\beta^2} - 1\right)$$

so that the corresponding correlation coefficient is

$$\rho_{ij} = \frac{e^{\rho\beta^2} - 1}{e^{\beta^2} - 1}. \tag{4}$$

We make three useful observations.

Remark 1. *Given any* $\beta > 0$, *the parameters* λ *and* μ *can be chosen to match any desired mean of* V_i *and variance of* V_i. *Further, given any* (β, λ, μ), ρ *can be chosen to match any desired correlation coefficient* ρ_{ij}.

Proof. These claims follow immediately from (2), (3), and (4).

Remark 2. *Given any* (n,k,t) *and any values of the parameters* (β,μ,ρ), $\lambda = 0$ *maximizes* $\delta(k,t,n)$.

Proof. Observe that

$$\delta(k,t,n) = \left(\frac{k-t}{k}\right)\frac{\lambda + e^{\mu+\beta z^{(n-k+t:n)}}}{\lambda + e^{\mu+\beta z^{(n-k:n)}}}.$$

Differentiating with respect to λ yields

$$\left(\frac{k-t}{k}\right)\frac{e^{\mu+\beta z^{(n-k:n)}} - e^{\mu+\beta z^{(n-k+t:n)}}}{\left(\lambda + e^{\mu+\beta z^{(n-k+t:n)}}\right)^2},$$

which is always negative.

Remark 3. *Given* $\lambda = 0$ *and any values of* (n,k,t), *the value of* μ *has no effect on* $\delta(k,t,n)$. *Proof.* With $\lambda = 0$,

$$\delta(k,t,n) = \left(\frac{k-t}{k}\right)\frac{e^{\mu+\beta z^{(n-k+t:n)}}}{e^{\mu+\beta z^{(n-k:n)}}}$$

where μ cancels.

86. Remark 1 implies that the choices of the location and scale parameters λ and μ allow our lognormal specification to match the first and second moments of any distribution of valuations, even when β is fixed. Remark 2 implies that, whatever the values of all other parameters, $\lambda = 0$ creates the largest values of $\delta(k,t,n)$ and therefore the greatest possible likelihood that reducing supply enhances revenue. Finally, Remark 3 implies that (once we set

$\lambda = 0$ as suggested by Remark 2), the scale parameter μ has no effect on $\delta(k,t,n)$. Thus, we can set $\mu = 0$ without loss. These three observations imply the following result.

Proposition. *Given any values of* (n,k,t,ρ,μ)*, the distribution of* $\delta(k,t,n)$ *when* $\lambda = \mu = 0$ *first-order stochastically dominates that of* $\delta(k,t,n)$ *under any other values of* (λ,μ).

87. This is an useful result. It implies that by setting $\lambda = \mu = 0$ we can obtain upper bounds on all key statistics concerning the effect of reducing supply on revenues (as measured by the ratio $\delta(k,t,n)$) under lognormal specifications that are calibrated to match exactly the mean and variance of the true distribution of valuations. This is possible without any idea what the true mean and variance actually are. Further, by Remark 1, while doing this we remain free to adjust ρ to match any desired correlation between valuations. Finally, we remain free to vary the shape parameter β, thereby examining the sensitivity of the results to the shape of the distribution.

88. Based on this result, we henceforth set $\lambda = \mu = 0$. We will consider several different values of the parameters

$$n, k, t, \beta, \rho_{ij}.$$

We consider $\beta \in \{0.25, 0.5, 1.0, 1.5\}$, spanning a wide range of shapes. We consider a range of correlation coefficients, $\rho_{ij} \in \{0.25, 0.5, 0.75\}$, which cover cases of weak and moderate correlation. Using (4), to set the correlation coefficient to a particular value of ρ_{ij} we set

$$\rho = \rho(\beta) = \frac{\ln\left(\rho_{ij}\left(e^{\beta^2} - 1\right) + 1\right)}{\beta^2}.$$

89. We begin by considering a one-unit reduction in supply ($t = 1$). Table 1 shows two types of outcomes. First we show the empirical frequency of observing $\delta(k,t,n) > 1$, i.e., the share of 1,000 simulations in which revenue was higher when supply was reduced. We do this for several different combinations of the parameters k and n corresponding to selling either 7 or 10 licenses to bidders with demands for either 14 or 20 licenses in total. Thus a reduction in supply of 1 unit corresponds to a set-aside of 10-14 percent of the cleared spectrum for unlicensed use. Results are present in the left portion of the table. We see that reducing supply typically reduces revenue. For example the first entry of 0.010 indicates that, with the parameter combination

$$\rho_{ij} = 0.25, \beta = 0.25, k = 7, n = 14,$$

the reduction in supply led to higher revenues in only 1 percent of the 1000 simulated auctions using this combination of parameters. Recall that by Proposition 1, each combination of parameters considered represents a large class of valuation distributions, among which the probability of a revenue gain can be lower than what is observed here, but cannot be higher. There are only a few parameter combinations (4 out of the 72 combinations tried) where the upper bound allows the possibility that a reduction in supply enhances revenue more than half the time (*i.e.*, where the entries in the left panel exceed 0.5). Note that the likelihood of a revenue enhancement is decreasing in the value of ρ_{ij}, since high correlation tends to shrink the spacing of the order statistics $v^{(n-k+t:n)}$ and $v^{(n-k:t)}$. This is reflected by our upper bounds as well. When the correlation among valuations is at least moderate ($\rho_{ij} \geq 0.75$),[94] there is no

[94] Recall that a correlation coefficient of 0.75 corresponds to an "R-square" of about 0.56, meaning that about 56 percent of the variance in one variable can be explained through a linear relation to the other. This would generally be considered moderate correlation.

combination of parameters under which our upper bounds allows the possibility of a revenue gain more than half the time.

90. The right portion of Table 1 show mean values of our upper bounds on the ratio $\delta(k,t,n)$ over the simulation draws at each combination of parameter values. For example, the first entry 0.891 implies an average 10.9 percent loss in revenue from reducing supply. Again, these figures should be interpreted as lower bounds on the average losses and upper bounds on the average gains. The previous results imply that most values in the right panel must be below 1. There are a few parameter combinations (2 out of 72) for which the upper bound revenue gains exceed 10 percent. However, the typical finding is a revenue loss of at least 3-7 percent.

Table 1: Revenue effects of reducing supply by 1 unit (t=1).

		Empirical Frequency of $\delta(k,t,n) > 1$				Mean value of $\delta(k,t,n)$			
	$k:n \rightarrow$	7:14	10:14	7:20	10:20	7:14	10:14	7:20	10:20
ρ_{ij}	β								
0.25	**0.25**	0.010	0.093	0.002	0.015	0.891	0.942	0.883	0.925
0.5		0.004	0.051	0.000	0.006	0.884	0.934	0.877	0.920
0.75		0.000	0.010	0.000	0.001	0.876	0.924	0.871	0.914
0.25	**0.50**	0.124	0.318	0.064	0.141	0.926	0.987	0.908	0.951
0.5		0.075	0.231	0.030	0.075	0.912	0.968	0.898	0.940
0.75		0.018	0.117	0.004	0.028	0.894	0.947	0.885	0.928
0.25	**0.75**	0.249	0.449	0.158	0.263	0.961	1.030	0.935	0.976
0.5		0.172	0.366	0.094	0.178	0.938	1.002	0.917	0.958
0.75		0.065	0.230	0.027	0.079	0.910	0.967	0.897	0.939
0.25	**1.00**	0.343	0.543	0.247	0.350	0.995	1.075	0.960	0.997
0.5		0.246	0.455	0.158	0.256	0.960	1.030	0.935	0.975
0.75		0.125	0.294	0.060	0.129	0.926	0.983	0.907	0.949
0.25	**1.25**	0.410	0.595	0.309	0.411	1.024	1.115	0.981	1.019
0.5		0.299	0.497	0.199	0.308	0.978	1.052	0.947	0.986
0.75		0.157	0.346	0.084	0.160	0.935	0.996	0.914	0.955
0.25	**1.50**	0.451	0.638	0.337	0.462	1.049	1.143	0.993	1.036
0.5		0.326	0.534	0.233	0.336	0.989	1.067	0.956	0.994
0.75		0.183	0.375	0.103	0.184	0.941	1.003	0.919	0.959

91. Table 2 provides the same set of results for the case in which the supply is reduced by two units, corresponding to a set-aside of 20-29 percent of the cleared spectrum. Results are similar, although there is more sensitivity of outcomes to the parameter values. The left panel of the table shows that there were 5 of 72 parameter combinations for which (upper bound) gains in revenue were achieved more than half the time. The majority of parameter combinations yielded revenue losses most of the time, sometimes in every one of the 1000 simulations. The right panel shows that for a few combinations of parameters, the upper bound allows the possibility of a large gain in revenue. However, typically we find that revenues would fall, with lower bound on the loss as high as 25 percent.

Table 2: Revenue effects of reducing supply by 2 units (t=2).

ρ_{ij}	β \ $k:n \rightarrow$	Empirical Frequency of $\delta(k,t,n) > 1$				Mean value of $\delta(k,t,n)$			
		7:14	10:14	7:20	10:20	7:14	10:14	7:20	10:20
0.25	0.25	0.000	0.023	0.000	0.001	0.772	0.873	0.759	0.845
0.5		0.000	0.006	0.000	0.000	0.761	0.858	0.750	0.836
0.75		0.000	0.000	0.000	0.000	0.747	0.840	0.739	0.826
0.25	0.50	0.051	0.266	0.013	0.074	0.834	0.955	0.806	0.893
0.5		0.017	0.150	0.004	0.025	0.809	0.919	0.786	0.872
0.75		0.001	0.034	0.000	0.002	0.779	0.881	0.764	0.850
0.25	0.75	0.190	0.475	0.091	0.217	0.900	1.034	0.855	0.941
0.5		0.090	0.337	0.032	0.115	0.857	0.979	0.820	0.907
0.75		0.013	0.145	0.003	0.023	0.807	0.918	0.785	0.872
0.25	1.00	0.326	0.617	0.187	0.340	0.967	1.123	0.900	0.983
0.5		0.193	0.473	0.084	0.215	0.900	1.034	0.852	0.938
0.75		0.051	0.239	0.014	0.067	0.833	0.946	0.802	0.890
0.25	1.25	0.413	0.685	0.279	0.452	1.023	1.201	0.945	1.026
0.5		0.250	0.549	0.137	0.284	0.930	1.076	0.876	0.961
0.75		0.080	0.316	0.026	0.098	0.850	0.970	0.816	0.902
0.25	1.50	0.487	0.732	0.332	0.512	1.073	1.256	0.971	1.058
0.5		0.301	0.597	0.175	0.329	0.955	1.106	0.894	0.976
0.75		0.100	0.355	0.038	0.118	0.860	0.983	0.825	0.909

I declare, under penalty of perjury, that the foregoing is true and correct.

Michael L. Katz

March 12, 2013

I declare, under penalty of perjury, that the foregoing is true and correct.

Phil Haile

March 12, 2013

I declare, under penalty of perjury, that the foregoing is true and correct.

Mark Israel

March 12, 2013

I declare, under penalty of perjury, that the foregoing is true and correct.

Andres Lerner

March 12, 2013

Reply Analysis of
Yeon-Koo Che and Phil Haile

March 12, 2013

Introduction

We have been asked by counsel for AT&T to respond to comments filed on the FCC's proposed incentive auctions. In Che, Haile and Kearns (2013) (henceforth "CHK") we provided extensive comments on the FCC's Notice of Proposed Rulemaking and accompanying proposal of Milgrom, Ausubel, Levin and Segal (2012) (henceforth "MALS"). Many of our responses to comments by others will refer to our discussion and proposals in CHK.

In general, most commenters agreed with our assessment that the MALS proposals regarding the forward and reverse auctions offered a strong baseline from which to build a final auction design.

For the forward auction, commenters generally agreed with us that the MALS design offers substantial improvements over the Simultaneous Multi-Round ("SMR") auction used in prior FCC spectrum auctions. There was general support for the use of clocks and generic licenses in particular. Many commenters also agreed with our concern about the exposure problem, which remains unaddressed by the MALS auction design and is likely to limit auction revenue, distort bidding behavior, and lead to inefficient allocations. On the other hand, some commenters expressed concern about the potential for introducing package bidding to the forward auction. In particular, some view package bidding as inherently too complex. Others object to package bidding based on a view that package bidding discriminates against small bidders.

A specific package bidding proposal was offered in CHK. As we explain below, our Clock Package Auction (CPA) proposal avoids the pitfalls underlying the commenters' concerns. The CPA alters the MALS design in only three ways:

1. It expands the set of objects offered to include a small number of packages, using a geographically driven hierarchical package design closely tied to the actual structure of bidder complementarities between spectrum licenses.
2. It specifies how excess demand can then be properly calculated.
3. It provides a rule governing price clocks that ensures that package prices are additive in the prices of the package components when possible.

The CPA proposal does not add significant complexity to the MALS auction design. Indeed it simplifies bidding for most bidders by providing a means of addressing the exposure problem, thereby avoiding the need for schemes by package bidders to reduce their exposure risk and

schemes by component bidders seeking to take advantage of others' exposure risk. Such strategies have been prevalent in past FCC spectrum auctions and create high demands on the sophistication of bidders seeking to bid optimally.

While this yields an important reduction in complexity relative to the MALS proposal, the MALS proposal's use of price clocks and generic licenses already simplifies bidding substantially relative to the SMR auction design. Thus, the CPA proposal design in fact offers substantial reductions in complexity relative to past FCC auctions.

We also explain below that the CPA does not discriminate against small bidders. Indeed the opposite is true. Contrary to common assertions that package bidding creates a threshold problem, we show that the threshold problem already arises in the MALS auction. Further we see no new potential for a threshold problem in the CPA that does not already exist in the MALS auction. In fact, there is at least one sense in which the CPA reduces the severity of the threshold problem relative to the MALS design and, *a fortiori*, the SMR auction design.

On the other hand, the CPA offers two specific corrections of biases against small bidders that exist in the MALS auction design. One is the exposure problem. Although exposure risk would affect almost all bidders in the MALS auction, it is important to recognize that small bidders seeking to enter the market are among those that need protection against this risk. The CPA offers such protection. The second bias against small bidders in the MALS auction design is the "overflow problem." As discussed in CHK, this flaw in the MALS design will tend to force small bidders out of the market by raising the prices they must pay even when their demands are not a source of scarcity. The CPA eliminates the overflow problem.

We also discuss general concerns that the CPA would be susceptible to incentives for manipulative bidding. We consider several specific types of manipulative strategies that might be attractive in other types of auctions and demonstrate that the specific rules of the CPA make these strategies unattractive to bidders. We see no new incentives for bid manipulation in the CPA relative to the MALS auction. Indeed, because elimination of the exposure problem eliminates the need for bidding schemes aimed at minimizing exposure risk (or exploiting that of other bidders), there may be fewer incentives for manipulative bidding in the CPA than in the MALS auction.

Finally, we address concerns about the reverse auction design raised by some commenters. We argue below that from a bidder's perspective there is no significant difference between a sequential and interleaved auction design. We also point out that, unlike other "sealed bid"

auction designs, the option to conduct the reverse auction by proxy bidding would not complicate bidding but would simplify it.

Complexity of Package Bidding

Several commenters suggest that package bidding is inherently complex.[1] This is true if one assumes that package bidding implies allowing bidding on all possible combinations of licenses. Even with generic licenses, with 172 EAs in the 50 states, this gives roughly 6 sexdecillion (6×10^{51}) different packages on which bids might be made!

However, package bidding is not synonymous with unrestricted packages. Further, the Clock Package Auction (CPA) proposed in CHK specifies a limited set of packages. Although in principle complementarities between objects in a multi-object auction could be arbitrary, in the case of spectrum licenses complementarities depend primarily on geographic contiguity and population distribution. This makes it possible to restrict the set of packages severely in terms of the number of packages considered while still allowing bidders to effectively express the relevant complementarities in their valuations.

Under the specific CHK proposal to offer EA licenses, MEA licenses, REAG licenses, and nationwide licenses, the number of objects for sale would increase from 172 to 229. Aside from the introduction of these objects, the CPA is essentially identical in complexity (indeed, in almost all dimensions) to the MALS ascending clock auction. The generic treatment of licenses keeps decision making as simple as possible and avoids the possibility that identical licenses sell at different prices. And bidders need not choose what to bid but only which objects they wish to demand at the current clock prices. Even with the proposed addition of package objects, the ascending clock auction design is in fact much simpler than the SMR auction that has been used in previous FCC spectrum auctions.

Further, the addition of packages will actually *reduce* complexity for most bidders, who will seek multiple complementary licenses. Unlike auctions that exclude packages, bidders in the CPA need not develop strategies for managing the severe exposure risk that would otherwise be involved in bidding for combinations of licenses needed by an entrant to build a viable network or by an existing provider seeking to make effective use of the newly offered spectrum band. Even bidders seeking single licenses face a simpler bidding problem in the CPA, as they

[1] *See, e.g.*, Comments of United States Cellular Corporation, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 51 (Jan. 25, 2013) ("USSC Comments"); Comments of Cellular South, Inc., *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 5 n.11 (Jan. 25, 2013) ("Cell South Comments").

have no incentives to manipulate their bids in attempts to exploit the exposure risk of package bidders.

Package Bidding and Treatment of Small Bidders

The Threshold Problem

Several commenters express concern about the effect that package bidding would have on small bidders, due to the "threshold problem" (Bykowsky, Cull and Ledyard (2000)).[2] The threshold problem can arise when a package bidder is competing against multiple bidders, each seeking a component of the package. In such situations, the "small bidders'' may have incentives to free ride by holding back their demand in the hope that others will contribute more toward pushing the sum of the component prices past the willingness to pay of the package bidder. Such free riding can result in allocation of licenses to the package bidder even when the small bidders together place greater value on them than the package bidder does.

The threshold problem is a potential concern in most types of auctions in which some bidders view licenses as complements. This includes the MALS auction, the SMR auction used in previous FCC auctions, and the CPA variation of MALS. However, we see no potential for a threshold problem in the CPA that does not also exist in the MALS auction (or in an SMR auction). And, as we show below, there is at least one sense in which the threshold problem can be more severe in the MALS auction than in the CPA**.**

The threshold problem has been discussed extensively since the first FCC spectrum auctions. Unfortunately, this discussion has often been imprecise. It is commonly asserted that the threshold problem is introduced by combinatorial auction designs. This is incorrect. The threshold problem exists in many auctions without combinatorial bidding, including the SMR auction used in previous FCC auctions and the MALS clock design proposed for the forward auction in the upcoming incentive auctions.

[2] *See, e.g.*, USSC Comments at 53; Comments of the MetroPCS, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 14 (Jan. 25, 2013) ("RTG Comments"); Comments of the Rural Telecommunications Group, Inc., *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 9 (Jan. 25, 2013) ("RTG Comments").

We will illustrate this with a simple example. Let there be two licenses, A and B. Suppose there are three bidders with valuations for the objects as follows:

	Object:	A	B	A+B
Bidder:				
1		3	0	3
2		0	3	3
3		0	0	4

The efficient allocation awards license A to bidder 1 and license B to bidder 2.

Consider the MALS auction and suppose that the current clock prices are $p_A = p_B = 1$. If all bidders follow straightforward bidding, bidder 1 will demand A as long as $p_A < 3$, bidder 2 will demand B as long as $p_B < 3$, and bidder 3 will demand a unit of each as long as $p_A + p_B < 4$.[3] The auction will end at prices $p_A = p_B = 2$ and the efficient allocation will be obtained.

However, consider a deviation by bidder 1. Instead of continuing to demand A at prices $p_A = p_B = 1$, he instead drops his demand for A, maintaining his eligibility by bidding on some other license whose price is rising in every round. If bidders 2 and 3 continue to follow straightforward bidding,[4] p_B will rise while p_A will not. Once p_B reaches $3-\varepsilon$, bidder 1 returns to demand A. The auction then ends at prices $p_A = 1+\varepsilon, p_B = 3$ where bidder 3 drops out. By withholding his true interest for A, bidder 1 is able to free ride on the straightforward bidding behavior of bidder 2 and obtain license A at a lower price. Of course, there is no reason for only bidder 1 to think this way. But if bidders 1 and 2 both attempt to free ride, bidder 3 may win. This is the threshold problem. Bidders 1 and 2 must both contribute to the effort to displace the package bidder, but each would prefer the other to contribute more.

This illustrates an important point. The threshold problem is not the result of package bidding (there is none in the MALS auction). Rather, it is the result of "package valuations,'' i.e., of complementarities that bidders act on to at least some degree. The same problem would arise in the SMR auction.

It is easy to see both that the threshold problem arises in the CPA as well and that there is no new threshold problem relative to the MALS auction. At prices

[3] Note that we are assuming here that bidder 3 is ignoring the exposure problem, but as we explain below, the conclusion does not hinge on this assumption.

[4] Under "straightforward bidding'' each bidder demands the set of objects that would maximize his profit if the current prices turned out to be final prices.

$$p_A = p_B = 1$$
$$p_{AB} = 2$$

bidder 1 is again tempted to withhold his demand for A, waiting until prices reach

$$p_A = 1$$
$$p_B = 3 - \varepsilon$$
$$p_{AB} = 4$$

to again demand A. When prices rise to

$$p_A = 1 + \varepsilon$$
$$p_B = 3$$
$$p_{AB} = 4 + \varepsilon$$

bidder 3 exits. However, once again, if bidders 1 and 2 both try to free ride this way, bidder 3 may win.

Although these examples suggest an identical threshold problem in the MALS auction and CPA, one might be concerned that we have been too pessimistic about the MALS auction. In particular, we have assumed above that bidder 3 ignores the exposure problem entirely when bidding. This may indeed be unrealistic. As discussed in CHK, the threshold problem is likely to suppress the bids of package bidders, likely leading to reduced revenue and inefficient allocations. However, less aggressive behavior by the package bidder does not necessarily soften the threshold problem. Above we assumed that bidder 3 continued to demand license j as long as

$$p_j \leq 4 - p_{-j}.$$

Suppose instead that he exposes himself to only half the risk, demanding j only as long as

$$p_j \leq \frac{4 - p_{-j}}{2}.$$

For example, if the price of A remains zero but that of B rises, this means that bidder 3 is willing to demand B only until its price reaches 2, thus putting on the line half of his package value.

Now the free riding incentive exists at the beginning of the auction. Suppose that the auction begins at reserve prices of ε. Hoping that bidder 2 bids straightforwardly, bidder 1 might, for example, plan to wait until p_B reaches $2 - \varepsilon$ to demand A for the first time with the auction then proceeding as follows

p_A	p_B	Demands
ε	ε	0,B,A+B
$\vdots$	$\vdots$	"
ε	$2-\varepsilon$	A,B,A+B
2ε	2	A,B,0

Thus, it is not generally true that the threshold problem softens when package bidders respond more conservatively to the threshold problem.[5] Here, the incentive to free ride begins immediately: each component bidder has an incentive to withhold its demand throughout the auction because, depending on how the other component bidder behaves, it may be possible to obtain the license at the reserve price. This contrasts with the CPA where the lowest price at which a component bidder could win is 1 (for example, bidder 3 is willing to pay 4 for AB while bidder 2 will pay no more than 3 for B; thus bidder 1 cannot win A at a price below 1).[6] Thus, there is at least one sense in which the threshold problem may be viewed as more severe in the MALS auction than in the CPA.

Note, however, that the use of price clocks in both the MALS auction and the CPA may reduce the need for bidders to “coordinate” in overcoming the threshold problem relative to an SMR auction. In the SMR auction, the same incentives arise. But the SMR auction provides no "suggested'' prices that might be used to coordinate. Ausubel, Cramton and Milgrom (2006, p. 134) have previously argued (in the context of the clock phase of the CCA) that "the price adjustment process is effectively resolving the threshold problem by specifying who should contribute what as the clock ticks higher." This may overstate the effectiveness of price clocks, but they may indeed reduce the need for bidders to "coordinate" to unseat a package bidder. One way to see this is to observe that a component bidder does not need to form a winning coalition with other component bidders to win his desired component license. All he needs is to demand the desired component in each round.

Another feature of the CPA is its use of additive package pricing (except in the case of excess demand for the package itself). Without this feature, large gaps could arise between the standing price for a package and the sum of the standing prices for the components of the package. This could be a serious concern when packages are added to the SMR auction, for example. When such gaps arise, bidders for the components must coordinate to overcome this gap in order to displace the package bidder. With additive package pricing, clock prices reveal to the component bidders a set of prices which, if accepted, would unseat the package bidder

[5] Of course, if the package bidder acts as if he has *no* complementarity, the threshold problem will not arise. However, given the substantial complementarities between spectrum licenses, the FCC should not hope for this outcome.

[6] Bidder 1 could still begin withholding demand at the beginning of the auction in the CPA. But unlike the MALS auction, he has no strict incentive to do so.

unless that bidder also agrees to a higher price. This may substantially mitigate the severity of the threshold problem.

This observation has been made previously by Goeree and Holt (2010, p. 148) in the context of their Hierarchical Package Bidding (HBP) extension of the SMR auction design, which uses additive package pricing to determine minimum acceptable bids: "bidders on individual licenses in that region would know how high they have to bid to unseat the provisional regional winner. In this sense, prices help these bidders solve a coordination or 'threshold problem'."[7]
Note that "package prices" are effectively additive in the MALS auction design as well: a bidder seeking the package AB must offer a total of $p_A + p_B$. Thus, we do not claim that the use of additive clock pricing in the CPA offers superior mitigation of the threshold problem relative to the MALS design. Rather, we point out that the CPA retains the substantial advantages of the MALS design without introducing any new threshold problem. Nonetheless, the previous example suggests that the CPA, by mitigating the exposure problem that exists in the MALS design, may in fact soften the severity of the free-riding incentives (threshold problem) that exist in the MALS auction design.

In practice, the threshold problem and its impact are less likely to be significant in clock auctions (e.g., MALS or CPA) than in the SMR auction. For strategic withholding of demand to be profitable, a component bidder must know that he is facing a package bidder and another component bidder to free-ride on. The presence of such opponents may be identifiable in an SMR auction, which reveals provisional winners in each round. But clock auctions do not reveal which opponents are demanding which objects. All a bidder can see are the prices quoted on different items; the sources of price movements are not revealed. A price increase on an individual license could just as likely be triggered by a component demand as by a package demand. This anonymity feature also makes ineffective any attempts by a bidder to strategically exploit a potential threshold problem, e.g., a component bidder pretending to be a package bidder or an individual bidder pretending to be a package bidder. The uncertainty about the free-riding potential does not of course mean that bidders will not attempt to free-ride. They may if they perceive a sufficient likelihood of an opportunity and expect a sufficient gain from it. But free-riding is not without risk. When a bidder holds back his demand at a price significantly below his value, he is risking a sizable profit since the auction could end in the next round. Uncertainty about even the existence of the free-riding incentive lowers the potential gain that could tempt a bidder to take on such risk.

[7] Goeree and Holt (2010) also provide evidence from the laboratory that, even in an SMR auction with package bidding, restricting packages to a hierarchical structure (as we proposed for the CPA) helps bidders overcome the threshold problem by eliminating ambiguity about which component prices must rise to displace the package bidder.

The Overflow Problem

In CHK we pointed out that the MALS auction design introduces a new type of bias against bidders seeking single licenses or small groups of licenses. Bidders seeking packages of licenses will be constrained by the fact that unequal quantities of spectrum will be cleared in different markets. Consequently there will be EAs in which the number of licenses available exceeds the maximum number of the encompassing regional packages that can be allocated. The auction design needs to account for this. Otherwise bidders for single EA licenses can face rising prices even when their demands are not a source of scarcity. This will push such bidders out of the market unnecessarily and lead to misallocation and/or undersell.

We discussed the overflow problem in greater detail in CHK, where we showed that the CPA eliminates the overflow problem. This is possible because the CPA provides a bidding language that allows the price clocks to ensure that EA license prices do not rise when the excess demand is for the package rather than for the EA license itself. This is possible only when bidders can express package bids and when the clock adjustment process properly accounts for feasibility constraints, making sure that demand for packages flows down to the EA licenses only when the demands for single EA licenses are themselves a source of scarcity at the current prices.

Entrants

Exposure risk has been neglected in most prior FCC auction designs.[8] In some cases this has likely led to withdrawal of potential entrants from the auction. In other cases, this has forced package bidders to bid strategically, deviating from straightforward bidding in hopes of resolving uncertainty about closing prices of some licenses before committing to other licenses in the package. Bidders competing against package bidders unprotected against exposure risk have incentives for strategic bidding designed to maximize their competitors' exposure risk, potentially softening competition. Such incentives for bid manipulation are undesirable in themselves, as they can lead to poor price discovery and inefficient allocations. Further, the

[8] An exception is the 700MHz Upper C Block auction of (regulatorily) impaired spectrum, where a SMR auction with limited hierarchical package bidding was used following the design of Goeree and Holt (2010). See also Rothkopf, Pekec and Harstad (1998) for an early proposal to use hierarchical packages in an ascending auction. Another exception is Auction 66 of spectrum for Advanced Wireless Services, where licenses for Regional Economic Areas were offered in addition to licenses for Economic Areas and Cellular Market Areas.

need to understand such bidding strategies places a heavy burden on entrants seeking to bid effectively in the auction.

Although the MALS forward auction design introduces a number of important improvements on the SMR auction, it does nothing to address the problems discussed above. The MALS design neglects the exposure problem entirely.

The CPA design substantially mitigates exposure risk by using a geography-based hierarchical package structure we understand to be closely tied to the actual structure of complementarities between licenses in the mobile wireless industry. By minimizing exposure risk, the CPA eliminates bias in the MALS design (and SMR) against bidders seeking packages by eliminating (or substantially reducing) the risk of exposure. This is likely to improve both the efficiency of the spectrum allocation and auction revenues. One can see evidence of the latter in the FCC's Auction 66, where bids for REAG licenses were on average 37 percent higher per MHz than those for EAs covering the same population.[9] The exposure problem is likely to affect all bidders, due to the economies of scale from horizontal spectrum contiguity (see CHK for additional discussion) and the fixed costs associated with introduction of a new frequency band to an existing wireless deployment. Smaller firms seeking to enter the wireless market certainly are not immune to this exposure risk. And they face, in addition, the need to establish a sufficient geographic footprint to enable service to consumers who now expect coverage to extend outside small areas like EAs. As argued by Cramton et al. (2007, p. 23), "Package bidding levels the playing field and removing it would seriously damage the prospects for new entry."

Manipulative Bidding

It has been suggested that the CPA design may introduce incentives for strategic bid manipulation. No specific manipulations have been articulated, and we speculate that the concerns may arise from a misunderstanding of the CPA.

The CPA changes no rules of the MALS auction design. The CPA design modifies the MALS design only by (1) adding new objects (packages), (2) explaining how excess demand can then be properly calculated, and (3) defining rules for how price clocks are to adjust to maintain additive package pricing when possible. All else is the same. This includes, for example, the rule regarding reductions in expressed demand: as in the MALS proposal, in the CPA a bidder may reduce his quantity demanded of an object only when its price increases.

[9] If one compares price per MHz-Pop, the premium paid for REA licenses was more than 100%.

We have already pointed out that, by eliminating (or substantially reducing) the exposure problem, incentives for strategic manipulation of bids that are present in the SMR and MALS design will be eliminated (or substantially reduced) by the CPA design. Thus, there is at least one way in which the CPA *reduces* incentives for manipulative bidding. Furthermore, we do not see any new opportunities for profitable bid manipulation that result from the modification of the MALS auction embodied in the CPA design proposal.

An example may help to illustrate the protection against profitable manipulation offered by the specific design of the CPA. Suppose there is one license available in each of two EAs, A and B. One bidder seeking the AB package competes against two component bidders demanding A and B, respectively. Call the first bidder the package bidder and the latter two bidders the A-bidder and B-bidder. There are several ways one might imagine a bidder manipulating his bids in hopes of improving his profit:

(i) *The package bidder may pretend to be a component bidder in order to divide and conquer the component bidders:* One possibility is for the package bidder to run up the price clock for A by repeatedly demanding it until the A-bidder drops out, then switch to demanding the AB package he actually desires. This strategy would not help the package bidder to lower the price for the package, since any increase in the price of A triggers a commensurate price increase in the package price. The package bidder can do no better than by demanding the desired package straightforwardly (i.e., until its price reaches his valuation for the package). Nor would either component bidder be preempted by such a manipulation by the package bidder. A component bidder can never lose by demanding its desired component straightforwardly (i.e., until price rises to his valuation for the component). This is in contrast to the SMR in which a package bidder could indeed lower the price of the package, or weaken the competition, by driving out a component bidder.[10] Thus, **due to the additive package pricing rule of the CPA, there is no gain from this type of manipulation**.

(ii) *A component bidder, say the A-bidder, may seek to shift the competitive burden to the B-bidder:* He may try to do this by either (i) withholding his demand on A (parking eligibility on some other licenses with rising prices), (ii) demanding B to push up its price, or (iii) demanding the package AB. We extensively discussed the first possibility earlier in considering the threshold problem, and the second possibility involves a risk of winning a license that the A-bidder does not desire. Importantly, these two options are also available in MALS with the same consequences. The only new option made available by package bidding in CPA is the last option. And this option is totally ineffective as a means of lowering the price for A, leading only to a risk of ending up with an unwanted item. Demanding the package AB creates excess demand for this

[10] This was the main motivation of the FCC 700 MHz auctions which limited the withdrawal of component bids even when they were no longer provisionally winning. Limiting bid withdrawal has a serious side effect, however, for it ties up the budget of the bidder and thus constrains his ability to move across different licenses as prices change.

package and leads to the same increase in the price of A that would have resulted if the A-bidder had just bid for A.[11] Thus, **the CPA's introduction of packages to the MALS auction introduces no new opportunity for manipulation of this type**.

(iii) *There are in fact no package bidders, but a component bidder may pretend to be a package bidder by demanding a package of licenses:* One can imagine a bidder engaging in such behavior in an attempt to cause his opponents to free-ride on each other (withhold their demands) and allow him to win. As mentioned earlier, such an attempt to "signal" package preferences might be effective in the SMR setting but will not work in a clock auction in which bidders see only prices rather than demands. The anonymity of demands in the CPA means that the opponents will not know the source of an observed price increase, so the bidder cannot communicate the message he wishes to send. At the same time, such an attempt will entail a risk of the A-bidder ending up with a package of licenses he does not want. Thus, **this strategy has cost but no benefit**.

We acknowledge (see also CHK) the possibility that some licenses may go unsold in the CPA. This can happen, for example, when a component bidder drops out but remaining component bidders manage to displace the package bidder. This kind of undersell potential should be familiar from the clock phase of the Combinatorial Clock Auction ("CCA"). However, the magnitude of undersell in the CPA will tend to be far less than that under the clock phase of the CCA. This is because in the clock phase of the CCA, a bidder may drop his demand for an object whose price has not risen, as long as the price has risen for some other object he also demanded. This is not permitted in the CPA.[12] Bidders may reduce demand only on objects whose prices have increased. This rule is natural in an auction and offers a compromise between the extremely lax bid withdrawal rule of the CCA clock phase and the severe MALS rule, which discriminates against package bidders by prohibiting such a bidder from reducing his demand for a package unless the price of *every* component has increased.

If some items are unsold at the end of the auction, we proposed in CHK that the FCC should retain the option of reoffering them via another clock auction. As discussed in CHK, the prospect of unsold items being available in such a supplementary resale auction, possibly at lower prices, could create incentives for "small" bidders to withhold demand in the primary auction. However, such a strategy would be highly risky, since such a bidder could not be

[11] The only case in which the A-bidder's added demand for AB would not "flow down" to object A under the CPA rules is when (due to unequal spectrum clearing in markets A and B) this additional unit of demand for AB does not conflict with any existing demand for one of the components. If that is component A, then the A-bidder does not need the price of B to rise for him to win A. If that is component B, then the A-bidder's manipulative demand for AB does not flow down to B. Thus, manipulative bidding for AB cannot help the A-bidder.

[12] In the CPA, only a bidder for a nationwide license has the same flexibility for demand reductions that exists in the CCA clock phase. If that is a significant concern, the national license could be excluded from the specific package structure proposed in CHK. The resulting structure would remain a multitree, as the CPA requires for unambiguous determination of excess demand. We understand (see for example the Comments of T-Mobile) that a substantial share of the geographic license complementarities that will exist in these auctions could be captured by having only MEA and REAG packages.

certain that his desired license would go unsold, or that the FCC would indeed choose to reoffer the license. Thus we do not expect such a strategy to be an attractive option for bidders.

Single Pass Reverse Auction

Several commenters expressed concern about separation between the forward and reverse auctions.[13] In CHK we proposed the option of conducting the reverse auction in a single pass. This option offers a number of advantages, including simplifying bidder participation in the reverse auction. Reverse auction bidders would not need to be reconvened to establish prices for each new closing target. And accepted bids in the reverse auction would be made on the same day with the same information. This contrasts with an interleaved design in which clock prices for the reverse auction resume from the closing prices obtained for the previous (unsuccessful) clearing target. In that case, bidders demanding high prices might effectively commit themselves to being repacked days or weeks ahead of the final offers that are made by other stations.

Further, the single-pass option would not introduce significant complexity for reverse auction bidders. From a bidder's perspective, the single-pass auction would be virtually identical to one of sequencing the reverse and forward auctions under an interleaved design. Just as with the interleaved design proposal, a bidder merely responds to a sequence of price offers by selecting its preferred option at each set of prices. The single pass option would traverse a wider range of prices than any single reverse auction stage under the interleaved design, but the bidder's options during the auction would be identical under both designs, as would the rules determining allocations and prices paid to bidders for each relinquishment option.

Proxy Bidding in the Reverse Auction

Several commenters expressed concerns about the demands on reverse auction bidders if a sealed bid mechanism or proxy bidding system is used. We share the concern that many types of sealed bid mechanisms would introduce unnecessary complexity in the reverse auction. For example, we discussed practical limitations of the Vickrey-Clarke-Groves (VCG) auction in CHK. We also discouraged the use of a discriminatory ("pay-as-bid") design in the reverse auction. A discriminatory auction requires substantial sophistication from bidders. To bid optimally, they must develop a clear understanding not only of their own valuations, but of the competition

[13] *See, e.g.*, MetroPCS Comments at 8.

they are likely to face. Such an auction design may be well suited to environments in which bidders have substantial bidding expertise, but not a one-off auction in which firms with little or no bidding experience are asked to bid to sell large assets.

Nevertheless, these limitations are not inherent to all sealed bid auctions, nor to clock auctions with proxy bidding. A clock auction with proxy bidding was one option we discussed in CHK, where we pointed out that proxy bidding may offer a substantial benefit to the well functioning of the reverse auction by allowing repacking problems to be solved offline rather than in real time. The single-pass reverse auction proposed in CHK adds no significant complexity to the reverse auction relative to the MALS clock auction proposal. Indeed, proxy bidding *simplifies* participation (this is why it is used by eBay, for example). Rather than standing by waiting to see whether prices reach a level where a bidder's preferred relinquishment option would switch, a bidder can simply report the "switch points" to the proxy system with assurance that his plan will be executed automatically.

References

Ausubel, L. M., P. Cramton, and P. Milgrom (2006). "The Clock-Proxy Auction: A Practical Combinatorial Auction Design," in *Combinatorial Auctions*, ed. by P. Cramton, Y. Shoham, and R. Steinberg, 115-138. MIT Press.

Bykowsky, M.M., R.J. Cull, R.J., and J.O. Ledyard (2000). "Mutually Destructive Bidding: The FCC Auction Design Problem," *Journal of Regulatory Economics*, 17 (3), 205–228.

Che, Y.K., P. Haile, and M. Kearns (2013). "Design of the FCC Incentive Auctions,'' comments on behalf of AT&T.

Cramton, P. , G. Rosston, A. Skrzypacz, and R. Wilson (2007). "Comments on the FCC Wireless Bureau's Proposed Competitive Bidding Procedures for Auction 73," (DA 07-3415, August 17, 2007; AU Docket No. 07-157).

Goeree, J.K. and C.A. Holt (2010). Hierarchical Package Bidding: A Paper & Pencil Combinatorial Auction," *Games and Economic Behavior*, 70, 146--69.

Milgrom, P., L. Ausubel, J. Levin, and I. Segal (2012). "Incentive Auction Rules Options and Discussion," Auctionomics and Power Auctions.

Rothkopf, M., A. Pekec, and R. Harstad (1998). "Computationally Manageable Combinational Auctions," *Management Science*, 44, 1131–1147.

ATTACHMENT 3

Letter from Brian Benison (AT&T) to
Marlene H. Dortch (FCC)
October 29, 2013

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Federal Regulatory

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October 29, 2013

Electronic Submission

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street S.W.
Washington, D.C. 20554

Re: *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, **GN Docket No. 12-268**
NOTICE OF ORAL EX PARTE PRESENTATION

Dear Ms. Dortch:

On Friday, October 25, 2013, Joan Marsh, Gary Phillips, Michael Goggin, Alex Starr and the undersigned of AT&T Services, Inc. (AT&T), met with Gary Epstein and Edward Smith of the Incentive Auctions Task Force, Ruth Milkman, Joel Taubenblatt, Susan Singer, Martha Stancill, Margaret Wiener and Michael Janson of the Wireless Telecommunications Bureau, and Evan Kwerel and Steve Wildmon of the Office of Strategic Planning.

The purpose of the meeting was to discuss eligibility and package bidding issues related to the incentive auction proceeding. The attached presentation served as the basis for that discussion.

If you have any questions or need additional information, please do not hesitate to contact me. Pursuant to section 1.1206 of the Commission's rules, this letter is being filed electronically with the Commission.

Sincerely,

/s/ Brian Benison

cc: Gary Epstein, Edward Smith, Ruth Milkman, Joel Taubenblatt, Susan Singer, Martha Stancill, Margaret Wiener, Michael Janson, Evan Kwerel, Steve Wildmon

THE 600 MHz FORWARD INCENTIVE AUCTION

PRINCIPLES FOR MAXIMIZING SUCCESS

OVERVIEW

To maximize the likelihood and scope of success in the 600 MHz Forward Incentive Auction, the Commission should:

- Allow unfettered participation by all qualified bidders
  - Restricting bidding ability of AT&T and Verizon not necessary to protect competition.
  - Restricting bidding ability of AT&T and Verizon would reduce auction revenues, decrease funds available for FirstNet and deficit reduction, reduce cleared spectrum amounts, and risk auction failure.
- Adopt Hierarchical Package Bidding
  - Exposure risk reduced, encouraging robust bidding.
  - Bids win based on highest economic value, not size of area sought.

THE PURPOSE OF SPECTRUM AGGREGATION RULES IS TO PREVENT FORECLOSURE IN DOWNSTREAM MARKETS

There is broad agreement that the purpose of a spectrum aggregation limit is to prevent foreclosure in downstream markets and that such limits are inappropriate absent substantial risk of such foreclosure.

A successful foreclosure strategy requires a provider both:

- To acquire so much of the available spectrum that it could raise the cost facing other firms by an amount sufficient to have a *significant* effect on downstream competition, and
- To have the ability to recoup the cost of its campaign to acquire and warehouse spectrum in higher prices for wireless services.

Spectrum aggregation policy should protect competition, not individual competitors.

- The question is not whether one provider has acquired spectrum that would benefit another provider, but whether the acquisition impairs competition itself.

at&t

MARKET FORECLOSURE VIA THE 600 MHz AUCTION WOULD BE IMPOSSIBLE

- There are four strong national wireless providers with large spectrum portfolios that have built or are building ubiquitous wireless broadband networks.

- The approximate 70 MHz yield expected* from the 600 MHz auction is too small to permit foreclosure, given the more than 500 MHz of spectrum now available for mobile wireless services, with more coming online next year.

- Most mobile wireless spectrum licenses are subject to build-out requirements that preclude "warehousing."

******Example based on a 2x35 band plan.*

at&t

SPRINT HAS SUBSTANTIAL SPECTRUM AND FINANCIAL RESOURCES

- Sprint is by far the largest spectrum holder in the country, with an average of almost 200 MHz in the top 100 markets.
- As its new owner, Softbank, has already done in Asia, Sprint plans to deploy LTE nationwide on its 2.5 GHz spectrum by mid- 2014.
- Sprint CEO has said this deployment will help give Sprint "competitive parity" and "will give us extraordinary capacity and some speed and performance advantages in the market."
- Sprint's CFO recently said that Sprint has plenty of "runway" to continue selling unlimited data plans, and that "we feel good about… our portfolio [of] spectrum vs. the competition".
- With backing from Softbank, Sprint can well afford to pay market price for any spectrum it decides to purchase – if it decides to participate in the auction.

T-MOBILE HAS SUBSTANTIAL SPECTRUM AND FINANCIAL RESOURCES

- T-Mobile has acquired large amounts of spectrum from AT&T, Verizon and MetroPCS (and is seeking more from U.S. Cellular).

- T-Mobile has become the dominant holder of AWS-1 spectrum, and it has used those holdings to launch a nationwide LTE offering that covers over 200 million people.

- In 2Q 2013, T-Mobile reported postpaid net adds of 688,000. Since T-Mobile merged with MetroPCS on May 1, its stock is up nearly 75%.
  - In an October 9 News Release, T-Mobile boasted that since late March it has won more net new postpaid customers than AT&T, Verizon and Sprint combined.

- T-Mobile's advertisements claim that its network is faster than AT&T's because it is less congested.

- Like Sprint, T-Mobile offers unlimited data plans.

- Owned by one of the largest telecom companies in the world, T-Mobile also can well afford the pay market price at the auction.

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A BASIC REALITY CHECK SHOWS THAT HAVING LOW-BAND SPECTRUM IS NOT NECESSARY TO COMPETE EFFECTIVELY

- Sprint and T-Mobile are competing very successfully without low frequency spectrum.
- Both chose not to participate in the 700 MHz auction.
- When Verizon offered its 700 MHz A and B Block spectrum, T-Mobile declined and fought aggressively, instead, for AWS divestitures.

THERE IS NO ECONOMIC OR ENGINEERING BASIS TO TREAT LOW-BAND SPECTRUM DIFFERENTLY FOR PURPOSES OF SPECTRUM AGGREGATION POLICY

- Those who argue for limits on low-band spectrum assert that such spectrum has better propagation than high frequency spectrum and therefore costs less to deploy.

- This purported advantage is irrelevant because:
  - Differences in the cost of build-out will be reflected (and offset) in the cost of the spectrum.
  - In non-rural areas, today's network challenges primarily concern capacity, not coverage.
    - In non-rural areas, providers must build dense networks whether they hold high-band or low-band spectrum.
    - As networks densify, higher frequency bands will be viewed as increasingly valuable specifically because they do not propagate too far thereby reducing interference.
  - In rural areas, no credible claim of foreclosure.
    - No indication from T-Mobile that it intends to expand its rural footprint.

BIDDING RESTRICTIONS ON AT&T AND VERIZON WOULD UNDERMINE THE 600 MHz AUCTION

- A central principle in the theory of auctions is that unfettered participation will maximize revenues.
  - While it is theoretically possible for auction restrictions to enhance revenues, none of the preconditions (all of which are necessary) for that to occur exists.

- Here, rules precluding participation by AT&T and Verizon would likely reduce auction revenues by billions of dollars.
  - Argument that excluding AT&T and Verizon could enhance participation and increase revenue is self-contradictory. If others are willing to pay more than AT&T and Verizon, then exclusion is not necessary. If others are not willing to pay more, then exclusion would yield less revenue.

- In the context of this unique two-sided auction, lower revenues would likely reduce the amount of spectrum made available for mobile services, threaten FirstNet funding and deficit reduction, and possibly lead to failure of the auction altogether.

- Even if the auction clears, limits on participation will result in a less efficient allocation of spectrum.

at&t

T-MOBILE'S PROPOSED CAP ON LOW BAND SPECTRUM WOULD EXCLUDE AT&T

- Assuming an 84 MHz clearing target, the spectrum cap that T-Mobile proposes, set at 1/3 of low band spectrum, would completely bar 2 of T-Mobile's largest 3 rivals from bidding against T-Mobile in most of the top metropolitan areas in the U.S.

- AT&T would be barred from bidding at all in 8 of the top 10 EAs.

- AT&T would be barred from bidding on a 10X10 MHz pair -- which even T-Mobile correctly acknowledges is the minimum channel size necessary to materially employ LTE's efficiencies -- in all of the top 10 EAs and 49 of the top 50.

- VZW reports that it would be excluded in 7 of the top 10 EA's and 13 of the top 20.

- T-Mobile's recent critique of these numbers is fatally flawed.

T-MOBILE'S "DYNAMIC MARKET PROPOSAL" DOES NOT CURE THE PROBLEMS CREATED BY ITS PROPOSED SPECTRUM CAP

- DMP would not prevent substantial reductions in auction revenue.
- DMP would substantially reduce competition in the auction by capping T-Mobile's two largest rivals' ability to bid.
- DMP would not ensure that caps do not lead to the failure to satisfy closing conditions at a given spectrum target.
- DMP could reduce the total quantity of spectrum reallocated or even lead to an auction failure.

DMP WOULD INTRODUCE SIGNIFICANT NEW PROBLEMS

- Additional complexity
- Exposure risks
- Impaired price discovery
- Incentives for manipulative bidding

HIERARCHICAL PACKAGE BIDDING WOULD MINIMIZE EXPOSURE RISK AND THUS MAXIMIZE REVENUE AND CLEARED SPECTRUM

- Bid-suppressing exposure risk occurs where, as here, significant geographic complementarities exist.
- The bid suppressing effects of this exposure risk may be more damaging in this auction, as it is likely to reduce the amount of spectrum allocated and could frustrate the statutory goals of FirstNet funding and deficit reduction.
- Hierarchical package bidding (HPB) minimizes exposure risk by permitting bidders to express the full value of geographic complementarities in their bids.
- As a result, HPB would foster widespread and robust auction participation, in which demand from all bidders is fully expressed, maximizing the amount of spectrum reallocated and generating higher revenues.

AT&T'S HPB PROPOSAL IS SIMPLE, TRANSPARENT AND FAIR

- AT&T proposes a simple form of HPB, with each pre-defined package (EAs, MEAs, and REAs) fully nested within the next-larger pre-defined package.
- A package bidder would win only if the total bid for the package exceeds the sum of the bids for individual licenses included in the package.
- HPB does not favor package bidders over individual bidders.
- Winning bids are selected solely on the basis of which bids express – and can be presumed to produce – the greatest economic value for consumers.
- HPB does not add computational or strategic complexity.
- HBP does not create any new "threshold" issue not already present in NPRM's Auctionomics proposal due to geographic complementarities.
- H Block Order provides no basis to avoid HPB here.

ATTACHMENT 4

Letter from Gary L. Phillips (AT&T) to
Marlene H. Dortch (FCC)
October 31, 2013

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Assoc. General Counsel

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October 31, 2013

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Dear Ms. Dortch:

RE: *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268

Numerous studies submitted in this proceeding have demonstrated that restricting the participation of AT&T and Verizon in the upcoming auction of 600 MHz spectrum would have substantial negative effects on forward auction revenues, the amount of spectrum made available in the auction, and the efficient allocation of that spectrum. In the attached paper, "The Impact on Federal Revenues from Limiting Participation in the FCC 600 MHz Spectrum Auction," Philip Haile, Maya Meidan, and Jonathan Orszag ("Haile/Meidan/Orszag" or "the authors") provide a quantitative assessment of the likely effects that participation restrictions would have on auction revenue.[1] The authors show that the participation restrictions that have been proposed by certain parties, including T-Mobile's proposal of a one-third cap on spectrum holdings below 1 GHz, combined with an exception to allow every bidder to acquire one 5x5 MHz license in every license area, would likely cause revenue losses of *billions* of dollars.

The authors' economic analysis is based on a forecasting method developed by Jeremy Bulow, Jonathan Levin, and Paul Milgrom ("BLM") that utilizes observations of bidder exposure to predict winning bids and auction revenues.[2] The BLM approach provides a natural framework for estimating the effects of participation restrictions on incentive auction revenues, and Haile/Meidan/Orszag extend the BLM approach and use data from historical FCC auctions to estimate both the percentage and absolute revenue reductions that would be likely if the Commission were to impose partial or full participation restrictions in the 600 MHz auction. The authors further demonstrate that their results are robust under a wide range of assumptions. In all modeled scenarios, participation restrictions yield multi-billion dollar revenue losses; in more restrictive scenarios, the losses are in the tens of billions of dollars.

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[1] Haile is the Ford Foundation Professor of Economics at Yale University. Meidan is Senior Economist at Compass Lexecon, LLC, an economic consulting firm. Orszag is a Senior Managing Director and member of the Executive Committee of Compass Lexecon; previously, Orszag served on President Clinton's National Economic Council and as the Assistant to the Secretary of Commerce and Director of the Office of Policy and Strategic Planning.

[2] *See* Bulow, Levin, and Milgrom, "Winning Play in Spectrum Auctions," Stanford University Working Paper (2009).

The authors' economic analysis also rebuts the speculation by auction limit proponents that these enormous revenue losses might somehow be offset by more aggressive bidding by other firms or by the entry of new bidders. Haile/Meidan/Orszag show that the number of bidders (or, alternatively, the budgets of non-AT&T/Verizon bidders) would need to essentially *double* to offset the adverse effects arising from even the least aggressive restrictions on auction participation under discussion. "Such increases in the number of bidders or budgets by existing bidders are implausible."[3]

Prompt, successful completion of the 600 MHz auctions is essential to the continued health and growth of the U.S. broadband wireless marketplace. The self-interested proposals for auction participation restrictions plainly threaten that outcome, and they should be rejected.

Sincerely,

/s/ Gary L Phillips

[3] The Impact on Federal Revenues from Limiting Participation in the FCC 600 MHz Spectrum Auction at 2.

The Impact on Federal Revenues from Limiting Participation in the FCC 600 MHz Spectrum Auction

Philip A. Haile
Maya Meidan
Jonathan M. Orszag[1]

October 30, 2013

[1] Haile is the Ford Foundation Professor of Economics at Yale University. Meidan is Senior Economist at Compass Lexecon, LLC, an economic consulting firm. Orszag is a Senior Managing Director and member of the Executive Committee of Compass Lexecon; previously, Orszag served on President Clinton's National Economic Council and as the Assistant to the Secretary of Commerce and Director of the Office of Policy and Strategic Planning. This paper was supported by funding from AT&T. The views and opinions expressed in this note are solely those of the authors and do not necessarily reflect the views and opinions of AT&T or any of the organizations with which the authors are or have previously been affiliated.

1 Executive Summary

- Several interested parties, including T-Mobile and Sprint, have suggested the FCC should limit the participation of AT&T and Verizon in the upcoming 600 MHz spectrum auction through caps on spectrum license holdings. In response, commenters have raised competition and/or telecommunications policy concerns about proposals to limit participation.
- This paper analyzes the fiscal implications of proposed limitations on participation in the incentive spectrum auction. Given the current size and projections for the Federal budget deficit, the budgetary impact of any limitations on participation in the incentive auctions has public policy implications that go far beyond the scope of competition and telecommunications policy.
- Our economic analysis predicts revenue losses of billions of dollars from even the *mildest* of the participation restrictions currently under discussion. More severe restrictions, which might result in *de facto* exclusion of AT&T and Verizon from the auction, would magnify this loss, implying auction revenue reductions of tens of billions of dollars. (Our analysis ignores the fact that lower auction revenue may result in a smaller quantity of spectrum cleared due to the structure of the 600 MHz auction; this would further increase the adverse effect on the Federal budget.)
- The same interested parties that have proposed caps on spectrum license holdings have also claimed that such revenue losses would be offset by more aggressive bidding strategies by other firms or by entry of new bidders. However, we estimate that the number of bidders outside the "big four" (AT&T, Verizon, Sprint, and T-Mobile) would need to more than double to offset the adverse effects arising from even the least aggressive restrictions on auction participation under consideration. Alternatively, the budgets of non-AT&T/Verizon bidders would need to increase by 80 percent to offset the same adverse effects. Such increases in the number of bidders, or in the budgets of existing bidders, are implausible.
- Therefore, the proposed limitations on participation, including T-Mobile's proposal of a one-third cap on spectrum holdings below 1 GHz, combined with an exception to allow every bidder to acquire at least one 5×5 MHz license in every market, are likely to reduce auction revenues by billions of dollars, which will adversely affect the Federal budget deficit.

2 Introduction

Sometime in 2014, the Federal Communications Commission (FCC) hopes to conduct "incentive auctions" to reallocate up to 120MHz of spectrum in the 600 MHz band from current broadcast television licensees to providers of mobile wireless services. The plans call for a "reverse auction" in which current licensees offer to relinquish licenses and a "forward auction" in which newly created mobile wireless licenses will be sold. Revenue from the forward auction will determine the amount of spectrum reallocated and will be used (i) to pay the TV broadcasters for their relinquished licenses,[2] (ii) to relocate television broadcasters to other spectrum bands, and (iii) to establish FirstNet, a nationwide network for first responders. Any additional revenue received from the incentive auction (after additional expenses such as the reallocation of spectrum from federal to commercial use and certain research and development activities) will go towards deficit reduction.[3] Given the current size and projections for the Federal budget deficit, the budgetary impact of any limitations on participation in the incentive auctions has broader public policy implications than just competition or telecommunications policy.

The FCC faces the challenging task of planning a successful auction that will satisfy mobile wireless providers' demand for additional bandwidth, induce TV broadcasters to sell their licenses, and generate sufficient revenue for the Federal government (both to establish FirstNet and for deficit reduction). The complexity and novelty of the upcoming auction has led multiple parties to weigh in on the question of which auction rules should be used by the FCC in order to achieve its goals. Several interested parties, such as T-Mobile and Sprint, have suggested the FCC should limit the participation of AT&T and Verizon in the auction through caps on spectrum license holdings.[4] In response, other commenters have pointed out that the proposed caps would restrict severely the bidding eligibility of AT&T and Verizon, leading to lower auction prices, reduced auction revenue, and an inefficiently low quantity of spectrum reallocated from broadcast television to mobile wireless.[5] As a result, some commenters have put forward alternative proposals, such as T-Mobile's proposal of a one-third cap on spectrum holdings below 1 GHz, combined with an exception to allow every bidder to acquire at least one 5×5 MHz license in every market.[6]

The goal of the present analysis is to provide a *quantitative* assessment of the likely effects that the proposed participation restrictions would have on forward auction revenue. Many parties have expressed

[2] If a broadcaster's price cannot be met with revenues from the forward auction, its license will not be sold.

[3] Congressional Budget Office, "Analysis of the Impact on the Deficit of the Budget Control Act of 2011 as Proposed in the Senate," July 27, 2011.
http://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/123xx/doc12338/senatebudgetcontrolact.pdf

[4] See, for example, testimony of Kathleen O'Brien Ham before the Subcommittee on Communications and Technology, July 23, 2013, pp.10-12 and Baker (2013).

[5] See, for example, Israel and Katz (2012, 2013) and Katz, Haile, Israel, and Lerner (2013a, 2013b).

[6] *See Ex Parte Letter* from Trey Hanbury, Counsel for T-Mobile USA, Inc. to Marlene H. Dortch, Secretary, Federal Communications Commission, WT Docket No. 12-269, May 30, 2013.

views about the likely qualitative effects. A near-universal message from the theory of auctions is that revenues are enhanced by *encouragement* of bidder participation, especially that of bidders likely to have large budgets and to place high value on the licenses for sale. However, it is also well understood that under certain, specific conditions there is a *theoretical possibility* that restricting participation could lead to higher revenue. Such a possibility can arise when participation costs are high and there are many "discouraged bidders" who are sufficiently pessimistic about their chances of winning that they are unwilling to participate unless strong bidders are excluded. Other commenters have discussed whether these special circumstances are plausible in the context of the 600 MHz spectrum auction.[7] It is important to note that even such special conditions are not sufficient to ensure that participation restrictions enhance revenues: this requires that the new participation encouraged by the exclusion of strong bidders is sufficient (both in numbers of bidders and in their willingness to pay) to overcome the adverse effects of the exclusion.

However, rather than engaging in further debate on the plausibility of special theoretical conditions, we aim to add light to the discussion by providing estimates of key quantities relevant to evaluation of participation restrictions from a policy perspective. These include the dollar value of revenue losses associated with a failure of the theoretical possibility to materialize, as well as the number of "discouraged bidders" that would need to exist in order for their participation to offset revenue losses introduced by limiting the participation of AT&T and Verizon.

Our approach combines data on past FCC spectrum auctions with the insights of Bulow, Levin and Milgrom (2009) (henceforth "BLM") regarding how bidders have behaved in these auctions. Such an approach allows us to assess the likely effects participation restrictions would have had in past spectrum auctions, offering the best available guidance on the likely effects of such restrictions in the upcoming 600 MHz auction.

Our analysis predicts forward auction revenue losses of $6.7 billion to $13.4 billion from even the *mildest* of the participation restrictions currently under discussion. More severe restrictions, which might result in *de facto* exclusion of AT&T and Verizon from the auction, would double this loss, driving auction revenue down by an estimated $13.4 billion to $26.8 billion. Our analysis also reveals that such losses are unlikely to be offset by more aggressive bidding strategies by other firms, or by entry of new bidders. For example, we estimate that the number of bidders outside the "big four" (AT&T, Verizon, Sprint, and T-Mobile) would need to more than double to offset even the most conservative estimates of adverse effects arising from restrictions on the participation of AT&T and Verizon.

[7] See, e.g., Katz et. al (2013b), pp. 5-15.

3 Methodology

3.1 Bulow, Levin, and Milgrom (2009)

As noted above, our analysis relies on an approach to revenue forecasting developed by BLM. BLM point out that in past FCC spectrum auctions, final revenues could have been predicted remarkably well from bids made earlier in the auction. To show this, BLM define the notion of *exposure*. A bidder's exposure in a given round of the auction is defined as the sum of its standing (provisionally winning) bids in the prior round and its additional bids (provisionally winning or not) in the current round.[8] *Total exposure* in a round of the auction is defined as the sum of the exposure of all bidders. BLM show that the *maximum total exposure*—the largest total exposure in any round of the auction—is typically realized well before the end of the auction. From that point on, total exposure remains roughly constant, even as prices climb and each bidder adjusts the set of licenses pursued. Only at the end of the auction is total exposure equal to the total value of the provisionally winning (at that point, *winning*) bids. But as BLM point out, the early rise of total exposure to a level roughly equal to that at the end of the auction allows bidders to predict final prices (more precisely, total revenue, which implies final average prices per MHz-POP) well before it is clear which bidders will win which licenses.

BLM explain this phenomenon by suggesting that a large share of bidding teams in spectrum auctions operate with budget constraints and, further, tend to follow a strategy (at least after an initial ramp-up period) of submitting bids in each round which, if accepted, would essentially exhaust their budgets. BLM refer to this as "budget bidding" and provide a discussion of why this might arise.[9] BLM show that this simple characterization of bidding performs remarkably well in explaining both individual and, especially, aggregate bidding behavior.

An implication of the BLM finding is that one needs only a good estimate of the *aggregate budget* (the total of all bidders' budgets) to predict accurately auction revenue. Because BLM were focused on the ability of bidders to predict final revenue (or, equivalently, final average prices per MHz-POP), they sought an estimator of total budgets that could be applied during the auction by bidders. This led them to focus on maximum total exposure as an estimator of aggregate budget. However, because budget-bidding holds only approximately, round-to-round noise in total exposure often results in a value of maximum total exposure that systematically overpredicts final revenue. BLM explored options for smoothing the maximum to avoid this bias, and we adopt a smoothing approach as well. In particular, we find that using

[8] The references to "rounds" and "provisionally winning bids" reflect the use of simultaneous multi-round ascending auctions in past FCC spectrum auctions.

[9] Importantly, it is not necessary that the firm bidding literally face constraints in capital markets. Although some smaller firms surely do face such constraints, even the large bidders typically bid in a way that is consistent with separation of decisions about the overall budget for the auction from decisions about how best to utilize that budget in the auction.

the *median total exposure* as an estimate of the aggregate budget offers substantial improvement in the accuracy and precision of the revenue predictions.[10]

3.2 Predicting the Effects of Participation Restrictions

The BLM analysis does not directly yield estimates of the effects of participation restrictions on revenues but it provides a very natural framework for doing so using their insights about bidder behavior.

3.2.1 Full Exclusion

We begin by asking what revenues would have been realized in past auctions had AT&T and Verizon been completely excluded. Full exclusion is a more extreme form of participation restriction than those explicitly proposed, although some proposals may be sufficiently limiting that they would have the same effect as exclusion.[11] In any case, examination of full exclusion is an essential step toward our analysis of less severe restrictions on participation.

Recall that BLM showed that the estimated aggregate budget of all bidders accurately predicts final auction revenue. Thus, to examine the effect of excluding one or more bidders, one need only modify the set of bidders over which budgets are aggregated. Specifically, we examine the total exposure over all non-AT&T/Verizon bidders, using the median of this exposure as an estimate of their aggregate budget. We show below that this yields an extremely accurate predictor of the ultimate contributions to revenues from non-AT&T/Verizon bidders.[12]

An initial estimate of the effect of excluding AT&T and Verizon from past auctions is directly implied: the estimated aggregate budget of non-AT&T/Verizon bidders is an estimate of the final auction revenue. Let $\hat{R}_a$ denote the predicted auction revenue in auction a when all bidders participate, and let $\hat{R}_a^E$ denote the predicted revenue in the same auction with AT&T and Verizon excluded. We calculate the predicted average percent revenue loss as

$$RL_E = \sum_a w_a \left(1 - \frac{\hat{R}_a^E}{\hat{R}_a}\right)$$

[10] We doubt this insight would be viewed as surprising to the authors of BLM. However, they were focused on prediction of auction revenue *during* the auction, and for that purpose the median provides a much less practical forecasting tool than does the maximum (or near maximum) total exposure seen "thus far" in the auction.

[11] For example, for a major mobile wireless provider, the fixed costs involved in supporting a new spectrum band may be too high to be justified by access to this band in only some markets or by access only to a 5×5 MHz position in the band nationwide.

[12] This is not required for the BLM forecasting approach to be valid, but is an implication of the "budget bidding" model they propose to explain it. Thus, this finding provides additional strong support for their model and to the approach of using estimated budgets to predict final revenue.

where w_a is the weight given to auction a (proportional to the total MHz-POP sold in that auction).[13] This provides an estimate of the average percentage revenue loss from the hypothetical exclusion of AT&T and Verizon from past FCC auctions. Under the assumption that RL_E provides a good guide to the percentage revenue that would be lost due to their exclusion in the 600MHz auction, one can obtain estimated dollar values of losses by multiplying RL_E by a forecast of auction revenue per MHz-POP that assumed no participation restrictions.

3.2.2 New Budgets

The prediction described above relies on an assumption that bidders do not adjust their budgets in response to a restriction on other bidders' participation. This may not be reasonable. If the participation of AT&T and Verizon were restricted, their competitors might expect to obtain the licenses they want at lower prices and, therefore, delegate smaller budgets to their bidding teams. In that case, our calculation would understate the revenue losses. Alternatively, these bidders might see an opportunity to buy more spectrum than they otherwise would have. If this effect is large enough, it might require spending more on spectrum and, therefore, larger budgets.

Ignoring these two possible adjustments to auction budgets may merely lead to offsetting biases. Nonetheless, the BLM methodology easily allows explicit consideration of changes in competitors' budgets. For example, if one believed that budgets of the competitors to AT&T and Verizon would increase by a factor of β, one can recalculate the predicted percentage revenue loss after such adjustment as

$$\sum_a w_a \left(1 - \frac{\beta \hat{R}_a^E}{\hat{R}_a}\right).$$

3.2.3 New Bidders

The calculations described above treat the set of non-AT&T/Verizon bidders as unaffected by restrictions on AT&T and Verizon's participation. We believe this is the most natural assumption, since we find it implausible that the costs of participation in the auction are so high (and the certainty of winning licenses so low) that there are bidders who are small enough to be discouraged from participation by the presence of AT&T and Verizon yet big enough to have a material effect on revenue. Nonetheless, the BLM approach again offers a way to provide a quantitative assessment of the possibility that added participation is likely to offset the losses otherwise associated with restricting the participation of AT&T and Verizon.

[13] One might alternatively use the actual revenue in the denominator instead of predicted revenue. Standard practice for counterfactual simulation is to use the model to predict outcomes under both policy regimes being compared, since this avoids findings that are merely artifacts of the model's inability to reproduce perfectly the data. Here, because the prediction of total revenue based on median total exposure is so accurate, using actual revenue in the denominator would in fact have very little effect on the results.

One might approach this in a way equivalent to the analysis of new budgets, simply by reinterpreting β above as the percent increase in the number of non-AT&T/Verizon bidders. Such a calculation, however, would be unrealistically optimistic about the budgets of new entrants. It is unreasonable to expect new entrants to have budgets as large as those of the two other large nationwide wireless providers, Sprint and T-Mobile. Thus, we instead obtain an estimate of the average budget per bidder (excluding AT&T, Verizon, Sprint, and T-Mobile) in past auctions, and assess how many new bidders (with this average budget) would have been needed to compensate for the exclusion of AT&T and Verizon in past auctions.

3.2.4 Partial Restrictions on Participation

The BLM-based method is also easily adapted to evaluation of policies that result in less severe limits on the actual participation of AT&T and Verizon. Our starting point is the natural assumption that the budgets delegated to AT&T and Verizon bidding teams will be roughly proportional to the total MHz-POP pursued by these firms. A recent FCC filing on behalf of AT&T describes effects on AT&T's bidding eligibility in top markets that would result from a strict one-third cap on low-band spectrum.[14] A Verizon filing reaches similar conclusions about its eligibility.[15] Rough calculations based on this information suggests that the eligibility to bid (measured in MHz-POP) of AT&T and Verizon would be cut by roughly 70 percent relative to the nationwide 10x10 position each might wish to pursue in the absence of participation constraints. With the 5×5 exception proposed by T-Mobile, similar calculations suggest a reduction of roughly 50 percent. Using these calculations as a guide, we will consider budget reductions of one-half and two-thirds.

3.3 Alternative Empirical Approaches

We considered other approaches to estimate the effects of participation restrictions on revenues. Our conclusion is that the BLM methodology is by far the best available method for answering the question we study. For example, theory alone cannot provide quantitative answers regarding revenue. An ideal empirical approach would compare revenues from past auctions without participation restrictions to revenues from identical auctions with exogenously imposed participation restrictions like those currently under discussion. But this ideal is impossible, not only due to the lack of exogenous variation in participation rules, but also due to substantial cross-country and cross-time variation in market characteristics, auction designs, and technological development, as well as wide variation in the participation restrictions imposed.

[14] See Che and Haile (2013).

[15] See *Ex Parte Letter* from Tamara Preiss, Vice President, Federal Regulatory Affairs, Verizon, to Marlene H. Dortch, Secretary, Federal Communications Commission, WT Docket No. 12-269, GN Docket No. 12-268, July 17, 2013

Statistical methods like regression analysis, often used to control for confounding factors in observational data, cannot overcome these problems. This is due both to a lack of exogenous variation in the implementation and design of participation restrictions and to sample sizes that preclude an attempt to control for even the few most important cross-auction differences.[16]

Another possible approach to consider is the modern "structural" empirical approach to auctions, which would combine data from past auctions and with a fully specified model of equilibrium bidding to estimate bidders' valuations based on their observed bids and equilibrium conditions.[17] One might then examine the potential effects of participation restrictions by simulating new equilibrium bidding subject to these restrictions. There are at least two reasons that this approach is not applicable. One is the lack of a fully developed equilibrium theory of bidding in auctions with the complexity of the FCC spectrum auctions. The second is the strong evidence from BLM that "it is bidders' budgets, as opposed to their license values, that determine average prices in a spectrum auction."[18] In fact, the approach we take may be viewed as a version of the usual structural approach to auctions, but replacing traditional models of bidding with BLM's budget-bidding model.

4 Validation Analysis

We begin by examining the performance of BLM's methodology for predicting auction revenue based on estimates of bidder budgets. We study the same set of FCC spectrum auctions considered by BLM, with the addition of auction 73, the most recent broadband spectrum auction and the largest to date in terms of revenue and bidder participation. Table 1 provides information on these auctions.

[16] For example, in an analysis prepared for Mobile Future, Earle and Sosa (2013) rely on indirect evidence regarding the effects of participation restrictions on revenues in small number of auctions in the U.S., Canada, and Europe. Those auctions may provide the best opportunity available to evaluate empirically the effects of participation restrictions on the evolution of the mobile wireless industry, particularly since such evolution takes time. But a small sample from many different countries provides no reliable basis for evaluating *revenue* effects. Similar problems limit the conclusions one can reach from the analysis of Cave and Webb (2013), prepared on behalf of Sprint. They do not attempt to compare auctions with and without spectrum limits, instead comparing auction prices across countries based on a measure of whether the spectrum caps were binding. The authors acknowledge that their measure is flawed (although they make an important unacknowledged error in asserting that a bidder that does not ultimately acquire its full cap is necessarily unaffected by the cap). Moreover, their sample is too small for meaningful statistical analysis. While these two studies reach opposite conclusions regarding revenues, an objective reading suggests that the evidence is completely uninformative on the revenue question. See also the discussion in Katz et. al (2013, pp. 13-15) regarding problems with (necessarily anecdotal) evidence from European spectrum auctions with participation restrictions.

[17] See, e.g., the survey of Athey and Haile (2006).

[18] BLM, p. 2.

Table 1: List of Auctions Considered

Auction	Description	Date concluded	Revenue ($M)	AT&T/VZ Participated?
22	C, D, E, and F Block Broadband PCS	4/15/1999	$ 533	No
30	39 GHz	5/8/2000	$ 467	Yes
33	Upper 700 MHz Guard Bands	9/21/2000	$ 546	No
34	800 MHz SMR General Category Service	9/1/2000	$ 337	No
35	C and F Block Broadbnd PCS (Auction was cancelled, all bids returned).	1/26/2001	$ 17,597	Yes
37	FM Broadcast	11/23/2004	$ 178	No
44	Lower 700 MHz Band	9/18/2002	$ 116	No[1]
53	Multichannel Video Distribution & Data Service (MVDDS)	1/27/2004	$ 137	No
58	Broadband PCS (Re-auction of a subset of PCS licenses returned to FCC)	2/15/2005	$ 2,254	Yes
66	Advanced Wireless Services	9/18/2006	$ 13,879	Yes
73	700 MHz Band (Spectrum Reclaimed Following Digital TV Transition)	3/18/2008	$ 19,120	Yes

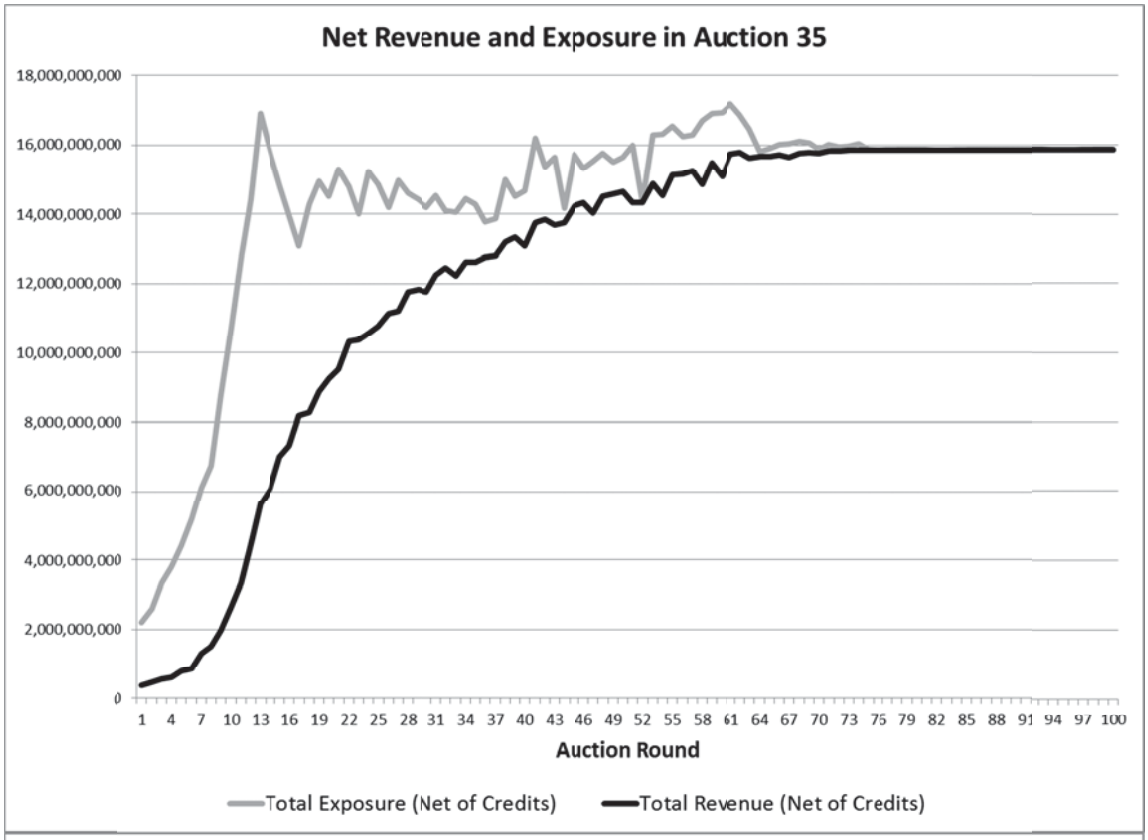
[1] In 2008, four of the winning bidders in auction 44 assigned their licenses to AT&T: Aloha Partners, Cavalier Group, DataCom Wireless and Milkyway Broadband.

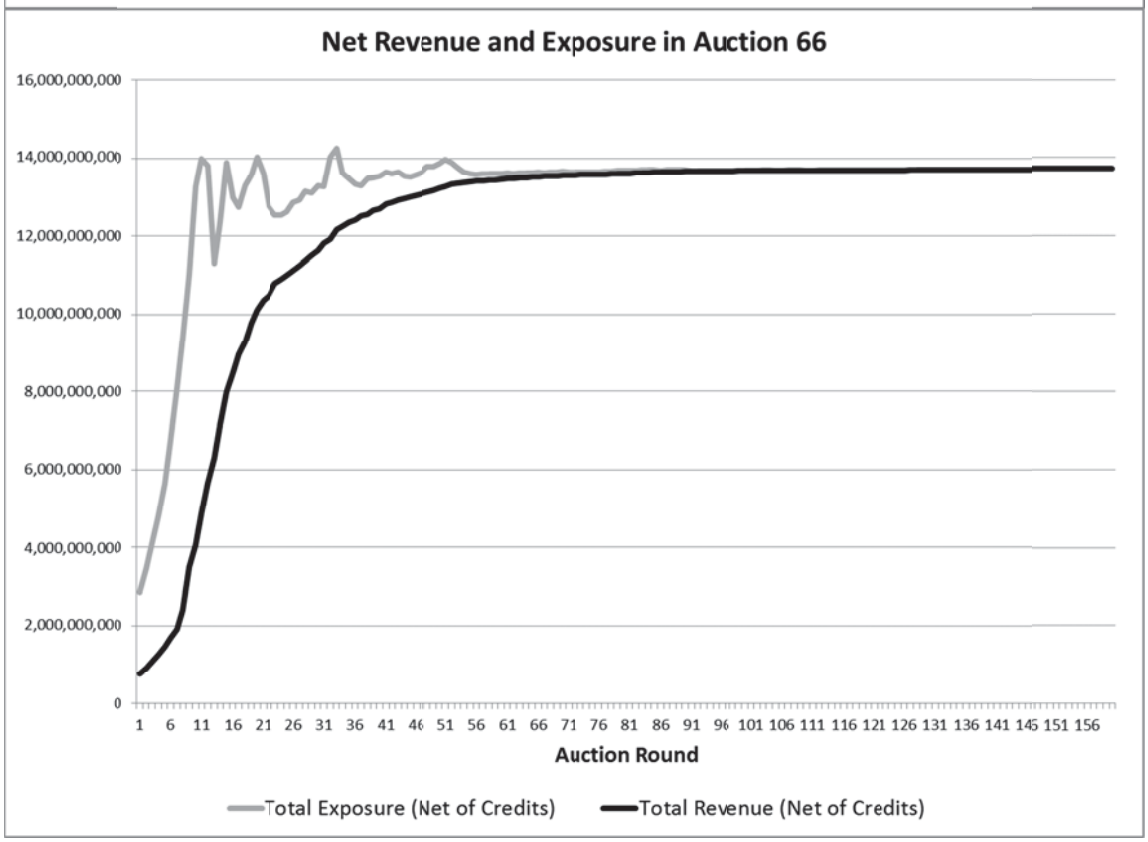
Figure 1 below illustrates the pattern of bidding in a few representative auctions. In each figure, the horizontal axis tracks rounds of the auction. Two curves are shown: one showing the total exposure in each round, the other showing the total value of provisionally winning bids in each round. These figures illustrate the same patterns discovered by BLM: typically total exposure ramps up early in the auction, then remains roughly constant until the end, when the value of all provisionally winning bids catches up. As discussed by BLM, these patterns are consistent with the budget-bidding hypothesis and provide a basis for predicting final revenues based on estimates of bidder budgets.

BLM proposed maximum total exposure as one possible estimator of bidder budgets because it was particularly attractive for their purposes. However, as can be seen already in the figures below, there is some round-to-round variation in total exposure that will cause the maximum total exposure to have an upward bias as a predictor of final revenue. BLM suggested ignoring the largest values of total exposure—for example, taking the third-highest total exposure to predict revenue.[19] Because we are not concerned with predictions that can be made early in the auction, but instead need only the best possible

[19] BLM suggest that the third-highest total exposure is the best predictor of revenue. We discovered a mistake in BLM's calculation of that variable. When correctly calculated, the third-highest exposure has similar properties to the maximum total exposure. This was one factor leading us to explore alternative measures with the same objective, but with improved prediction accuracy.

Figure 1: Total Net Revenue and Exposure for Selected Auctions





estimates of the aggregate budget, we consider two alternatives. The first is the median total exposure. Median total exposure provides a natural estimator of the aggregate budget under the budget-bidding hypothesis, one that is robust to the existence of rounds in which the budget-bidding hypothesis breaks down—e.g., due to bidding errors, early aggressive bids designed to intimidate, or a ramp-up period early in the auction. Our second alternative is the 75th percentile (across all rounds) of the total exposure. If, for example, the ramp-up period occupies the first-half of the auction, then the 75th percentile would offer a natural measure of the typical total exposure during the budget-bidding half of the auction.

Table 2 compares actual revenues to the predictions obtained using the budget-bidding hypothesis and the three estimators of aggregate budget.[20] All three do well for most auctions, although the upward bias of maximum total exposure is clear. Median total exposure and 75th percentile total exposure substantially reduce this bias and yield extremely accurate predictions for most auctions. Consistent with the budget-bidding hypothesis, there is typically little difference between the median and 75th percentile.

Table 2: Total Net Revenue and Exposure ($ Millions)

	(A)	(B)	(C)	(D)	(E)
Auction Number	Auction Net Revenue	Maximum Exposure Round/ Final Rounds	Maximum Total Exposure	75th Percentile Total Exposure	Median Total Exposure
22	$ 412	12/78	$ 597	$ 412	$ 412
30	$ 411	31/73	$ 424	$ 411	$ 407
33	$ 520	17/66	$ 779	$ 541	$ 524
34	$ 319	24/76	$ 337	$ 320	$ 317
35	$ 15,866	61/101	$ 17,189	$ 15,878	$ 15,832
37	$ 146	17/62	$ 255	$ 210	$ 168
44	$ 88	82/84	$ 90	$ 88	$ 85
53	$ 119	18/49	$ 148	$ 119	$ 117
58	$ 1,871	5/91	$ 2,014	$ 1,882	$ 1,871
66	$ 13,700	33/161	$ 14,264	$ 13,700	$ 13,690
73[1]	$ 19,119	26/261	$ 22,384	$ 19,120	$ 19,119

[1] Total net revenue and exposure exclude block D, which did not meet the applicable reserve price. Google has been excluded from the exposure calculations.

We note that BLM excluded auction 73 from their analysis because of the behavior of Google, which had a provisionally winning bid of $4.7 billion on a national package license through round 27, but then

[20] Throughout we calculate revenue and exposure net of bidding credits, since it is the net payment of bidders with bidding credits that determine revenue. For purposes of predicting prices rather than revenue, however, one would use bids gross of bidding credits, since gross bids determine prices. BLM were focused on predicting prices and therefore examined gross bids.

exited the auction. Clearly this behavior is inconsistent with the budget-bidding model. As explained by BLM, this reflected the very specific and well understood objectives of Google with respect to the "open access'' provision in auction 73.[21] Including Google's bids in the calculation of total exposure thus leads to significant overestimates of final revenue ($27.1 billion maximum total exposure versus $19.1 billion revenue). Rather than omit this auction entirely from our analysis, we instead exclude only Google's bids from the analysis. Google's bids would have been relevant had the open access reserve price not been met; but once it was met, the auction was roughly as if Google were never a bidder. By excluding Google, we effectively consider the auction that took place once the auction-specific uncertainty over the special open-access provision was resolved, yielding an auction much more like that expected for the 600 MHz licenses. As can be seen in Table 2, the revenue prediction based on maximum total exposure for auction 73 without Google is much improved (if still imperfect), at $22.4 billion. Further, median total exposure in auction 73 matches revenue nearly exactly.

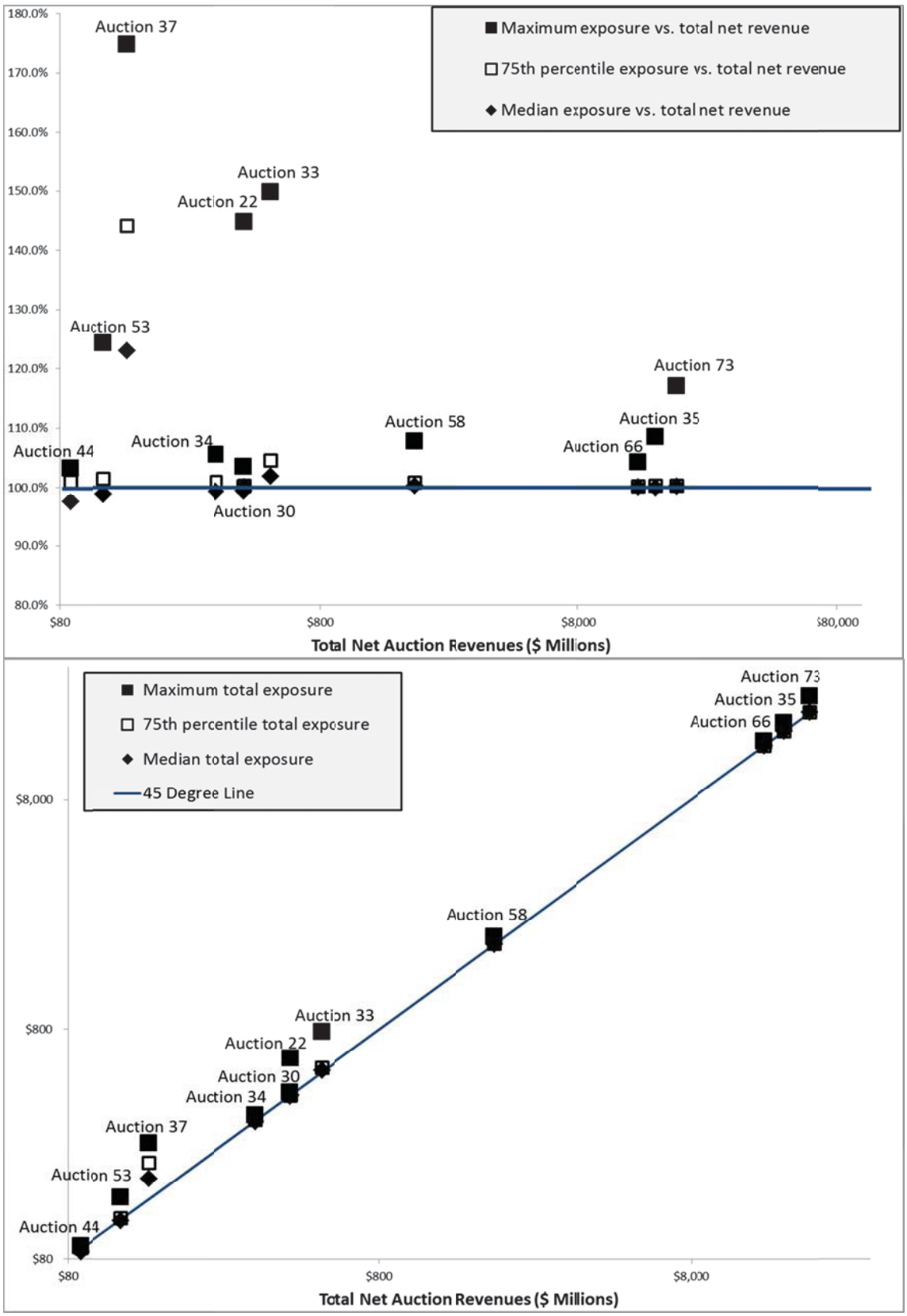
In Figure 2, we illustrate the accuracy of our three aggregate budget estimators as predictors of total auction revenue.[22] The top panel plots the ratio of the predicted revenue to total revenue using each of our three estimators of aggregate budget. For most auctions (most notably, the high revenue ones) the prediction is within 10 to 20 percent of actual revenue. Of the three estimators of aggregate budget considered, maximum total exposure generates the highest revenue predictions, which systematically exceed actual revenue. Median total exposure seems to be the most conservative estimate and is typically within three percent of actual auction revenue (with the exception of auction 37).

In the bottom panel, we plot the three revenue predictions against actual auction revenues. Most predictions lie close to the 45-degree line. Again, the greater accuracy of the median and 75th percentile measures is in evidence, as is the particularly high level of accuracy for high-revenue auctions.

[21] As noted in BLM's paper, Google lobbied the FCC to include an "open access" band in the auction. The winner of that band was required to allow the operations of devices and software from independent providers (such as Google), but only if the FCC's reserve price of $4.6 billion was met. Google participated in the auction until the reserve was met and the open-access provision was guaranteed, and then immediately ceased bidding.

[22] This is similar to Figure 6 in BLM. See our earlier discussion of differences in the treatment of auction 73, of bidding credits, and our estimators of aggregate budget.

Figure 2: Ratio of Total Revenue Predictors to Total Revenue by Auction



To provide a formal evaluation of the three estimators of aggregate budget, we calculated the mean squared prediction error (MSE) for each estimator as a predictor of auction revenue. To do this, we normalized the total revenue in each auction to 100 percent. As shown in Table 3, median total exposure has both the smallest average prediction error and smallest sample variance. Therefore, the median total exposure also has the smallest MSE. Henceforth, we will use median total exposure as our predictor of revenue. In Appendix B, we repeat the analysis using the two alternative measures.

Table 3: Mean and Standard Deviation of Net Revenue Predictors

	Maximum Total Exposure	75th-Percentile Total Exposure	Median Total Exposure
Mean	121.9%	104.5%	100.9%
Standard Deviation	23.1%	12.6%	4.6%
MSE	10.1%	1.8%	0.2%

5 Predicted Revenue with Participation Restrictions

5.1 Exclusion of AT&T and Verizon

As discussed in Section 2, we begin by assessing the counterfactual revenue in past FCC auctions under the hypothetical exclusion of AT&T and Verizon. We do this by excluding AT&T and Verizon from the estimates of aggregate budget. Thus, our predictor of the counterfactual auction revenue is equal to the median total exposure of non-AT&T/Verizon bidders.[23]

Table 4 shows the resulting predictions for a comparison with the actual contributions to revenues from non-AT&T/Verizon bidders. As Figure 3 illustrates, median total exposure of these bidders provides a remarkably good predictor of their ultimate contributions to auction revenues. This revenue prediction is typically within five percent of their total contribution to revenue. The exceptions are auctions 35 and 37, where our prediction overestimates the revenue contributions of non-AT&T/Verizon bidders.

[23] Bidders were considered to be a part of AT&T or Verizon if they were: (1) part of the company prior to the auction; (2) acquired by the company right after the auction; or (3) part of a joint-venture or bidding partnership with AT&T or Verizon. In Appendix C, we repeat the analysis using an inclusive criterion, whereby any bidder that was acquired by the company at any point in the future is included as part of AT&T or Verizon in a given auction. See Appendix A for a list of bidders considered as AT&T or Verizon in each case.

Table 4: Net Revenue and Exposure, Non-AT&T/VZ Bidders ($ Millions)

Auction Number	(A) Actual Net Revenue from non-AT&T/VZ	(B) Combined Median Exposure of non-AT&T/ VZ
22	$ 412	$ 412
30	$ 401	$ 397
33	$ 520	$ 524
34	$ 319	$ 317
35	$ 4,865	$ 5,787
37	$ 146	$ 168
44	$ 88	$ 85
53	$ 119	$ 117
58	$ 1,255	$ 1,257
66	$ 9,491	$ 9,487
73[1]	$ 3,057	$ 3,057

[1] Net revenue and exposure exclude block D, which did not meet the applicable reserve price. Google has been excluded from the exposure calculations.

Note: See appendix A for information on bidders classified as AT&T and Verizon in each of the above auctions.

Figure 3: Ratio of Median Exposure to Total Revenue by Auction

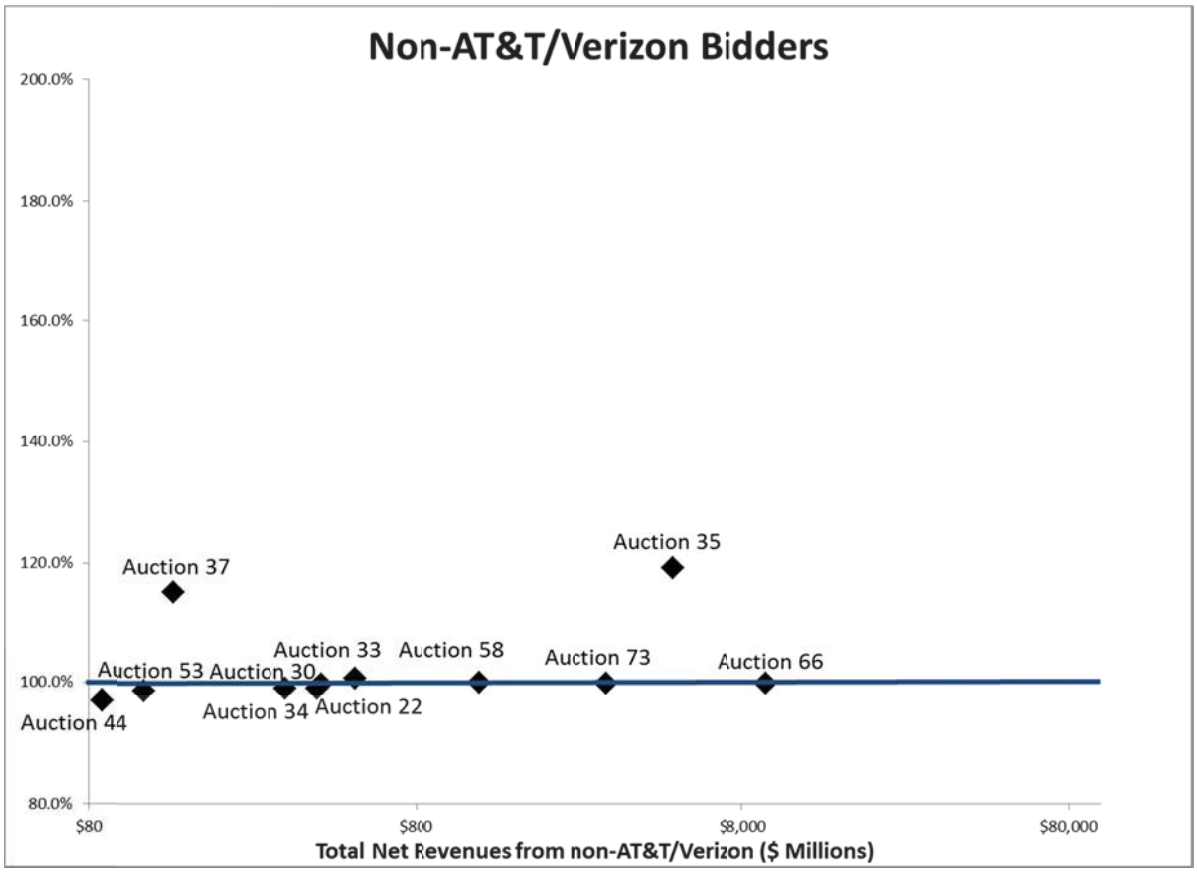


Table 5 shows the ratio of aggregate budget without AT&T and Verizon to the aggregate budget of all bidders.[24] As the final line shows, this yields a weighted average of 61 percent.[25] This is a key finding of our analysis: in past FCC spectrum auctions, exclusion of AT&T and Verizon would have led to a predicted loss of 61 percent in revenue. In table B-5 (see appendix B) we predict the share of revenue loss using several alternative estimates as robustness checks. The results are quantitatively similar to those of table 5. Based on this finding, we conclude that full exclusion (whether *de jure* or *de facto*) of AT&T and Verizon from the 600 MHz auction, would likely result in a loss of approximately 60 percent of forward auction revenues at any given spectrum clearing target.[26]

Table 5: Estimated Share of AT&T and Verizon out of Total Net Revenue

Auction Number	AT&T/Verizon's Share of Total
30	2.5%
35	63.4%
58	32.8%
66	30.7%
73[1]	84.0%
Weighted Avg. Ratio:	**60.7%**

[1] Net revenue and exposure exclude block D, which did not meet the applicable reserve price. Google has been excluded from the exposure calculations.

To translate the percentage loss to dollars, we rely on the average price of $1.19 per MHz-POP (net of bidding credits) in the lower 700 MHz auction (auction 73).[27] Auction 73 is the most recent mobile wireless frequency spectrum auction and involved spectrum with characteristics similar to those of the 600 MHz band. Nonetheless, the average price per MHz-POP from auction 73 is a conservative estimate of current values for unimpaired (i.e. interference-free) low-frequency spectrum (such as almost all of the 600 MHz spectrum), since auction 73 included impaired A block spectrum, unpaired lower D and E block spectrum, and open access conditioned upper C block spectrum.[28,29,30] To calculate the potential revenue

[24] One of the auctions considered in Table 5, auction 30, was for very high frequency spectrum (39 GHz) that we understand is not suitable for mobile wireless use. AT&T participated in that auction as a long distance company that purchased the spectrum to provide fixed point-to-point data services. AT&T had a very small presence in these last mile business services, as reflected by its small share in the auction revenue. We kept auction 30 to be consistent with BLM's original sample, although its inclusion probably leads us to conservative conclusions about the likely effects of restricting AT&T participation.

[25] Note that when we exclude auction 73, which by far had the highest revenue from AT&T and Verizon, the estimated revenue share from AT&T and Verizon is lower by roughly 13 percentage points.

[26] Reductions in forward auction revenue at a given spectrum clearing target could also result in a smaller quantity of spectrum cleared. We ignore this additional (and important) source of potential harm from limits on auction participation.

[27] We used 2010 census population (307.8 million) to calculate the average price per MHz-POP in auction 73.

[28] In fact, the unimpaired, paired, unconditional spectrum (B Block) was sold for over $2.00 per MHz-POP in auction 73 and subsequent secondary market prices have been even higher.

[29] See FCC's auction 73 Band Plan, available at http://wireless.fcc.gov/auctions/data/bandplans/700MHzBandPlan.pdf, and FCC's second report and order, FCC 07-32, pp. 229-230, 241-250.

from the auction, we multiply this conservative estimate of price per MHz-POP by the population covered (based on the 2010 Census) and then by hypothetical quantities of spectrum cleared. The dollar loss from excluding AT&T and Verizon is then calculated by multiplying the predicted revenue from the auction by the estimated share of revenue loss from Table 5.

The results are displayed in the top panel of table 6 below. We examine a range of possible values for the quantity of spectrum cleared: 60 MHz, 80 MHz, 100 MHz or the full 120 MHz. The estimated revenue loss in dollars ranges from $13.4 billion to $26.8 billion when we use the average price from auction 73.

As previously discussed, we believe auction prices per MHz-Pop for 700 MHz spectrum are a reasonable (conservative) predictor of prices in the 600 MHz auction (absent restrictions on participation). A possible alternative is to use a 2011 Congressional Budget Office (CBO) estimate, suggesting that the average unit price to be paid by winning bidders in future FCC auctions would be about 70 cents per MHz-POP.[31] The CBO's price estimate is much lower than the average price per MHz-POP in auction 73 because the former is discounted to account for the fact that most future spectrum auctions (unlike the 600 MHz spectrum auction) will be of relatively low quality. Many of these spectrum blocks will be burdened by federal government operations. And all of the spectrum likely to be auctioned in the future, with the exception of the upcoming 600 MHz spectrum auction, will be high-frequency spectrum, which typically brings less at auction in areas where it will be used to support coverage-driven expansion, because its weaker propagation characteristics may require larger investments in network infrastructure to achieve the same coverage. The CBO's general-purpose estimate is, therefore, too low for the 600 MHz spectrum, and using the CBO price estimate will therefore substantially understate the losses implied by participation restrictions. Nonetheless, using CBO's estimate in our calculation would still yield substantial predicted losses, ranging from $7.9 billion (assuming 60 MHz are cleared by the auction) to $15.7 billion (assuming 120 MHz are cleared by the auction).

[30] See Comments of the National Association of Broadcasters, FCC Docket No. 12-268, footnote 5, for a discussion of the impact of interference on auction 73 Block A revenue.

[31] Congressional Budget Office Cost Estimate, S. 911 Public Safety Spectrum and Wireless Innovation Act, July 20, 2011, p. 5 http://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/123xx/doc12322/s911.pdf

Table 6: Estimated Net Revenue Loss from Proposed Auction Rules ($ Millions)

Scenario I: Full Exclusion				
	Auctioned Bandwidth			
	60 MHz	80 MHz	100 MHz	120 MHz
	$13,391	$17,855	$22,318	$26,782
Scenario II: Partial Exclusion				
% Reduction in AT&T and Verizon Budgets (assumed)	Auctioned Bandwidth			
	60 MHz	80 MHz	100 MHz	120 MHz
50%	$6,695	$8,927	$11,159	$13,391
67%	$8,927	$11,903	$14,879	$17,855

Notes: (1) We assume that the auction markets cover the entire U.S. population, estimated at 308.7 million according to the 2010 Census; (2) To calculate potential Net Revenue loss in dollars, we rely on the average price per MHz-POP in auction 73 ($1.19).

5.2 Partial Exclusion

The bottom panel of Table 6 displays the estimated revenue losses in dollars under three partial exclusion scenarios. As discussed in Section 2, we consider cases in which AT&T and Verizon's auction budgets are not driven to zero (nonparticipation) but are cut by one-half or two-thirds. The predicted revenue losses here are equal to the budget reductions. Thus, the predicted revenue losses under these scenarios are smaller, but still substantial. For example, with a 50 percent budget reduction—a figure we believe may accurately reflect the effect of a one-third cap with 5×5 exception (see section 3.2.4 above)—we predict a loss of between $6.7 billion and $13.4 billion when we use the average price in auction 73 of $1.19 per MHz-POP.[32]

5.3 New Budgets

As discussed in Section 2, it is unclear whether restrictions on the participation of AT&T and Verizon would raise or lower the budgets of other bidders. Reductions in other bidders' budgets would exacerbate the harm to revenues, while increases in budgets would partially offset the harm. Outcomes of past auctions provide no basis for evaluating which outcome is more likely. Thus, in this section, we calculate by how much non-AT&T/Verizon budgets will have to increase to leave net revenue unharmed by the participation restrictions. Specifically, we calculate the required percentage increase auction by auction and then find the average.

[32] Even if we use the above-mentioned CBO revenue forecast of 70 cents per MHz-POP, the predicted losses from partial exclusion are substantial: with a 50 percent budget reduction, we predict a loss of between $3.9 billion (assuming 60 MHz are cleared by the auction) and $7.9 billion (assuming 120 MHz are cleared by the auction). As discussed already, both the evidence from auctions of similar (700 MHz) spectrum and the broad purpose of the CBO price estimates strongly suggest that the CBO price estimates are too low for predicting prices (absent participation restrictions) in the 600 MHz auction. Consequently, these estimates based on the CBO forecasts are likely to understate substantially the harm from participation restrictions.

Table 7 shows the results. Under partial exclusion, the budgets of other bidders would need to increase by between 80 percent (assuming a one-half reduction in AT&T and Verizon's budget) and 106 percent (assuming a two-thirds reduction in budget). Such budget increases are implausible. Even larger budget increases—over 150 percent according to our estimates—would be needed to compensate for full exclusion of AT&T and Verizon.[33]

Table 7: Estimated % Increase in Budgets of non-AT&T/VZ bidders that Fully Compensates for AT&T/VZ Revenue Loss

	Partial Exclusion Scenarios		Full Exclusion
	One-Half Reduction	Two-Thirds Reduction	
Required Percent Increase in Bidder Budgets	**79.5%**	**106.0%**	**159.0%**

Notes: (1) Revenue predictions based on median exposure of non-AT&T/Verzion bidders and median total exposure; (2) Each cell contains the average of the predicted required increases by auction; (3) See appendix A for detailed information on which bidders were classified as AT&T and Verizon in auctions 30, 35, 58, 66 and 73.

5.4 New Bidders

We also consider the possibility that the full or partial exclusion of AT&T and Verizon would encourage the participation of other bidders, as hypothesized by parties citing the theoretical possibility that such a dynamic could allow participation restrictions to enhance revenue. As discussed in Section 2, we do this by asking how many new bidders—each with the average budget of bidders other than the "big four" (AT&T, Verizon, Sprint, and T-Mobile)—would be necessary to bring the aggregate budget back to the same level that would have existed without restrictions on the participation of AT&T and Verizon. This calculation is likely to be overly optimistic about revenues from new entrants, since marginal participants should be expected to contribute less to revenue on average than the firms actually bidding against the big four in past auctions.[34]

Table 8 shows the results. We find that the number of bidders beyond AT&T, Verizon, Sprint, and T-Mobile would need to increase by nearly 150 percent in order to make up for the revenue loss from a one-half reduction in the budgets of AT&T and Verizon. Such an increase in participation is highly implausible. More restrictive limits on the participation of AT&T and Verizon require even more

[33] If we calculate the average using actual auction revenue as weights (reflecting the assumption that the upcoming 600 MHz auction may be more similar to past high-revenue auctions in terms of AT&T/Verizon and non-AT&T/Verizon shares of total revenue), the required budget increases are even higher. The increases range from 132 percent (assuming a one-half reduction in AT&T and Verizon's budget) to 177 percent (assuming a two-thirds reduction in budget) to 265 percent (assuming full exclusion).

[34] Recall that, according the theory offered by proponents of participation restrictions, these "new bidders" are actually discouraged bidders who either value too few licenses or have license valuations that are too low to allow them to bid profitably when competition is unrestricted.

unrealistic levels of new entry to offset the harms to revenue—a quadrupling of participation in the case of full exclusion of AT&T and Verizon!

Table 8: Percent Increase in Participation Required to Recoup Revenue Loss

	Partial Exclusion		Full Exclusion
	One-Half Reduction	Two-Thirds Reduction	
Required Percent Increase in Number of Bidders	**146%**	**194%**	**291%**

Notes: (1) Revenue predictions based on median exposure of non-AT&T/Verzion bidders and median total exposure; (2) Each cell contains the weighted average (based on acutal auction revenue) of the predicted required increase by auction; (3) See appendix A for detailed information on which bidders were classified as AT&T and Verizon in auctions 30, 35, 58, 66 and 73.

6 T-Mobile's "Dynamic Market Rule"

T-Mobile has recently proposed a new scheme for conducting the 600 MHz spectrum auction with spectrum caps that adjust in response to failures to meet minimum revenue requirements. Under T-Mobile's "Dynamic Market Rule" (DMR) the auction would first be conducted with stringent participation restrictions (e.g., the 1/3 cap with a 5 × 5 MHz exception) in place. However, if the resulting prices fail to meet minimum net revenue requirements for a clearing target (quantity of spectrum to be sold), participation restrictions would be gradually relaxed until either (a) the minimum revenue requirement is satisfied or (b) no more relaxations are possible under the T-Mobile rules. In the latter case, the clearing target would then be reduced, the most stringent participation restrictions reinstated, and the iterative procedure begun again with the reduced clearing target. We refer readers to T-Mobile's proposal and the analysis of Che and Haile (2013) for additional details and discussion. Here we briefly discuss what the analysis above can reveal about the likely effects of implementing this most recent T-Mobile proposal for restricting the participation of its largest competitors.

6.1 Case 1: "Best-Case" Scenario

T-Mobile argues that the relaxation of participation restrictions under the DMR is merely an insurance policy—a contingency unlikely to be necessary because revenues are likely to be sufficiently high to meet minimum revenue requirements when stringent participation restrictions are in effect. The analysis above gives a compelling reason to doubt this claim. Nonetheless, we begin by examining the likely revenue implications of the DMR proposal under this very optimistic scenario.

In this scenario, the quantitative assessment above can be applied directly. That is because the initial phase of the DMR auction—that before relaxation of any constraints—is essentially identical to an auction without any provision for relaxation of the caps.[35] It is possible that such an auction would yield prices sufficient to meet the minimum net revenue requirement for a given clearing target. If this were to occur, all auction outcomes (including the harm to revenue) would be as if there had been a single auction in which the caps were fully in place. For example, if the most stringent restriction used in the DMR is the 1/3 cap with a 5 × 5 MHz exception, our estimated losses of $6.7 billion to $13.4 billion due to participation restrictions still apply, although estimates in the higher end of this range are more likely given the assumption of this scenario—*i.e.*, that the participation restrictions had no adverse effect on the quantity of spectrum cleared.

As discussed above, it is possible that competing bidders would alter their budgets in response to restrictions on participation by AT&T and Verizon, although it is unclear whether budgets are more likely to rise or fall. But even assuming that they rise, we have shown above that only implausibly large budget increases could substantially offset the harm from the proposed participation restrictions. Likewise, it is possible that some marginal bidders would enter the auction in response to limits on competition from AT&T and Verizon. However, as demonstrated above, only implausibly large increases in the number of bidders could offset the substantial revenue losses imposed by restrictions on the participation of AT&T and Verizon.

6.2 Case 2: Relaxation of Caps

A second possibility is that some relaxation of participation restrictions under the DMR would be needed in order to meet the minimum revenue requirements, but that doing so ultimately would allow the FCC to sell the same number of licenses it would have sold in the absence of participation restrictions. If this were to occur, some of the revenue harm of participation restrictions would be avoided through the relaxation of caps prescribed by the DMR. As Che and Haile (2013) discuss extensively, the gradual relaxation of caps under the DMR will not eliminate all harm. This is due in part to limits on which caps are relaxed under the DMR rules, new exposure risks created by the DMR rules, harms to price discovery created by the DMR rules, bidding restrictions that interfere with efficient matching of bidders to licenses, and new incentives for manipulative bidding. Even ignoring these problems, however, it should be clear that the gradual relaxation of caps can only partially mitigate the revenue harm arising from the caps.

[35] The main complication is that bidders' anticipation of the *possibility* of relaxation could distort bidding behavior, likely leading to reduced revenues. We abstract from this possibility in this discussion.

This is easy to see. Suppose that the net revenue requirement for the relevant clearing target is equivalent to $1.00 per MHz-POP and that, in the absence of the 1/3 cap with 5 × 5 exception, average auction prices would have been $1.25 per MHz-POP. When the DMR begins, the caps are fully in place. Taking our more conservative estimate that this reduces the budgets of AT&T and Verizon by 50 percent, average prices in this phase of the auction would be only $0.87 per MHz-POP.[36] This shortfall would trigger the gradual relaxation of caps. Unless the FCC overshoots (or the problems mentioned above cause the complete failure of this clearing target), eventually net revenues of $1.00 per MHz-POP will be achieved. The effect of the DMR on revenue would then be losses of $0.25 per MHz-POP ($1.25 - $1.00), or roughly $7.7 billion in lost revenue if we assume clearing of 100 MHz.[37]

6.3 Case 3: Reduced Spectrum Clearing

The worst outcome from an efficiency perspective is that the participation restrictions lead to a reduction in the quantity of spectrum cleared. It is difficult to make a precise revenue prediction in this case. However, one of the two cases above will apply, only with a smaller quantity of spectrum than that which would have been cleared in the absence of interference with competition. Thus, in this case substantial harms to both efficiency and revenues should be expected.

7 Conclusion

Using the insights of BLM regarding budget-bidding, we have assessed the revenue effects that restrictions on the participation of AT&T and Verizon would have had in past FCC spectrum auctions. Using this counterfactual analysis as a guide to the likely effects of such restrictions in the upcoming 600 MHz auction, we reach the conclusions that (1) restrictions on the participation of AT&T and Verizon would have substantial adverse effect auction revenue, with likely losses in the billions of dollars; (2) even if other bidders would on net expand their budgets in response to limits on the participation of AT&T and Verizon, it is extremely unlikely that this could compensate for the revenue losses from restrictions on AT&T and Verizon; and (3) it is highly implausible that restrictions on participation of strong bidders could lead to sufficient gains in participation by others to avoid substantial revenue losses.

References

[36] Recall that we estimated that AT&T and Verizon together account for 60.7 percent of the aggregate budget in past FCC spectrum auctions. Applying a 50 percent reduction to this contribution yields an estimated aggregate budget that is 50% × 60.7% = 30.35% smaller than without any participation restriction. (1-0.3035) × $1.25 = $0.871.

[37] 308.7 million POP × 100 MHz × $0.25/MHZ-POP = $7.7 billion.

Athey, Susan, and Philip A. Haile (2006), "Empirical Models of Auctions," in Richard Blundell, Whitney Newey, and Torsten Persson, eds., *Advances in Economics and Econometrics, Theory and Applications: Ninth World Congress, Volume II,* Cambridge University Press, Ch. 1, pp. 1-45.

Baker, Jonathan, "Spectrum Auction Rules That Foster Mobile Wireless Competition," WT Docket No. 12-269, March 12, 2013.

Bulow, Jeremy, Jonathan Levin, and Paul Milgrom, "Winning Play in Spectrum Auctions" (2009), Stanford University Working Paper.

Cave, Martin, and William Webb (2013), "Spectrum Limits and Auction Revenue: The European Experience." WT Docket No. 12-268, July 29, 2013.

Che, Yeon-Koo and Philip A. Haile (2013), "Comments on T-Mobile's 'Dynamic Market Rule' Proposal," FCC GN Docket No. 12-268 and WT Docket No. 12-269, August 13, 2013.

Comments of the National Association of Broadcasters in the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, Docket No. 12-268, available at http://www.nab.org/documents/filings/BandPlanSupplComments061413.pdf.

Earle, Robert, and David W. Sosa (2013), "Spectrum Auctions Around the World: An Assessment of International Experiences with Auctions Restrictions." July 2013.

Ex Parte Letter from Tamara Preiss, Vice President, Federal Regulatory Affairs, Verizon, to Marlene H. Dortch, Secretary, Federal Communications Commission, WT Docket No. 12-269, GN Docket No. 12-268, July 17, 2013

Israel, Mark A. and Michael L. Katz (2012), "Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings," Attachment A to Comments of AT&T Inc., *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, November 28, 2012

Israel, Mark A. and Michael L. Katz (2013), "Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings (Reply Declaration)," Attachment B to *Reply Comments of AT&T Inc.*, WT Docket No. 12-269, January 7, 2013

Katz, Michael, Philip. A. Haile, Mark A. Israel, and Andres V. Lerner (2013a), "Spectrum Aggregation Policy, Spectrum-Holdings-Based Bidding Credits, and Unlicensed Spectrum,'' Exhibit B to *Comments of AT&T Inc.*, WT Docket No. 12-269, March 12, 2013

Katz, Michael, Philip. A. Haile, Mark A. Israel, and Andres V. Lerner (2013b), "Comments on Appropriate Spectrum Aggregation Policy with Application to the Upcoming 600 MHz Auction." *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, June 13, 2013.

Second Report and Order, FCC 07-132, available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-07-132A1.pdf.

Testimony of Kathleen O'Brien Ham, VP Federal Regulatory Affairs, T-Mobile US, Inc. before the Subcommittee on Communications and Technology, House Committee on Energy and Commerce, available at http://docs.house.gov/meetings/IF/IF16/20130723/101177/HHRG-113-IF16-Wstate-HamK-20130723.pdf

Appendix A: List of Bidders Considered as Part of AT&T, Verizon, Sprint and T-Mobile

Baseline Definition:

Entity	Bidder name	Year Acquired/ Merged	Auctions
AT&T	Alaska Native Wireless, L.L.C.	JV	35
	American Cellular Corporation	JV	66
	AT&T Mobility Spectrum, LLC		73
	AT&T Wireless PCS, LLC		30, 35
	Cavalier Wireless, LLC	2008, via Aloha	73
	Cingular AWS, LLC	2004	66
Verizon	Cellco Partnership d/b/a Verizon Wireless		35, 58, 66, 73
	GTE Pacifica, Inc. d/b/a Verizon Pacifica		58
	Vista PCS, LLC	JV	58
Sprint	NEXTBAND Communications, L.L.C.	JV	30
	SprintCom, Inc.		35
	SVC BidCo, L.P.	Consortium	35
	Wirefree Patrners III	Partnership	58
T-Mobile	Cook Inlet/VS GSM V PCS, LLC	JV	35
	Cook Inlet/VoiceStream PCS LLC	JV	22
	Cook Inlet/VS GSM VII PCS, LLC	JV	58
	T-Mobile License LLC		66
	VoiceStream PCS BTA I License Corporation	Predecessor	35

Note: Bidders were considered to be a part of AT&T, Verizon, Sprint or T-Mobile if they were: (1) part of the company prior to the auction; (2) Acquired by the company right after the auction; or (3) part of a joint-venture or bidding partnership with the company;

Additional Bidders included in Inclusive Definition:

Entity	Bidder name	Year Acquired/ Merged	Auctions
AT&T	Alaska Native Broadband 1 License, LLC	2013 via Cricket Corporation	58
	Aloha Partners, L.P.	2008	35,44
	Cavalier Group, LLC	2008	44
	Cavalier Wireless, LLC	2008	66
	Cricket Licensee (Reauction), Inc.	2013	58,66
	Cricket Licensee 2007, LLC	2013	73
	DataCom Wireless, L.L.C.	2008	44
	DCC PCS, Inc.	2007	35
	Denali Spectrum License, LLC	2013 via Cricket Corporation	66
	Edge Mobile, LLC	2008	58
	Leap Wireless International, Inc.	2013	22,35
	MilkyWay Broadband, LLC	2008	35,44
	Salmon PCS, LLC	Acquired 2004 via Cingular	35
AT&T/ Verizon	Alltel Corporation,	2009 (Verizon)	35, 73
	Alltell Communications (subsidiary)	2013 (AT&T)	
Verizon	NORTHCOAST COMMUNICATIONS, L.L.C	Investor/2002	35
Sprint	Airgate PCS, Inc.	2006	35
	Alamosa PCS Holdings, Inc.	2006	35
	Hawaiian Wireless, Inc.	2005 via Nextel	34
	Nextel Spectrum Acquisition Corp.	2005	33, 34, 35
T-Mobile	MetroPCS 700 MHz, LLC	2013	73
	MetroPCS AWS, LLC	2013	66
	Royal Street Communications, LLC	2012 Via MetroPCS	58
	Triton PCS License Company L.L.C.	Partnership (2004)/Acquired (2008)	33

Note: In addition, bidders were considered to be part of the inclusively defined entities if they were acquired by the entity at any point in the future.

Appendix B: Using Alternative Revenue Predictions (Maximum and 75th Percentile)

Previously, we have examined the impact of excluding AT&T and Verizon on auction revenues by considering the difference between the total exposure and the combined exposure of all other bidders except AT&T and Verizon. This method has the advantage of being more closely tied to the methodology presented by BLM and also has the advantage of pooling exposure over more bidders, potentially reducing the prediction noise. There is, however, an alternative way for calculating the impact of excluding AT&T and Verizon, which is to estimate the total budgets of AT&T and Verizon directly using the combined exposure of AT&T and Verizon. In what follows, we extend tables 4 through 8 by calculating the revenue loss from the combined exposure of AT&T and Verizon. As an additional robustness check, we repeat the analysis using two revenue predictors considered in table 2 above: maximum exposure and the 75th percentile exposure.

In table B-4, we calculate the maximum, 75th percentile and median exposure of AT&T/Verizon and non-AT&T/Verizon bidders. Note that maximum exposure overestimates actual revenue for AT&T and Verizon and (even more so) for non-AT&T and Verizon bidders, particularly for auctions 58 and 73. The 75th percentile estimate is closer to actual revenue, but still higher than actual revenue and median exposure in most cases.

Table B-4: Net Revenue and Exposure, AT&T/VZ versus All Others ($ Millions)

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
Auction Number	Actual Net	Maximum AT&T+ VZ	75th Percentile AT&T+ VZ	Median AT&T+ VZ	Actual Net Revenue	Maximum non AT&T/ VZ	75th Percentile non-	Median non-AT&T/ VZ
22		$ -	$ -	$ -	$ 412	$ 597	$ 412	$ 412
30	$ 10	$ 27	$ 13	$ 10	$ 401	$ 413	$ 401	$ 397
33		$ -	$ -	$ -	$ 520	$ 779	$ 541	$ 524
34		$ -	$ -	$ -	$ 319	$ 337	$ 320	$ 317
35	$ 11,002	$ 11,293	$ 11,000	$ 10,075	$ 4,865	$ 11,904	$ 6,254	$ 5,787
37		$ -	$ -	$ -	$ 146	$ 255	$ 210	$ 168
44		$ -	$ -	$ -	$ 88	$ 90	$ 88	$ 85
53		$ -	$ -	$ -	$ 119	$ 148	$ 119	$ 117
58	$ 800	$ 836	$ 800	$ 798	$ 1,071	$ 1,453	$ 1,117	$ 1,075
66	$ 4,211	$ 4,916	$ 4,211	$ 4,204	$ 9,489	$ 10,723	$ 9,489	$ 9,483
73[1]	$ 16,061	$ 16,795	$ 16,068	$ 16,064	$ 3,057	$ 7,605	$ 3,059	$ 3,057

[1] Net revenue and exposure exclude block D, which did not meet the applicable reserve price. Google has been excluded from the exposure calculations.
Note: See appendix A for detailed information on which bidders were classified as AT&T and Verizon in each of the above auctions.

In table B-5, we estimate the share of revenue from AT&T and Verizon using the alternative budget predictors mentioned above. First, using AT&T and Verizon's exposure, we examine the ratio between their maximum, 75th percentile and median exposure and maximum, 75th percentile and median total

exposure, respectively. Similarly, we use non-AT&T/Verizon exposure to calculate the ratio between their maximum, 75th percentile and median exposure and maximum, 75th percentile and median total exposure, respectively. The difference between one and the non-AT&T/Verizon exposure ratios provide alternative estimates of AT&T and Verizon's revenue shares.

Table B-5: Alternative Estimates for Share of AT&T and Verizon out of Total Net Revenue

	AT&T/Verizon vs. Total Exposure Ratios, using:					
	(A)	(B)	(C)	(D)	(E)	(F)
	AT&T/Verizon Exposure			Non-AT&T/Verizon Exposure		
Auction Number	Maximum vs. Maximum Total Exposure	75th Pctile vs. 75th Pctile Total Exposure	Median vs. Median Total Exposure	Maximum vs. Maximum Total Exposure	75th Pctile vs. 75th Pctile Total Exposure	Median vs. Median Total Exposure
30	6.3%	3.0%	2.4%	2.5%	2.4%	2.5%
35	65.7%	69.3%	63.6%	30.7%	60.6%	63.4%
58	32.4%	32.7%	32.8%	9.2%	31.3%	32.8%
66	34.1%	30.7%	30.7%	24.6%	30.7%	30.7%
73[1]	75.0%	84.0%	84.0%	66.0%	84.0%	84.0%
Weighted Avg. Ratio:	**59.0%**	**62.6%**	**60.8%**	**41.3%**	**59.8%**	**60.7%**

[1] Net revenue and exposure exclude block D, which did not meet the applicable reserve price. Google has been excluded from the exposure calculations.

Notes: (1) See appendix A for information on bidders classified as AT&T and Verizon in each of the above auctions.

The estimated revenue shares in table B-5 are fairly close to one another and to the estimates in the body of the paper. The exception is the maximum exposure of non-AT&T/Verizon, which is much lower. As evident from tables B-4 and 2 above, maximum exposure overestimates the revenue from non-AT&T/Verizon bidders for auctions 35 and 73, and the bias is larger than the bias in the estimated total revenues for the same two auctions. Consequently, the estimated share of aggregate budget (and, therefore, revenue) attributable to AT&T and Verizon is biased downward. Note that this large bias both supports our choice to focus on the median exposure in the body of the paper and argues against using maximum total non-AT&T/Verizon exposure in the calculation.

Next, we estimate the dollar revenue losses from the exclusion of AT&T and Verizon using the average of the share of revenue loss in columns (A) and (D) (50% based on maximum exposure), (B) and (E) (61% based on 75th percentile exposure), or (C) and (F) (61% based on median exposure). The results are presented in table B-6 below. Using the average price in auction 73, the revenue loss based on maximum exposure ranges from $11.0 billion (assuming 60 MHz are cleared by the auction) to $22.1 billion (assuming 120 MHz are cleared by the auction). The revenue loss based on the 75th percentile of maximum exposure ranges from $13.5 billion to $27.0 billion, respectively.

Table B-6: Estimated Net Revenue Loss from Proposed Auction Rules ($ Millions)

Scenario I: Full Exclusion				
	Auctioned Bandwidth			
Estimated Loss Based on:	**60 MHz**	**80 MHz**	**100 MHz**	**120 MHz**
Maximum exposure	$11,056	$14,741	$18,426	$22,112
75th Percentule Exposure	$13,489	$17,985	$22,481	$26,978
Median Exposure	$13,397	$17,863	$22,329	$26,795

Notes: (1) We assume that the auction markets cover the entire U.S. population, estimated at 308.7 million according to the 2010 Census; (2) To calculate potential Net Revenue loss in dollars, we rely on the average price per MHz-POP in auction 73 ($1.19).

In table B-7, we estimate the percent increase in the budget of non-AT&T/Verizon bidders that would be required to recoup the lost revenue, using the two alternative revenue predictors. The revenue estimates for AT&T and Verizon are based on the difference between the maximum or 75th percentile exposure and the maximum or 75th percentile combined exposure of non-AT&T/Verizon bidders, respectively. We consider full exclusion and partial exclusion (one-half or two-third reduction). The table displays the average of each auction's required increase in the budgets of non-AT&T/Verizon bidders. The estimates using 75th percentile exposure are very similar to those in the body of the paper. The estimates based on maximum total exposure are much lower, due to the previously mentioned upward bias in the predicted non-AT&T/Verizon revenue for auctions 35 and 73. Although the calculation suggests a required of more than one-quarter in the budgets of non-AT&T/Verizon bidders, the bias likely leads to a significant understatement the size of the required compensating budget adjustments.[38]

Table B-7: Estimated % Increase in Budgets of non-AT&T/VZ bidders that Fully Compensates for AT&T/VZ Revenue Loss

Required Percent Increase in Bidder Budgets	Maximum AT&T/VZ vs. non-			75th Pctile AT&T/VZ vs. non-		
	Partial Exclusion		Full Exclusion	Partial Exclusion		Full Exclusion
	One-Half Reduction	Two-Thirds Reduction		One-Half Reduction	Two-Thirds Reduction	
	28.4%	**37.9%**	**56.8%**	**77.1%**	**102.8%**	**154.2%**

Notes: (1) Each cell contains the average of the predicted required increases by auction; (2) See appendix A for detailed information on which bidders were classified as AT&T and Verizon in auctions 30, 35, 58, 66 and 73.

Lastly, we examine alternative estimates for the number of bidders required to recoup the revenue loss from the exclusion AT&T and Verizon in table B-8. Using maximum exposure of AT&T/Verizon and other bidders, we estimate that the number of bidders will have to increase by between about 50 percent

[38] When we use a weighted average (using actual auction revenue as weights), the required increase based on the maximum exposure estimates ranges from 48 percent (for the one-half reduction scenario) to 96 percent (for full exclusion).

and 100 percent for the partial exclusion scenarios. The estimates based on the 75th percentile exposure are very similar to the estimates presented in the body of the paper.

Table B-8: Percent Increase in Participation Required to Recoup Revenue Loss

	Maximum Exposure			75th Percentile Exposure		
	Partial Exclusion		Full Exclusion	Partial Exclusion		Full Exclusion
Required Percent Increase in Number of Bidders	One-Half Reduction	Two-Thirds Reduction		One-Half Reduction	Two-Thirds Reduction	
	51%	**68%**	**101%**	**141%**	**188%**	**282%**

Notes: (1) Each cell contains the weighted average (based on acutal auction revenue) of the predicted required increase by auction; (2) See appendix A for detailed information on which bidders were classified as AT&T and Verizon in auctions 30, 35, 58, 66 and 73.

Appendix C: Calculating Total Exposure, Potential Revenue Loss Using Inclusive Definition of AT&T, Verizon, Sprint and T-Mobile

In this section, we repeat the analysis in tables 4-8 using an inclusive definition for AT&T and Verizon (see Appendix A for details).

Table C-4: Net Revenue and Exposure, AT&T/VZ versus All Others ($ Millions)

Auction Number	(A)	(B)
	Actual Gross Net Revenue from non-AT&T/VZ	Median non-AT&T/ VZ Exposure
22	$ 394	$ 393
30	$ 401	$ 397
33	$ 520	$ 524
34	$ 319	$ 317
35	$ 1,750	$ 1,843
37	$ 146	$ 168
44	$ 47	$ 45
53	$ 119	$ 117
58	$ 853	$ 855
66	$ 8,492	$ 8,482
73[1]	$ 3,057	$ 3,056

[1] Net revenue and exposure exclude block D, which did not meet the applicable reserve price. Google has been excluded from the exposure calculations.

Table C-4 displays total revenue and predicted revenue for AT&T/Verizon and non-AT&T/Verizon bidders. As expected, both are higher for AT&T and Verizon and lower for non-AT&T/Verizon bidders once the definition of AT&T and Verizon bidders is extended. The extended definition of AT&T and

Verizon likely overstates their revenue share prediction since the bidding budget of the post-merger entity is probably less than the sum of the two pre-merger budgets. In this sense, the estimates and predictions in this section may be viewed as upper bounds, although it is hard to say how tight these bounds are. The restrictive definition of AT&T and Verizon used in the body of the paper may be underestimating the revenue share from these entities, for the same reason.

The shares of revenue from AT&T and Verizon in table C-5 are 10 percentage points higher than those calculated using the restrictive definition, at 71 percent. This leads to higher estimates of dollar revenue losses in table C-6: the estimated revenue losses from even the mildest of the participation restrictions range from $7.8 billion (assuming 60 MHz are cleared by the auction) to $15.7 billion (assuming the full 120 MHz are cleared by the auction).

Table C-5: Estimated Share of AT&T and Verizon out of Total Net Revenue

Auction Number	AT&T/Verizon's Share of Total
30	2.6%
35	88.4%
58	54.4%
66	38.1%
73[1]	84.0%
Weighted Avg. Ratio:	**71.3%**

[1] Net revenue and exposure exclude block D, which did not meet the applicable reserve price. Google has been excluded from the exposure calculations.

Table C-6: Estimated Net Revenue Loss from Proposed Auction Rules ($ Millions)

Scenario I: Full Exclusion				
	Auctioned Bandwidth			
	60 MHz	**80 MHz**	**100 MHz**	**120 MHz**
	$15,711	$20,948	$26,185	$31,422
Scenario II: Exclusion from 65% of top-20 markets				
% Reduction in AT&T and Verizon Budgets (assumed)	**Auctioned Bandwidth**			
	60 MHz	**80 MHz**	**100 MHz**	**120 MHz**
50%	$7,856	$10,474	$13,093	$15,711
67%	$10,474	$13,965	$17,457	$20,948

Notes: (1) We assume that the auction markets cover the entire U.S. population, estimated at 208.7 million according to the 2010 Census; (2) To calculate potential Net Revenue loss in dollars, we rely on the average price per MHz-POP in auction 73 ($1.19).

The estimated increase in the budgets of other bidders required to compensate for the exclusion of AT&T and Verizon is given in Table C-7. The estimated increase in the number of bidders that will do the same is provided in Table C-8. As expected, all of these measures are larger when we use a more inclusive definition of AT&T and Verizon

Table C-7: Estimated % Increase in Budgets of non-AT&T/VZ bidders that Fully Compensates for AT&T/VZ Revenue Loss

	Partial Exclusion Scenarios		Full Exclusion
	One-Half Reduction	Two-Thirds Reduction	
Required Percent Increase in Bidder Budgets	**129.8%**	**173.0%**	**259.5%**

Notes: (1) Revenue predictions based on median exposure of non-AT&T/Verzion bidders and median total exposure; (2) Each cell contains the average of the predicted required increases by auction; (3) See appendix A for detailed information on which bidders were classified as AT&T and Verizon in auctions 30, 35, 44, 58, 66 and 73.

Table C-8: Percent Increase in Participation Required to Recoup Revenue Loss

	Partial Exclusion		Full Exclusion
	One-Half Reduction	Two-Thirds Reduction	
Required Percent Increase in Number of Bidders	**566%**	**755%**	**1132%**

Notes: (1) Revenue predictions based on median exposure of non-AT&T/Verzion bidders and median total exposure; (2) Each cell contains the weighted average (based on acutal auction revenue) of the predicted required increase by auction; (3) See appendix A for detailed information on which bidders were classified as AT&T and Verizon in auctions 30, 35, 44, 58, 66 and 73.

ATTACHMENT 5

Reply Comments of AT&T Inc.
January 23, 2014

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matters of	)	
	)	
Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions	)	GN Docket No. 12-268
	)	
Amendment of the Commission's Rules with Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands	)	GN Docket No. 13-185

REPLY COMMENTS OF AT&T

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TABLE OF CONTENTS

I. INTRODUCTION & SUMMARY 1

II. DISCUSSION 5

A. AT&T's CPA Proposal Does Not Disadvantage Smaller Carriers or Rural Consumers……... ……..5

B. Under AT&T's CPA Proposal, the Efficiency and Revenue Benefits Vastly Outweigh Any "Undersell" Costs…….....9

C. AT&T's CPA Proposal Does Not Encourage Gaming…….....10

D. Spectrum Caps Are No Substitute For Package Bidding…….....10

E. The Commission Should Not Employ CMAs…….11

III. CONCLUSION 13

Reply Comments of AT&T

AT&T Services, Inc., on behalf of the subsidiaries and affiliates of AT&T Inc. (collectively, "AT&T"), respectfully submits these Reply Comments in response to the Public Notice entitled "*Wireless Telecommunications Bureau Seeks Comment on a Proposal to License the 600 MHz Band Using 'Partial Economic Areas'*".[1]

I. Introduction and Summary

In deciding what geographic license size and bidding procedures to adopt, the Commission should focus sharply on the central factor that distinguishes this auction proceeding from all others. In a typical auction, the Commission first defines the frequency blocks it commits to clear and simply asks carriers to bid for those blocks. If the auction rules are suboptimal, less money is deposited into the Treasury, but consumers nonetheless reap the benefits of greater bandwidth for mobile broadband applications. In *this* auction, by contrast, the Commission must persuade a variety of auction participants to satisfy the statutory auction-closing criteria for any target level of spectrum: namely, forward-auction revenues must exceed winning reverse-auction bids plus administrative and estimated repacking costs. If revenues fall short of that benchmark, the Commission will have to settle for less cleared spectrum, and in the worst-case scenario, the auction could fail altogether.

That unique fact has profound consequences for the decisions the Commission makes in establishing a geographic license size area and bidding procedures. To a significant degree, those decisions (among others) will determine not only how much money changes hands, and not only whether spectrum goes promptly to providers able to extract the most value from it, but also *how*

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[1] *Wireless Telecommunications Bureau Seeks Comment on a Proposal to License the 600 MHz Band Using "Partial Economic Areas"*, Public Notice, DA 13-2351, GN Docket Nos. 12-268, 13-185 (rel. Dec. 11, 2013) ("*Public Notice*").

much spectrum is available to such providers and their customers in the first place. Suboptimal decisions would not only reduce revenues, but deprive consumers of the primary benefit that Congress sought to achieve in the Spectrum Act: reallocating as much spectrum as possible for commercial mobile broadband services. The Commission should thus take all steps needed to make this auction succeed, in the sense that the auction will meet the statutory closing conditions for the maximum possible amount of freed-up spectrum.

Towards that end, the Commission should adopt AT&T's package bidding proposal, which AT&T has called "Clock Package Auction" or "CPA".[2] Such package bidding is necessary to maximize efficiency, revenue, and the amount of repurposed spectrum by capturing the large complementarities that regional and national carriers will derive from offering service on the same 600 MHz bands across multiple geographic areas, without handicapping smaller carriers' ability to obtain individual or relatively few licenses. Indeed, in the *absence* of such package bidding rules, bidders might exit the forward auction early to avoid the classic exposure risk of "winning" a hodgepodge of scattered spectrum assets that lack much of the value they would have presented had they been part of a seamless geographic package. That exposure risk would thus suppress forward-auction participation, reduce the amount of repurposed spectrum, and increase the risk of auction failure.

Tellingly, most opponents of package bidding in this proceeding simply ignore the exposure problem and, if unaddressed, the threat that it poses to auction efficiency, revenues, and the amount of cleared spectrum. At the same time, these commenters raise a host of theoretical

[2] *See, e.g.*, Comments of AT&T Inc., GN Docket No. 12-268 (filed Jan. 25, 2013) ("AT&T Comments") at pp. 51-58 and Ex. B, Design of the FCC Incentive Auction, Yeon-Koo Che, Phil Haile, Michael Kearns (Attachment 2 hereto); Reply Comments of AT&T Inc., GN Docket No. 12-268 (filed Mar. 12, 2013) ("AT&T Reply Comments") at pp. 53-60 and Ex. C, Reply Analysis of Yeon-Koo Che and Phil Haile (Attachment 3 hereto).

objections to package bidding that simply do not apply to the specific CPA package bidding approach proposed by AT&T.

As demonstrated in the attached analysis by economist Phil Haile, AT&T's CPA design proposal does *not* materially increase auction complexity, introduce bias against small/local bidders, enhance opportunities for gaming, or create any additional exposure risk for small/local bidders.[3] As Dr. Haile cautions: "When evaluating the package bidding criticisms of T-Mobile, U.S. Cellular and others, it is important to be precise about which package bidding approach is being considered. Limitations of particular package auction designs considered in the past should not be mistaken for limitations inherent to package bidding generally."[4] AT&T's CPA package bidding proposal can be incorporated in the 600 MHz auction design to address the exposure problem and enhance efficiency and revenues without triggering any of the harms that its opponents claim.

T-Mobile complains that any type of package bidding is likely to increase excess supply (*i.e.*, the risk of "undersell") due to a package bidder's dropping its demand for a package when only some of its components are in excess demand.[5] But what matters is how package bidding would affect auction revenue and efficiency, and any "extra" undersell that arises under AT&T's CPA proposal would be the result of allowing bidders to express complementarities in order to attain *more* efficient license allocations. In addition, it is well understood among auction experts that undersell is an implication of (*i.e.*, a necessary condition for) revenue maximization. In any

[3] Philip A. Haile, Reply Comments on Package Bidding, GN Docket Nos. 12-268, 13-185 (dated Jan. 23, 2014) ("Haile Analysis") (Attachment 1 hereto) at 3**.**

[4] Haile Analysis at 2.

[5] Comments of T-Mobile USA, Inc., GN Docket Nos. 12-268, 13-185 (filed Jan. 9, 2014) ("T-Mobile Comments") at 3-4.

event, as Dr. Haile explains, the available evidence suggests that the incremental undersell risk of package bidding is modest and that the benefits of package bidding vastly outweigh the costs.[6]

T-Mobile's proposal to substitute participation restrictions (*i.e.*, spectrum caps on AT&T and Verizon) for package bidding is equally misguided and appears to reflect an agenda that has nothing to do with the wisdom of introducing package bidding. T-Mobile proposes to reduce exposure risk by *limiting competition* for licenses.[7] As Dr. Haile notes: "one cannot take seriously the argument that harming efficiency and revenue by limiting competition is the best remedy (or any remedy at all) for the harms to efficiency and revenue that would arise from failing to address the auction design flaws [i.e., failing to provide for package bidding] that create exposure risk."[8]

Finally, AT&T's CPA proposal would work best with the Economic Area ("EA") licenses proposed by the Commission.[9] But if necessary, AT&T's CPA proposal could work with smaller license areas, such as the so-called Partial Economic Areas ("PEAs") proposed by the Competitive Carriers Association ("CCA"), as long as they fully nest within EAs.[10] In all events, the Commission should not employ Cellular Market Area ("CMA") licenses, as they engender the greatest exposure risk and thus possess the least potential to generate revenue and repurpose spectrum.

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[6] Haile Analysis at 6-8.

[7] T-Mobile Comments at 6.

[8] Haile Analysis at 10-11.

[9] *See, e.g.*, *In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, Notice of Proposed Rulemaking, 27 FCC Rcd 12357 (2012) ("*Incentive Auction NPRM*") at ¶ 148.

[10] Haile Analysis at 2.

II. Discussion

A. AT&T's CPA Proposal Does Not Disadvantage Smaller Carriers or Rural Consumers.

Package bidding opponents assert that package bidding violates section 309(j) the Act[11] and sound public policy by disadvantaging smaller carriers and rural customers in various ways.[12] Many of these assertions have already been fully debated earlier in this proceeding; moreover, many of these assertions simply do not apply to the CPA auction design proposed by AT&T.[13] Thus, AT&T will address them in relatively short order here.

Package bidding opponents argue that package bidding will inevitably steer rural license areas towards package bidders and away from smaller carriers who purportedly have a greater interest in serving those areas.[14] This argument fails for several reasons.

First, AT&T's CPA proposal does *not* favor bidders for packages over bidders for individual EAs (or PEAs). AT&T's CPA proposal *does* favor maximization of consumer welfare, instead. Specifically, AT&T's CPA proposal does not set aside any licenses for package bidders; and smaller bidders continue to have the opportunity to acquire individual licenses needed to complement existing holdings. Furthermore, a package bidder could win all licenses in all EAs within the relevant geographic package only if the total price for that package exceeds the sum of the bids that would otherwise prevail, including all EA (or PEA)-specific

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[11] 47 U.S.C. § 309(j) (directing the Commission to design competitive bidding systems that, *inter alia*, avoid excessive concentration of licenses and disseminate licenses among a wide variety of applicants).

[12] *See, e.g.*, Comments of United States Cellular Corporation, GN Docket Nos. 12-268, 13-185 (filed Jan. 9, 2014) ("USCC Comments") at 32-48.

[13] As stated previously, when evaluating the package bidding criticisms in this record, it is important to keep in mind precisely which package bidding approach is being challenged. Limitations of particular package auction designs considered in the past should not be mistaken for limitations inherent in package bidding generally. Many of the concerns expressed in this record simply do not apply to the CPA auction design proposed by AT&T. *See, e.g.*, Haile Analysis at 2-3.

[14] *See, e.g.*, USCC Comments at 32-33, 36, 44-47.

bids. That mechanism will pick winners solely on the basis of which combination of bids expresses – and can be presumed to produce – the greatest economic value for consumers.[15]

Second, AT&T's CPA proposal would not risk leaving 600 MHz licenses in rural areas neglected by larger carriers when there may have been smaller bidders allegedly more interested in actively serving those areas. The Commission undoubtedly will adopt build-out requirements for 600 MHz licenses, and those requirements will surely apply in every license area, regardless of whether the licensee won the license through a package bid or a bid on an individual license. Accordingly, the suggestion that package bidding would lead to reduced deployment in rural areas is baseless.

Third, AT&T already serves rural areas as well as urban/suburban areas.[16] Indeed, AT&T competes vigorously on the basis of scope and quality of coverage. As a result, there is no credible ground to believe that AT&T will shortchange rural license areas in packages that it may win.

Package bidding opponents also raise theoretical concerns about a "threshold" or "free rider" problem to justify rejection of package bidding.[17] This concern is not determinative under the circumstances here. Restricting packages to a hierarchical structure helps bidders overcome the threshold problem by eliminating ambiguity about which component prices must rise to displace the package bidder. In any event, a threshold problem cannot be a basis for opposing a

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[15] *See, e.g.*, Haile Analysis at 4-6; Attachment 3 (AT&T Reply Comments, Ex. C) at 1-10. USCC's claim that "[p]ackage bidding could also permit large carriers to obtain a package of licenses for a sum lower than what individual licensees are willing to pay on a per-license basis" (USCC Comments at 45**)** is incorrect in the case of AT&T's CPA proposal. *See, e.g.*, Haile Analysis at 4-5.

[16] *See, e.g.*, http://www.att.com/network/ (then click on "Coverage" to see a map of AT&T's wireless network coverage nationwide); http://news.cnet.com/8301-1035_3-57616700-94/at-t-covers-more-than-270-million-with-4g-lte/ (stating that, as of January 6, 2014, AT&T's LTE service covered 270 million Americans, and AT&T plans to raise that number to 300 million by the end of 2014).

[17] *See, e.g.*, USCC Comments at 33-36, 45.

well-designed mechanism for package bidding (such as AT&T's CPA proposal), because it *neither arises from nor is exacerbated by package bidding*. Instead, the threshold problem arises from the market reality that – in *any* spectrum auction, with or without package bidding – some bidders will perceive complementarities in holding licenses in geographically adjacent regions, and they will place bids designed to capture those complementarities.[18]

Package bidding opponents contend, in addition, that package bidding increases auction complexity to such a degree that smaller carriers will lack the resources to competitively participate.[19] This contention is erroneous as applied to AT&T's CPA proposal. To be sure, an auction without AT&T's CPA proposal would have fewer bidding objects. But given the small number of package tiers proposed here (especially if the Commission sticks with its proposal to license on the basis of EAs),[20] the difference would be trivial, and far from enough to deter auction participation. And even more importantly, by eliminating exposure risk for package bidders, AT&T's CPA proposal can actually simplify bidding for those seeking individual licenses by simultaneously eliminating the incentives to manipulate such individual bids in attempts to exploit the exposure risk of package bidders, which has been a complex and highly demanding strategy prevalent in past spectrum auctions.[21]

Package bidding opponents raise two additional purported sources of undue complexity, neither of which applies to AT&T's CPA proposal. T-Mobile argues that package bidding would introduce several complications due to the ability of a package bidder to quit demanding a

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[18] *See, e.g.*, Attachment 3 (AT&T Reply Comments, Ex. C) at 4-8; Haile Analysis at 5-6.

[19] *See, e.g.*, USCC Comments at 40-43.

[20] Indeed, the CCA's proposal to employ PEAs for geographic license areas would add more auction objects to the 176 originally proposed by the Commission than AT&T's CPA proposal would add.

[21] *See, e.g.*, Attachment 3 (AT&T Reply Comments, Ex. C) at 1-3; Haile Analysis at 3-4.

package when its price rises.[22] However, AT&T's CPA proposal does not permit any bidder to withdraw any bid. Thus, perhaps T-Mobile's real concern involves the circumstances under which a bidder is permitted to reduce the quantity of an object it demands. But AT&T's CPA proposal treats all objects (packages and individual licenses) symmetrically in this regard, thus favoring neither package bidders nor individual license bidders.[23] USCC argues that package bidding would introduce a new exposure risk for bidders on individual licenses, due to potential reinstatement of previously losing bids.[24] Such reinstatement risks might exist in some kinds of package bidding, but not in AT&T's CPA proposal, which does not permit reinstatement of previously losing bids.[25]

Package bidding opponents further claim that prepackaging groups of licenses does not allow efficient aggregation. In their view, setting predetermined packages of licenses improperly presumes that each bidder has the same aggregation strategy and would value the packages equally; in actuality, each bidder will have different packaging needs and strategies, depending on its unique business model and existing portfolio. Thus, opponents assert that prepackaging groups of licenses harmfully interferes with bidders' ability to tailor packages as they wish, thereby reducing auction participation and revenues.[26] This assertion fatally ignores two key points. First, incorporating AT&T's CPA proposal would not hinder any carrier's ability to attempt to tailor unique license packages on an ad hoc EA-by-EA (or PEA-by-PEA) basis; it

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[22] T-Mobile Comments at 1-5. T-Mobile refers to this ability as an option to "withdraw" a bid. *See, e.g.*, T-Mobile Comments at 2.

[23] Haile Analysis at 12. Specifically, any bidder may reduce the quantity demanded of an object only when the price of that object increases. *Id*.

[24] *See, e.g.*, USCC Comments at 36-40.

[25] Haile Analysis at 9.

[26] *See, e.g.*, USCC Comments at 45-48.

would simply provide additional options for carriers interested in attempting to obtain relatively larger, contiguous groupings of EAs (or PEAs). And second, those additional, pre-packaged options are essential to minimizing the exposure risk that would otherwise substantially suppress bidding by such carriers. Thus, the reality is that AT&T's CPA proposal would *promote* efficiency and revenues, not diminish them.

B. Under AT&T's CPA Proposal, the Efficiency and Revenue Benefits Vastly Outweigh Any "Undersell" Costs.

T-Mobile raises a concern about the potential for excess supply or "undersell" – the failure of some licenses to sell at the incentive auction, potentially due to a package bidder's dropping its demand for a package when only some of its components are in excess demand.[27] Such potential for undersell likely does exist to some degree under AT&T's CPA proposal. But this observation is meaningless in isolation, without attempting to quantify the elevation of undersell risk or the auction benefits that would inherently accompany any increase in such risk. Any "extra" undersell that arises under AT&T's CPA proposal would be the direct result of the proposal's ability to minimize exposure risk, allowing bidders to express complementarities in order to attain more efficient license allocation and thereby maximize auction revenue. All available evidence suggests that, under AT&T's CPA proposal, the increased risk of undersell would be relatively tiny, whereas the increase in efficiency and revenues would be huge. In other words, any undersell costs would be vastly outweighed by efficiency and revenue benefits.[28]

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[27] T-Mobile Comments at 3-4.

[28] Haile Analysis at 6-8; Attachment 3 (AT&T Reply Comments, Ex C) at 12-13. As Dr. Haile explains, "although failing to sell a license may sound like a source of inefficiency (and it would be if all else could be held fixed), this is not true in general, since bidder behavior depends on the auction rules. Any 'extra' undersell that arises under the CPA would be the result of allowing bidders to safely express complementarities in order to attain more efficient license allocations." Haile Analysis at 6-7.

C. AT&T's CPA Proposal Does Not Encourage Gaming.

T-Mobile suggests that package bidding would introduce opportunities for a particular type of gaming called "parking", whereby a bidder can, potentially to its advantage, harm price discovery by hiding its intentions early in the auction, maintaining eligibility by bidding for a package it does not want but whose price is sure to keep rising.[29] In AT&T's CPA proposal, however, such behavior would involve substantial risk for the bidder, because "[b]ids in the CPA are binding offers to purchase" and "[o]nly if a bidder were certain that others will drive up the price of an object can he bid for it without risk of winning."[30] Moreover, T-Mobile's concern seems to reflect a presumption that the traditional MHz-Pop based activity rule would be used. But AT&T's CPA proposal recommends use of a "revealed preference" activity rule, instead – consistent with recent auction theory designed precisely to minimize manipulative hindrances to price discovery such as parking.[31]

D. Spectrum Caps Are No Substitute For Package Bidding.

T-Mobile argues that, given the purported problems with AT&T's CPA proposal, the Commission should minimize exposure risk by adopting spectrum caps, instead.[32] T-Mobile is correct that exposure risk could be reduced by limiting competition itself. However, as AT&T has already argued at length in this proceeding and elsewhere before the Commission, such limitations on competition would likely result in dramatic reductions in auction efficiency and revenue, contrary to the fundamental purposes of the incentive auction. As a result, AT&T's CPA proposal is the far superior choice for reducing exposure risk and thereby maximizing the

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[29] T-Mobile Comments at 4-5.

[30] Haile Analysis at 8 n.15.

[31] Haile Analysis at 8. *See generally* Attachment 3 (AT&T Reply Comments, Ex. C) at 10-13.

[32] T-Mobile Comments at 6.

incentive auction's revenue generation and spectrum reallocation.[33] Indeed, T-Mobile seems to have shoehorned its spectrum cap proposal into this pleading cycle for purposes other than to truly address the relative merits of package bidding, such as the purpose of potentially reducing the cost to T-Mobile of obtaining 600 MHz spectrum at auction.[34]

E. The Commission Should Not Employ CMAs.

Some commenters continue to press the Commission to adopt CMAs as the geographic license area for the incentive auction of 600 MHz spectrum.[35] As even the economists[36] commissioned by the Rural Wireless Association, Inc. and NTCA-The Rural Broadband Association (collectively, "RWA/NTCA") admit, however, as license size shrinks, geographic exposure risk enlarges.[37] Thus, employing 734 CMAs rather than the 176 EAs proposed by the Commission would make the exposure risk for carriers seeking regional or national footprints skyrocket, which could substantially suppress bids, reduce the amount of repurposed spectrum, and perhaps scuttle the incentive auction altogether. Moreover, because CMAs do not nest within EAs or any other larger existing geographic areas,[38] AT&T's CPA proposal could not readily be used to minimize exposure risk. Furthermore, adopting CMAs would entail auction implementation risks for the Commission and bidders, and also substantial deployment

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[33] *See, e.g.*, Haile Analysis at 9-11.

[34] *See, e.g.*, Haile Analysis at 9-11.

[35] *See, e.g.*, USCC Comments at 9-32.

[36] NERA Economic Consulting, *Local and Regional Licensing for the US 600 MHz Band (Incentive Auction)* (January 2014) ("NERA Report"), attached to Ex Parte Letter from Richard Marsden, NERA, to Marlene Dortch, FCC, GN Docket Nos. 12-268, 13-185 (undated).

[37] NERA Report at 21-23.

[38] *See, e.g.*, NERA Report at 5, 34.

complications for winning bidders.[39] Consequently, along with AT&T's CPA proposal regarding package bidding, the Commission should adopt its own EA proposal regarding geographic license areas. The Commission could, instead of EAs, adopt some form of the PEAs proposed by the CCA; but for the reasons explained above and in AT&T's Comments, such a choice would be defensible only if accompanied by AT&T's CPA proposal or equally effective package bidding rules.[40]

[39] *See, e.g.*, *Incentive Auction NPRM* at ¶¶ 147-148; Comments of Verizon and Verizon Wireless, GN Docket Nos. 12-268, 13-185 (filed Jan. 9, 2014) at 3. Even the economists commissioned by RWA/NTCA concede that using CMAs rather than EAs "would not be ideal from a perspective of managing implementation risks" (although the complexities allegedly would not be "insurmountable"). NERA Report at 11, 25-26, 31.

[40] Comments of AT&T, GN Docket Nos. 12-268, 13-185 (filed Jan. 9, 2014). The bifurcated auction proposal proffered by RWA/NTCA (*see, e.g.*, NERA Report) is a flawed, Rube Goldberg contraption that has already drawn considerable cogent criticism in the record. AT&T will not pile on here except to observe that the proposal assumes – quite incorrectly – that AT&T has immaterial interest in serving rural areas. *See, e.g.*, NERA Report at 44. As previously stated, AT&T competes vigorously regarding breadth of wireless service coverage.

III. Conclusion

For the foregoing reasons, the Commission should adopt its proposal to license 600 MHz spectrum on an EA basis, and should also adopt AT&T's CPA package bidding proposal. However, it would not be arbitrary or capricious for the Commission to choose to license 600 MHz spectrum on a PEA basis, but only if the Commission were also to adopt AT&T's CPA proposal or equally effective package bidding rules.[41]

Respectfully submitted,

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[41] AT&T's positions here apply to the AWS-3 proceeding, as well. *See, e.g.*, *Public Notice* at 3.

ATTACHMENT

1

Reply Comments on Package Bidding

FCC GN Docket Nos. 12-268 & 13-185

January 23, 2014

Philip A. Haile[1]

1 Introduction

I have been asked by counsel for AT&T to review and comment on recent FCC filings on the topic of package bidding in the 600 MHz spectrum auctions.[2] Package bidding is motivated by the exposure problem and its adverse effects on auction revenue and efficiency, issues already discussed extensively in this proceeding and in prior FCC auction proceedings.[3] In the most recent comment round, some commenters, including T-Mobile and U.S. Cellular, contend that allowing package bidding in the 600 MHz auctions would necessarily introduce excess complexity, bias against smaller bidders, gaming opportunities, harm to revenue and efficiency due to excess supply (or "undersell"), and other undesirable effects. T-Mobile further contends that the exposure problem can be mitigated without these problems if auction participation limits (*i.e.*, spectrum caps) are substituted for package bidding. As I explain below, these claims are misguided: package bidding can be incorporated in the 600 MHz auction design in ways

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[2] "Comments of T-Mobile USA, Inc.," GN Docket No. 12-268, January 9, 2014 (hereinafter "T-Mobile Package Bidding Comments"); "Comments of United States Cellular Corporation," GN Docket No. 12-268, January 9, 2014 (hereinafter "U.S. Cellular Package Bidding Comments").

[3] See, *e.g.*, Yeon-Koo Che, Philip Haile and Michael Kearns, "Design of the FCC Incentive Auctions," attachment to Comments of AT&T Inc., GN Docket No. 12-268, January 25, 2013 (hereinafter "CHK"); Gregory L. Rosston, "Implementing Package Bidding in the 700 MHz Band to Improve Consumer Welfare," WT Docket No. 06-150, February 5, 2007; Declaration of Dr. Gregory L. Rosston and Dr. Scott Wallsten, Attachment A to Comments of Access Spectrum, LLC, Columbia Capital III, LLC, Pegasus Communications Corporation and Telecom Ventures , LLC, WT Docket No. 06-150, September 29, 2006; Comments of Paul Milgrom and Karen Wrege, WT Docket No. 06-150, September 20, 2006; Reply Comments of Paul Milgrom and Karen Wrege, WT Docket No. 06-150, October 20, 2006.

that would enhance efficiency and revenues. T-Mobile's alternative proposal to reduce competition for 600 MHz licenses, in contrast, could "address" the exposure problem only at the cost of auction revenues and efficiency.

Previously, AT&T provided a detailed proposal for incorporating package bidding in the 600 MHz auction.[4] Relative to the clock auction design of Milgrom, Ausubel, Levin and Segal ("MALS"),[5] this proposal involves adding a small number[6] of pre-defined packages to the auction and allowing competition to determine which licenses are allocated as parts of packages and which are awarded on a standalone basis. CHK called this auction design the Clock Package Auction ("CPA"). CHK also suggested a particular package structure with licenses for each Economic Area ("EA"), Major Economic Area ("MEA"), Regional Economic Area Group ("REAG"), and for the nation as a whole. That suggestion yields a hierarchical structure for packages, something shared by the "Hierarchical Package Bidding" ("HBP") auction design explored previously by the FCC.[7] However, because the CPA is based on the MALS clock auction design rather than the traditional Simultaneous Multi-Round (SMR) auction, the CPA would inherit the substantial advantages of the MALS design and would operate quite differently from the HPB auction. The CPA could be adapted to other package designs as well—for example, adding smaller licenses that nest into EAs (such as the "PEAs" favored by some smaller carriers) or dropping the nationwide package.

When evaluating the package bidding criticisms of T-Mobile, U.S. Cellular and others, it is important to be precise about which package bidding approach is being considered. Limitations of particular package auction designs considered in the past should not be mistaken for limitations inherent to package bidding generally. Many of the concerns expressed by T-Mobile and U.S. Cellular simply do not apply to the CPA auction design. For example, the comments

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[4] See CHK and "Reply Comments of Yeon-Koo Che and Phil Haile," attachment to Comments of AT&T Inc., GN Docket No 12-268, March 12, 2013 (hereinafter "CH").

[5] P. Milgrom, L. Ausubel, J. Levin, and I. Segal, "Incentive Auction Rules Options and Discussion," appendix to Notice of Proposed Rulemaking, FCC 12-118, September 28, 2012.

[6] With the specific design proposed in CHK, the number of objects (license types) would increase from 172 to 229.

[7] See, *e.g.*, Jacob K. Goeree and Charles A. Holt, "Hierarchical Package Bidding: A Paper and Pencil Combinatorial Auction," *Games and Economic Behavior*, 70, 2010 and "Auction of H Block License in the 1915-1920 MHz and 1995-2000 MHZ Bands," Comments Sought on Competitive Bidding Procedures for Auction 96,'' Federal Communications Commission, AU Docket No. 13-178, July 15, 2013.

regarding excess complexity, bias against small/local bidders, new opportunities for gaming, and exposure risk for local bidders all appear to reflect either a misunderstanding of the CPA design or an assumption that a different type of package bidding would be used. As previously demonstrated in CHK and CH and discussed further below, the CPA design does not materially increase complexity, introduce bias against small/local bidders, enhance opportunities for gaming, or create any additional exposure risk for small/local bidders.

Two of T-Mobile's comments warrant further consideration. T-Mobile contends that any type of package bidding is likely to increase excess supply (the risk of undersell) due to a package bidder's dropping its demand for a package when only some of its components are in excess demand. That is likely true, but it is not a useful observation on its own because it amounts to forgetting about the benefits component of cost-benefit analysis. Any "extra" undersell that arises under the CPA would be the result of allowing bidders to express complementarities in order to attain more efficient license allocations. The available evidence suggests that the incremental undersell risk is modest and that the benefits of package bidding vastly outweigh the costs.

T-Mobile's proposal to substitute participation restrictions (on AT&T and Verizon) for package bidding appears to reflect an agenda that has nothing to do with the wisdom of introducing package bidding. T-Mobile's proposal does reveal a great deal about the risks to revenue and efficiency that would result from the artificial limits on competition favored by T-Mobile. I elaborate on each of these points below.

2 Excessive Complexity

Both T-Mobile and U.S. Cellular assert that package bidding would introduce excessive complexity to the auction.[8] One can certainly imagine package auction designs that would introduce substantial, even prohibitive, complexity. However, such complexity is not inherent

[8] See *e.g.*, T-Mobile Package Bidding Comments at 1, 3, 5, 6; U.S. Cellular Package Bidding Comments at 32, 40-43, 45.

to package bidding in general. And the CPA would, in particular, be substantially *less* complex than prior FCC spectrum auctions.

The CPA is based on the new clock auction design proposed by MALS. As discussed extensively elsewhere, the MALS auction design offers a number of substantial simplifications to the SMR auction design used previously by the FCC. These design improvements substantially simplify bidding decisions, aid price discovery, and eliminate many opportunities for gaming. The CPA builds on these major design improvements, altering the MALS design in only three ways: (i) expanding the set of objects offered to include a small number of pre-specified packages; (ii) specifying how excess demand can be properly calculated; and (iii) specifying a rule to govern price clocks, ensuring that package prices are additive in the prices of the package components when possible (and otherwise superadditive).

Consequently, the CPA would not add significant complexity to the MALS auction design, particularly from the perspective of bidders. This has already been explained in detail in CHK and CH. In fact, the CPA would substantially *simplify* the auction relative to the MALS design (and, *a fortiori,* relative to the SMR auction) by substantially eliminating the exposure problem, thereby avoiding the need for bidders to pursue bidding schemes aimed at reducing their own exposure risk or at exploiting the exposure risk of their opponents (see CH).

3 Intrinsic Bias Against Small/Local Bidders

Both T-Mobile and U.S. Cellular assert that package bidding is inherently biased against small bidders or local bidders—those seeking smaller coverage footprints.[9] This is incorrect. As discussed already in CHK and CH, the CPA would create no bias in favor of or against any class of bidder. No licenses would be set aside for package bidders, and a package would be awarded only when a package bidder offers a price that exceeds the sum of prices offered for the component licenses. U.S. Cellular's claim[10] that "[p]ackage bidding could also permit large carriers to obtain a package of licenses for a sum lower than what individual licensees are

[9] T-Mobile Package Bidding Comments at 3; U.S. Cellular Package Bidding Comments at 32-36.
[10] U.S. Cellular Package Bidding Comments at 45.

willing to pay on a per-license basis" is incorrect in the case of the CPA. In fact, as discussed at length by CHK and CH, the CPA would *eliminate* an important bias against local bidders—that arising from the "overflow problem" under the MALS auction design.

It is true that the introduction of package bidding would also remove (or at least reduce) a bias against package bidders: that arising from exposure risk. As a result, package bidders would be more likely to win when their value for the spectrum was highest. Bidders seeking smaller footprints understandably would not favor this. But one should not confuse removal of bias against package bidders with introduction of bias against local bidders.[11] Removal of biases is one of the purposes of improving auction design: to obtain more efficient allocations and to allow bidders to better express their full willingness to pay, thereby enhancing auction revenue.

U.S. Cellular makes specific reference to the "threshold problem'' as a source of bias against local bidders under package bidding. This claim reflects a common but incorrect belief that the threshold problem is introduced by package bidding. This has been discussed at length in CH. As explained there, the threshold problem arises not from package bidding but from the presence of package *valuations* (complementarities between licenses). As CH showed, the threshold problem is present in both the traditional SMR auction design and in the clock auction design proposed by MALS.

Where it exists, the threshold problem can be a potentially significant source of inefficiency and suppression of revenue. However, I am not aware of even an example of a threshold problem that would arise under the CPA auction design but not the MALS design, much less an argument that the threshold problem would be systematically more severe under the CPA. Thus, whereas there has been a tendency to think that optimal spectrum auction design must make tradeoffs between the exposure problem and the threshold problem, I am not aware of evidence that such a tradeoff even exists in comparing the MALS (without package bidding) vs. CPA (with package bidding) designs. On the other hand, concerns about the threshold problem offer one motivation for abandoning the SMR auction design. As CH pointed out, the MALS auction and CPA may substantially mitigate the threshold problem relative to that which would arise under

[11] See U.S. Cellular Package Bidding Comments at 34.

the traditional SMR auction design, due to the proposed information disclosure rules, the use of price clocks, and the use of generic licenses.

4 Bid "Withdrawals"

T-Mobile argues that package bidding would introduce several problems due to the ability of a package bidder to quit demanding a package when its price rises. T-Mobile refers to this ability as an option to "withdraw" a bid, although neither the MALS nor CPA auction rules permit any bidder to withdraw any expression of demand: any expression of demand (*i.e.*, any bid) would be a binding offer. Thus T-Mobile's concern here involves the circumstances under which a bidder is permitted to reduce the quantity of an object it demands. The CPA rules treat all objects (packages and individual licenses) symmetrically on this issue: a bidder may reduce the quantity demanded of an object only when the price of that object increases.[12]

4.1 Undersell

T-Mobile raises a concern about the potential for excess supply or "undersell"—the failure of some licenses to sell at the auction, potentially due to a package bidder's dropping its demand for a package when only some of its components are in excess demand. Although undersell can arise in the MALS auction design as well, I agree that undersell is likely to be somewhat greater under the CPA rules. However, this is not a useful observation on its own. What matters is how package bidding would affect auction revenue and efficiency.

Perhaps surprisingly (although not to auction experts) it is not true in general that auctions with less undersell generate greater revenue or greater efficiency. In fact, even in the simplest auction settings, undersell is an *implication* (*i.e.*, a necessary condition for) revenue maximization.[13] Likewise, although failing to sell a license may sound like a source of

[12] This is a more restrictive rule than that used in the "clock phase" of the "Combinatorial Clock Auction," where a bidder may drop its demand on an object whose price has not risen as long as the price rises for some object the bidder demanded in the preceding round. Thus, in the CPA, only a bidder for a nationwide license would have the same flexibility in the CPA as in the Combinatorial Clock Auction. As suggested previously in CH, if this flexibility is a concern, nationwide licenses could be excluded from the CPA. Including packages only at the MEA and REAG levels would still yield a multitree structure, as the CPA requires for unambiguous determination of excess demand.

[13] See, *e.g.*, Roger B. Myerson, "Optimal Auction Design," *Mathematics of Operations Research*, 6, 1981.

inefficiency (and it would be if all else could be held fixed), this is not true in general, since bidder behavior depends on the auction rules. Any "extra" undersell that arises under the CPA would be the result of allowing bidders to safely express complementarities in order to attain more efficient license allocations.

Thus, an evaluation of undersell alone is irrelevant: it amounts to forgetting about the benefits component of cost-benefit analysis. The relevant questions about revenue and efficiency concern (a) whether, on net, allowing package bidding is likely to enhance or diminish revenue and efficiency, and (b) the potential for correcting any adverse outcomes that arise.

The only attempt I am aware of to evaluate (a) is the simulation analysis in CHK. There we found, consistent with T-Mobile's concern, that package bidding leads to a larger rate of undersell, although the undersell rate was fairly small in both cases (about 3 percent undersell with package bidding, 0.3 percent without). However, the net effects of package bidding on revenues and efficiency were positive and large. For example, in the baseline simulation, the median percentage gain in revenue from the CPA was 67.1 percent, and the 75th percentile gain was more than 100 percent. In terms of efficiency, the CPA achieved at least 90 percent of the (infeasible) first-best in over 91 percent of the replications. By contrast, the MALS auction (without packages) achieved this level of efficiency in only 37 percent of the replications.[14]

No simulation study can answer with certainty what the net effects of package bidding will turn out to be. But these findings provide the only evidence available thus far regarding the likely effects of package bidding (following the CPA) on efficiency and revenue. At a minimum, they reinforce what is already a simple matter of logic: one cannot merely argue that package bidding might lead to greater undersell, since greater undersell can arise from improvements in auction design that lead to vast improvements in efficiency and revenue.

Finally, regarding question (b) above, it seems worth pointing out that revenue losses due to a failure to account for complementarities in the auction design would be irreversible. We might hope that resale markets would undo at least some of the inefficiency resulting from an

[14] See CHK for additional details and simulations.

absence of package bidding, but the Federal Government will capture no additional revenue. Undersell, on the other hand, can be at least partially mitigated by offering residual licenses at some future date.

4.2 Gaming

T-Mobile suggests that package bidding would introduce opportunities for a particular type of gaming, whereby a bidder hides its intentions early in the auction, maintaining eligibility by bidding for a package it does not want but whose price is sure to keep rising. T-Mobile does not elaborate on the motives for such "parking" behavior, but it is well understood that, should it arise, parking can harm price discovery, potentially to the advantage of the bidder.

In the CPA, such behavior would involve substantial risk for the bidder.[15] But, more important, the concern seems to reflect a presumption that the traditional MHz-Pop based activity rule would be used. The possibility of parking under that rule is well recognized and has led to the recent development of alternative "revealed preference" activity rules, which minimize such hindrances to price discovery.[16] CHK recommended the use of a revealed-preference activity rule in the CPA.

More broadly, although opportunities for gaming must be considered very carefully, initial intuitions that the CPA would introduce substantial new opportunities for gaming or "manipulative bidding" have so far failed to stand up to careful scrutiny. Many of the notions experts in the field have about package bidding and gaming appear to be tied tightly to the opportunities to game the rules when package bids are added to the SMR auction design. This is understandable, given the long history of the SMR auction at the FCC. However, when comparing the CPA to the MALS auction design, the most important differences in likely gaming appear to be the CPA's elimination of incentives for package bidders to pursue manipulative bidding schemes designed to minimize their own exposure risk or to exploit that of their competitors. Thus, adoption of the CPA design for package bidding would simultaneously serve

[15] Bids in the CPA are binding offers to purchase. Only if a bidder were certain that others will drive up the price of an object can he bid for it without risk of winning.
[16] See, *e.g.*, Peter Cramton, "Spectrum Auction Design," *Review of Industrial Organization*, 42, 2013.

the goals of limiting the harmful effects of exposure risk and limiting the opportunities for manipulative bidding. These issues have been discussed previously by CH.

5 Reinstatement of Losing Bids

U.S. Cellular argues that package bidding would introduce a new exposure risk for local bidders, due to potential reinstatement of previously losing bids.[17] I agree that any auction design that includes reinstatement of losing bids could create substantial risks (for any bidder). Such a risk would exist in some types of package auctions, but not the CPA. In the CPA there is no reinstatement of previously losing bids.[18] Under the CPA rules, a bidder would be allocated a license only if this bidder is demanding that license when the price clock stops.

6 Participation Restrictions

T-Mobile argues that limits on bidder participation offer a better approach to limiting exposure risk that arises from complementarities between licenses. This is an argument the FCC should examine closely, as it reveals a great deal about the dangers that participation restrictions would pose to the auction.

Exposure risk arises from the interaction between two auction features:

> ***competition***: bidders must compete for scarce licenses; thus, a package bidder may fail to win the package it desires because others value the licenses more highly;
>
> ***noncontingent offers***: without package bidding, offers to buy a license are not contingent on whether other licenses are also acquired.

[17] U.S. Cellular Package Bidding Comments at 36-40. Reinstatement of losing bids refers to the phenomenon, permitted by some auction rules, that a bidder not offering to buy a given license at the end of the auction is forced to buy that license based on an offer to buy made earlier in the auction. This practice can limit undersell, but at the cost of introducing substantial risk to bidders, inhibiting straightforward bidding and price discovery.

[18] U.S. Cellular may be confusing AT&T's CPA proposal with other package auction designs. This is also suggested by their use of the moniker HPB to refer to the AT&T proposal. The specific package design proposed in CHK is hierarchical but, as explained above, the CPA rules differ considerably from those of the SMR-based HPB auction previously considered by the FCC.

Exposure risk is the risk that competition and noncontingent offers interact—that a package bidder unwilling to outbid others for the licenses in a package is stuck making good on his offer to buy a component license, one that may have little standalone value to him. Because this risk involves the interaction between competition and noncontingent offers, by eliminating/reducing either feature, one could eliminate/reduce exposure risk.

Auction theorists have given a great deal of attention to how best to relax the restriction to noncontingent offers in order to reduce the exposure problem and, thereby, preserve package bidders' willingness to compete. Presumably this focus reflects the view that competition is essential to an auction. But T-Mobile is correct in pointing out that exposure risk could also be limited by limiting competition itself. By limiting competition, especially that of bidders likely to value licenses highly, the chance that a package bidder is displaced by higher-value competitors is diminished. Of course this would be achieved at the cost of auction revenues and efficiency, by preventing bidders who place higher value on a license from expressing this demand. In an extreme case, limiting the level of competition relative to the number of licenses available could lead to disastrous results.[19] This dire scenario seems stunningly close to the hope expressed by T-Mobile:

"*With reasonable spectrum-aggregation limits, the threat of any bidder losing a substantial number of key market areas (i.e., the exposure risk) is greatly reduced. For instance, should multiple paired blocks of spectrum come to market with reasonable aggregation limits, every carrier should be able to acquire licenses over all or substantially all of their desired footprint*." (Comments of T-Mobile at 6).

The point of holding an auction is, of course, that not all carriers will be able to acquire all the licenses that they would like to have. An auction is meant to determine how best to allocate the scarce spectrum resource and to ensure that the Federal Government obtains a substantial share of the spectrum value. Limiting competition works directly against both purposes.

Unrestricted bidders seeking packages would be helped in many ways by the restrictions on competition proposed by T-Mobile. But one cannot take seriously the argument that harming

[19] See Paul Klemperer, ``How (Not) to Run Auctions: The European 3G Telecom Auctions," *European Economic Review*, 46, 2002.

efficiency and revenue by limiting competition is the best remedy (or any remedy at all) for the harms to efficiency and revenue that would arise from failing to address the auction design flaws (restrictions to noncontingent offers) that create exposure risk.

ATTACHMENT

2

Design of the FCC Incentive Auctions*

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Contents

I Executive Summary **1**

1 Overview **1**

2 Strengths of the Proposal **5**

3 Concerns **7**
3.1 Forward Auction 7
3.2 Reverse Auction 10
3.3 Closing Rules 13

4 Key Proposals **14**
4.1 Forward Auction 14
4.2 Reverse Auction 16
4.3 Closing Rules 19

5 Conclusion **20**

II Forward Auction **21**

6 The NPRM and MALS Proposals **21**
6.1 Clock Auction 21
6.2 SMR Auction 22

7 Primary Concerns **23**
7.1 Exposure Risk 23
7.2 Frequency Contiguity 26
7.3 The Overflow Problem 28
7.4 Other Sources of Inefficiency 31

8 Clock Package Auction **34**
8.1 Objects for Sale 36
8.2 Hierarchical Structure 37
8.3 Overview of the Clock Package Auction 39
8.4 Feasible Supply and Feasible Allocations 40
8.5 Total Demand, Excess Demand 42
8.6 Price Clocks 43
8.7 Examples 44
8.8 Properties of the CPA 49

9 Supplementary Bidding **54**

10 Improved Assignment Phase **57**
10.1 Random Priority with Enriched Preferences 58
10.2 Assignment Auction 62

11 Other Concerns and Recommendations **63**
11.1 Generic Licenses 63
11.2 Bidding Credits 64
11.3 Activity Rule 65

III Reverse Auction **67**

12 The NPRM and MALS Proposals **67**
12.1 Descending Clock Auction 68
12.2 Other Reverse Auction Designs 70

13 Primary Concerns **70**
13.1 Computational Complexity 70
13.2 Delay and Uncertainty Due to Target Failures 71

14 Single-Pass Reverse Auction **71**
14.1 Single-Pass: Baseline 72
14.2 Single-Pass with Proxy Bidding 74

15 Addressing Algorithmic Issues **75**
15.1 Background and Context 77
15.2 Computational Complexity in a Descending Clock Auction 80
15.3 Computational Complexity in Sealed-Bid Auctions 87
15.4 Empirical Evaluations of Reverse Auction Mechanisms 89
15.5 Specific Requests for Repacking Constraint Data 93

IV Closing Rules **95**

16 The NPRM and MALS Proposals **95**

17 Primary Concerns with the One-Sided Closing Trial **96**

18 Two-Sided Closing Trial **97**
18.1 Baseline Proposal 97
18.2 Closing Trial with Proxy Bidding 100
18.3 Avoiding Overshooting 101

Appendix A Clock Package Auction Simulations **103**
A.1 Simulation Design 103
A.2 Results: Baseline Specification 108
A.3 Sensitivity Analysis 114

Appendix B Other Concerns with CCA Supplementary Bidding **118**

Appendix C Proof of Theorem 4 **120**

Appendix D Reverse Auction Simulations **122**

Part I

Executive Summary

1 Overview

The FCC's September 2012 Notice of Proposed Rulemaking ("NPRM") proposes an ambitious plan to create a marketplace in which spectrum currently licensed for broadcast television can be repurposed for more highly valued mobile wireless use. This "Incentive Auctions" proposal involves using auctions to determine which users value the spectrum most highly, license spectrum to these users, and compensate current licensees who relinquish spectrum rights. The FCC has conducted many spectrum auctions in the past. But this is the first time an auction to sell spectrum rights is to be combined with an auction to purchase spectrum rights from existing licensees. Designing such a marketplace is complicated not only by incumbent claims on the spectrum, but also by technological constraints for mobile wireless and broadcast television uses.

Broadly speaking, there are two components of the proposed auction design: (1) a *reverse auction* in which current broadcast television licensees can offer to sell their licenses; and (2) a *forward auction* in which mobile wireless carriers may offer to purchase licenses. The quantities of spectrum transferred from broadcast television licensees to wireless carriers in each geographic area will be determined through a sequence of trials, starting with high *target* quantities that subsequently decline as necessary. Payments and spectrum reallocations take place only when a target quantity is identified at which wireless carriers are willing to buy at prices generating revenues that exceed the total cost of purchasing from broadcast television licensees. Indeed, because remaining broadcast television licensees must be "repacked" into another region of the frequency spectrum in order to create a viable wireless

spectrum band plan, buyers will be required to pay prices sufficient not only to compensate sellers, but also to cover repacking costs and costs of administering the auction itself.

The need to repack TV licensees without creating interference introduces significant complications to the design of a reverse auction. Repacking constraints are "global," in the sense that placing a broadcaster in one market in a particular frequency can affect the feasibility of placing broadcasters in the same or nearby frequencies in other markets. For example, Washington, D.C. and Philadelphia, PA are sufficiently proximate that use of a UHF channel in one may preclude use of the same channel in the other market. For the same reason, decisions regarding channel usage in Philadelphia are also likely to affect New York City, which then may affect Bridgeport, CT, and then Boston, MA. Similarly, a Washington D.C. assignment may affect feasible assignments in Baltimore, MD and possibly Richmond, VA. Thus, channel usage can have a "daisy-chain" effect that can link major metropolitan areas—as well as smaller communities—that are hundreds of miles apart.

There is considerable variation across markets in the density of broadcast television licensees, as well as within-market variation in stations' "contours"—geographic coverage areas, which must be substantially maintained after repacking. Further, cross-market variation in the willingness of TV licensees to go off the air creates challenges to designing a viable nationwide band plan, and introduces the likelihood that the prices required to clear a given quantity of spectrum will vary substantially across markets.

The main auction design proposal was developed in Milgrom, Ausubel, Levin, and Segal (2012) ("MALS"). The authors are prominent economists with extensive experience in market design, including the design of prior FCC spectrum auctions. They propose the use of "clock" auctions in both the forward and reverse auctions. In a clock auction, prices are offered by the FCC. Bidders respond by indicating the trades they would like to make at those prices. Prices are then adjusted (e.g., upward in the forward auction), and the process continues until the trades desired by all bidders match the trades that are available.

The term "clock" refers to the fact that price offers are made by the "auctioneer" (here, the FCC), not by bidders. Bidders' choices in the auction are limited to expressions of quantities that would be demanded or supplied at the current price offers. Relative to other types of auction designs, including the Simultaneous Multi-Round (SMR) auction used in prior FCC spectrum auctions, a clock auction offers a number of advantages, including simplification of bidding and assurance that the auction keeps moving toward a final allocation.

The reverse auction would begin with provisional target quantities of spectrum to be cleared in each market. Although there would be a single nationwide reverse auction, it will utilize different clocks for each market and each *relinquishment option*—e.g., go off the air, share with another station, or move to a lower band. The option to "remain in the current band" (i.e., to be repacked) is always available as well. Bidders who do not participate in the auction are automatically assigned to this option. Participation in the auction is strictly voluntary. Clock prices may differ across bidders within a market and may move at different speeds, due to differences in coverage areas, in the feasibility of each option, in the costs of repacking, or in the effect of repacking one station on the ease of repacking others.

The auction clocks begin with high initial ("reserve") prices chosen by the FCC for each feasible relinquishment option in each market. Each bidder selects the option he[1] finds most attractive at these prices. Roughly speaking, prices are then lowered, bidders again express their preferences, and the process iterates until prices reach a level just low enough that the quantity of spectrum offered in each market equals the target quantity.

Complicating this simple description is the fact that feasibility considerations will limit repacking options. Each clearing target determines the amount of spectrum available for repacking bidders who choose to stay on the air. Before prices are adjusted during the auction, the feasibility of repacking each remaining bidder (i.e., the feasibility of adding that bidder to the set to be repacked) must first be checked. If it becomes infeasible for a given

[1] For clarity we use "he" to refer to bidders despite the fact that bidders are firms.

bidder to be repacked, his current relinquishment offer will be provisionally accepted at the current clock price for that option. The feasibility checking iterates until it is the case that each remaining bidder could feasibly be repacked. Only at this point do clock prices decline for these remaining bidders.

In the proposed forward clock auction, the FCC would simultaneously offer licenses in every market. Here the proposed notion of a market is an Economic Area ("EA") as defined by the Bureau of Economic Analysis. There will typically be more than one class of license available in each market; e.g., licenses for 10MHz of "paired" spectrum (5 MHz for wireless uplink, 5MHz for downlink), and licenses for 5MHz of unpaired (downlink only) spectrum. Licenses for different combinations of EA and class are treated as distinct *objects* and will have different clocks. Multiple *units* of each object, corresponding to specific frequencies, will typically be available. However, all units of the same object are treated as generic. At the beginning of the auction, all objects are given low initial (reserve) prices by the FCC. Potential buyers respond to these prices by specifying the number of units of each object that they would wish to purchase at these prices. Prices for objects with excess demand (demand that exceeds the available supply) then rise, and bidders indicate their demands at these new prices. This process continues until the quantity of spectrum demanded in each market is no larger than the associated target quantity. Thus, the forward auction stops at prices just high enough to eliminate excess demand relative to the target quantities.

At this point, the total revenue that would be generated nationwide by selling the target quantities at the forward auction prices are compared to the total cost of purchasing the same quantities at the provisional reverse auction prices. The difference between the total nationwide revenue and total nationwide cost is the *net revenue* that would be generated at the current clearing target. If this net revenue is sufficient to cover the expected nationwide repacking costs, the "grand auction" ends, licenses are reallocated, and all payments are made. If the net revenue is insufficient, there is a provision for continuing the forward

auction to determine whether there are higher prices that forward auction bidders are willing to accept and which would close the gap. If this *closing trial* fails, the clearing targets are reduced. The reverse auction then resumes, pushing prices lower until supply is equated to the new target. Symmetrically, the forward auction resumes, with prices rising until demand is equated to the new targets. Net revenue is checked and the grand auction either terminates or resumes with still lower clearing targets.

2 Strengths of the Proposal

The proposed design has a number of significant virtues.

Simplicity A clock auction keeps the decisions for a bidder as simple as possible: a bidder need only choose the trades he would like to make at the prices currently offered. In the reverse auction, this means choosing one from a short list of relinquishment options, including the option to remain on the air in one's current band. For the forward auction, this means choosing the types and quantities of licenses the bidder would wish to purchase if the current clock prices turn out to be the final prices. The use of generic licenses provides additional simplicity by avoiding artificial distinctions between substantially identical licenses.

Simplicity is one of the dimensions in which the proposed design appears to be a significant improvement on the SMR design used in the previous ("forward") FCC auctions. We discuss the SMR auction in more detail below. Simplicity is also a substantial advantage of the clock design relative to the theoretically attractive but highly opaque Vickrey-Clark-Groves (VCG) auction. In a VCG auction it can be difficult for bidders to understand how their actions translate to outcomes during the auction.

Success The clock auction design ensures that the auctions will proceed to termination in reasonable time and will terminate at a feasible allocation.[2] Some alternative auction designs can stall or proceed only very slowly.

Transparency Identical licenses will trade at identical prices. No bidder will discover that he was excluded despite offering a price more favorable than that at which a similarly situated bidder was allowed to trade. These properties need not hold in a VCG or SMR auction.

Price Discovery In the forward auction, many licenses are offered simultaneously. A bidder's valuation of a particular license may depend on which complementary licenses he is also able to acquire. Further, the desirability of one combination of licenses will depend on the prices at which alternative combinations are available. In a multi-object clock auction, clock prices provide valuable feedback along the way about where all prices are likely to end up. This facilitation of "price discovery" can enable bidders to focus on the most relevant sets of licenses and to reoptimize their spectrum aggregation strategies as the auction proceeds.

Competition The auction design allows bidders on both sides (forward and reverse) to compete on even footing for the most valuable use of the spectrum. No particular type of bidder is treated more favorably than another. And no spectrum is set aside for either use: bids determine the quantity of spectrum allocated to mobile wireless vs. broadcast television. Combined with the use of generic licenses in the forward auction, which avoids artificial thinning of competition, these features will encourage efficiency of the final spectrum allocation.

[2] This assertion is subject to potential computational challenges, disccussed below, that are associated with determining the feasibility of repacking each television licensee that has not already dropped out of the auction.

Limited Scope for Manipulation We see little scope for manipulation that could undermine the efficiency of the allocation or limit revenues generated. This contrasts, for example, with the SMR design, which is susceptible to collusion, signaling, and entry by speculators who can harm both revenues and efficiency.

3 Concerns

We see many favorable features of the MALS proposal and believe it is the best starting point from which to design the details of the incentive auctions. Nonetheless, there are several features that give us concern. Below we discuss a few of the most important issues. In the subsequent section we summarize several proposed modifications that we believe can address these concerns.

3.1 Forward Auction

Exposure Risk Our most serious concern with the proposed forward auction design is its treatment of complementarities between licenses. Such complementarities will exist for many (perhaps the vast majority of) forward auction bidders: any bidder who will wish to assemble coverage over regions larger than a single EA. The clock auction design allows bidders to pursue packages of licenses, but only by offering to buy each individual license that is part of the desired package. Such a strategy becomes problematic when the value of one license is highly dependent on whether other licenses in the package are also acquired.

Consider, for example, a bidder seeking to obtain a coverage footprint in the Philadelphia Major Economic Area ("MEA"), which is comprised of three EAs. Under the MALS auction design, such a bidder would have two options. One is to aggressively pursue all three EA licenses, offering to buy all of them as long as the total cost stays below the value these licenses have to him as a whole. This can be a very risky strategy. It is possible that the

clock stops for one of the EA licenses while prices for the other two rise to levels that make the package unprofitable. A bidder following the aggressive strategy would be stuck: he would be forced to make good on his offer to purchase the first license. This license alone might not allow a viable service offering, but the bidder would be forced pay a price that he agreed to under the assumption that he would be able to offer coverage throughout the Philadelphia MEA. The risk of this highly unprofitable outcome is known as "exposure risk" or the "exposure problem."[3] It is a serious problem for firms seeking to offer service in any area larger than a single EA.

The other option for such a bidder is to bid conservatively, avoiding the exposure risk. This is also undesirable. It can lead to inefficient allocations (if the most valuable use of the spectrum is as part of a package) and to reduced revenues (even if the most valuable use is not in packages). Revenues are of particular importance here due to the interaction between the forward and reverse auctions. Unlike prior FCC auctions, here revenues and efficiency cannot be separated.

Frequency Contiguity A second major concern is that the NPRM and MALS proposals do not make adequate provisions for bidders to obtain contiguous blocks of spectrum. Two types of frequency contiguity are important. First, within a geographic area, wireless service providers seeking to offer LTE or LTE-Advanced services desire significant blocks of spectrum in adjacent frequencies. We understand that such *vertical contiguity* is essential to optimal performance of these technologies. Second, bidders seeking coverage areas encompassing multiple EAs desire licenses in identical frequencies in each EA. We understand that such *horizontal contiguity* minimizes interference at boundaries and allows use of more efficient network deployment.

The current proposals for assigning individual licenses to winners of generic licenses in

[3] See, for example, the extensive discussion of the exposure problem in the edited volume of Cramton, Shoham, and Steinberg (2010).

each EA may address the need for vertical contiguity within a single EA. But they would not allow bidders to express their broader needs for frequency contiguity. For example, the proposed random assignment of specific frequencies to winners in each EA virtually guarantees a lack of horizontal contiguity. The result would be a reduction in bidders' willingness to pay, inefficiently low quantities of spectrum cleared, and inefficient allocation of the spectrum that is cleared.

Other Sources of Misallocation: The Overflow Problem We have already discussed potential misallocation arising from the exposure problem and the needs for frequency contiguity. In some cases misallocation may take the form of *undersell*—failure to sell some units. Misallocation can also arise from other sources. Some, like the possibility that market clearing prices do not exist—are inherent to any allocation mechanism with anonymous prices. However, at least one additional source of misallocation is particular to the MALS design, which provides no language for bidders to express whether their demand for a particular license is driven by interest in a larger bundle of licenses. Without such language, bidders seeking small groups of licenses can face rising prices even when their own demands are not a source of scarcity.

An example will illustrate the problem. Consider the Boston MEA, which includes the Bangor, Portland, and Boston EAs. Suppose that six 10MHz paired licenses are available in Bangor and Portland, but only five in the Boston EA. This implies that at most five bidders could obtain MEA-wide coverage. Suppose that at some point in the auction "regional bidders" seeking MEA-wide coverage (or coverage in a larger area that includes the MEA) are demanding seven licenses, while there is only one Portland EA license demanded by a firm seeking coverage in Portland alone. Suppose the regional bidders have an all-or-nothing strategy in this MEA: they are not interested in any strict subset of the 3 EAs. In such a situation, we would like the auction to "hold on" to the offer of the Portland-only bidder: we

know that only five units of demand from the regional bidders can be satisfied. So selling all licenses requires allocating to the Portland-only bidder. However, under the MALS design, the auction will count eight units of demand for the Portland license, conclude that this license is in excess demand, and raise its price. This will force the Portland-only bidder to either pay a higher price or exit, even though his demand is not a source of scarcity. This will tend to force such a bidder out of the market unnecessarily.

We term this phenomenon the *overflow problem*. With a richer bidding language, the auction design could account for feasibility constraints and limit the extent to which demand for large packages "flows down" to be counted as demand for the smaller packages and individual licenses nested in the larger package. Without such a language, too much demand flows down. This creates artificial competition for smaller bidders. This bias against smaller bidders will lead to undersell and/or inefficient allocations of licenses.

3.2 Reverse Auction

Computational Complexity Fully optimal clearing of a given target quantity of spectrum would minimize the total costs of clearing and of repacking television broadcasters who remain on the air. Reaching this fully optimal solution is certainly infeasible. An immediate problem is that the reservation values of broadcast TV licensees are unknown. Licensees must volunteer to sell and will not oblige if asked to reveal their true reservation values so that the efficient quantity of spectrum could be cleared at the lowest possible cost. This *incentive compatibility* constraint alone makes it impossible to pay each cleared television licensee the lowest price he would accept for his license. A second problem is the computational complexity involved in finding a cost-minimizing allocation. This complexity arises from the effect of repacking one station on the feasibility (or cost) of repacking others. Even if bidders' reservation values were known to the FCC, the cost minimization problem is an integer programming problem of a type known to be computationally hard in general.

The unique challenge in the reverse auction design is to handle adequately both incentive compatibility and computational feasibility while also keeping the rules sufficiently simple and transparent. Here, issues of auction design and computational considerations are intertwined in a way that has not previously been well explored in the theory or practice of auction design.

The clock auction proposed by MALS offers one possible approach. Taking bidding strategies as given, it replaces minimization of total cost with minimization of payments to cleared licensees, subject to sequential verification of repacking feasibility. As long as more bidders than necessary are volunteering to be cleared, prices fall, leading to repacking of bidders with the highest reservation values. In the simplest form of the proposed design, repacking constraints would enter only through verification that it is feasible to repack a bidder before he is offered a new set of prices. This approach puts priority on the cost of clearing relative to the cost of repacking. Only when it is infeasible for a bidder to be repacked would the auction allow repacking costs to affect the choice of which broadcasters are to be cleared. Possible variations include using repacking constraints to adjust relative clock speeds or to score bidders' offers. This would allow repacking costs to play a larger role, but repacking would still be done sequentially, possibly leading to suboptimal choices. The degree of suboptimality may depend heavily on the nature of the repacking constraints, about which the FCC has thus far released little information.

Further, the MALS clock auction does not avoid significant computational challenge. Formally, feasibility checking takes the form of a "graph coloring problem," which is known to be computationally hard in the worst case. Without knowing the fine details of repacking constraints, it is impossible to determine whether the feasibility checking required by the MALS proposal is itself computationally feasible.

The NPRM also entertains other types of reverse auction designs, where full optimization over bids and repacking costs might play a more prominent role. Few details are provided,

making a careful analysis of such options difficult. However the discussion in the NPRM suggests the possibility of a tradeoff between computational complexity and optimality of alternative auction designs. Whether there is such a tradeoff—and where particular proposals lie on (or inside) the frontier—is unclear however, again because the NPRM is vague about the nature of the repacking constraints and imprecise about the amenability of this type of constrained optimization problem to solution using standard algorithms or specialized algorithms adapted to the features of the repacking problem.

Without details of the repacking constraints, it is impossible to evaluate the computational complexity of alternative auction designs, or to evaluate their performance in terms of expenditure, quantity of spectrum cleared, and efficiency.

Real-Time Feasibility Checking A potentially significant drawback of the proposed reverse clock auction is its requirement of real-time feasibility checking. As already noted, feasibility checking is likely be computationally challenging. Requiring that this be done in real time as the auction proceeds may be especially demanding. Because the feasibility of repacking must be checked for each bidder every time clock prices are to be decremented, there will be many opportunities for the auction to stall or even fail altogether, due to computational delay or failure. This may lead to the use of approximate solutions, harming efficiency.

Delay and Uncertainty Due to Target Failures. Because the FCC seeks to find the maximum quantity of spectrum that should be reallocated, the initial clearing targets will almost certainly be too high. It is likely that several clearing targets will need to be tried before reaching one that satisfies the closing conditions for the grand auction.

Under the current rules, each time the target is reduced, the forward auction must pause while reverse auction bidders are reconvened in order to obtain new "supply" prices for the reduced target quantities. In addition to the burden this creates for bidders, this feature of

the auction design will delay completion of the grand auction. It may also introduce uncertainty for reverse auction bidders, since truthful bidding would require some broadcasters to take actions that commit them to assignments days or weeks ahead of other bidders.

3.3 Closing Rules

The MALS proposal recognizes that the forward and reverse auctions could stop at prices that lead to failure of the net revenue requirement even when some bidders would be willing to improve their offers enough for the revenue requirement to be met. Some inefficiency of this type is unavoidable, due to incentive compatibility constraints (Myerson and Satterthwaite (1983)). However, separation of the forward and reverse auctions leads to greater inefficiency than necessary. Although the purpose of the incentive auctions is to allocate scarce spectrum competitively, a clock auction in the forward market induces competition only between mobile wireless carriers. Forward auction bidders compete to be among the provisional winners, but do not compete directly with sellers for final ownership of spectrum. Likewise, a reverse clock auction creates competition only between current broadcast television licensees. Reverse auction bidders compete to be provisional sellers, but the two sides never compete directly to determine how much spectrum should be transferred from potential sellers to potential buyers. The result is that both the forward and reverse auction will tend to stop too soon, i.e., at prices that are unnecessarily low in the forward auction and unnecessarily high in the reverse auction.

This is recognized in the MALS proposal and underlies their suggestion that, when net revenue falls short, the forward auction would continue—prices would continue rising until either the revenue target is reached or total demand falls. This *closing trial* would allow provisional winners in the forward auction to express their willingness to offer better prices when necessary to ensure that they are allocated the licenses they seek. This is an important addition to the design. However there is no such provision for the supply side: reverse

auction bidders lack the corresponding opportunity to improve their price offers to ensure that profitable sales take place. Even if there are reverse auction bidders who would like to offer prices substantially below those set by the reverse auction (recall that these prices are the maximum prices that clear the fixed target), those bidders will have no opportunity to express this. The result will be unnecessary inefficiency. Some trades that both buyers and sellers would like to make will not take place. The total quantity of spectrum shifted from broadcast television to mobile wireless will be inefficiently (and unnecessarily) low.

4 Key Proposals

We offer a number of specific proposals aimed at addressing the concerns described above, as well as others discussed in more detail below. Here we describe the most important of these proposals.

4.1 Forward Auction

Clock Package Auction To address several concerns, including those relating to exposure, horizontal contiguity, and the overflow problem, we propose a variation of the MALS forward auction in which prices are offered not only for EA licenses, but also for a prespecified set of packages. For example, the "objects" offered in the auction might be licenses for each EA, for each Major Economic Area (MEA), for each Regional Economic Area Group (REAG), and for the entire United States. Within the fifty states there are 172 EAs, which lie in 48 MEAs, and 8 REAGs. Thus, relative to the original design, the number of objects for sale would expand only marginally.

As with the MALS proposal, clock prices would start low, with bidders expressing their demands at each set of prices. Prices rise on objects with excess demand until reaching a level at which demand no longer exceeds supply. When possible, prices of packages will equal

the sum of the prices of the package components. However, when feasibility constraints and strong demand for packages necessitate, the package price may exceed the sum of component prices. This ensures that package bidders have no advantage or disadvantage relative to bidders seeking individual licenses and encourages straightforward bidding.

We call this proposed design the Clock Package Action ("CPA").[4] It departs only modestly from the original MALS design, but addresses several of our most important concerns. Important to our proposal is that packages are specified as consisting of horizontally frequency-contiguous spectrum.[5] By allowing bidders to make offers for horizontally contiguous packages, the CPA provides a way for bidders to express the substantial complementarities between individual licenses that may be dependent on horizontal frequency contiguity.

To the extent that the offered packages cover the packages of interest to bidders, the CPA also addresses the problem of bidder exposure arising from geographic complementarities. A bidder interested in a package can bid on the package without risk: if the price climbs to a level that exceeds his valuation of the package, he will be free to stop demanding the package and redirect his interest elsewhere. The CPA also avoids the overflow problem by enriching the bidding language in a way that permits accounting for all feasibility constraints when calculating excess demand. Although there is no strict dominance relation between the CPA and the MALS forward auction design in terms of efficiency or revenue, a simulation study suggests that substantial efficiency and revenue gains from using the CPA may be likely.

Re-Offer Unsold Licenses Whatever the design of the forward auction, there is a significant possibility that some cleared licenses will remain unsold. MALS refers to such unsold licenses as "residue." We give several examples in the text below. An important question is

[4] This is distinct from what has sometimes been called the "Package Clock Auction," a version of what we call "Combinatorial Clock Auction" below.

[5] We discuss possible relaxations in the body of our report.

whether unsold licenses should be re-offered by the FCC. This question is less simple than it may initially seem. On one hand, unused licenses are an obvious source of inefficiency, and selling them also generates additional revenues. On the other hand, anticipation of an opportunity to bid for unsold licenses could distort bidding behavior in the primary auction.

Short of using a VCG mechanism for the forward auction (which we do not recommend), we see no way to completely avoid these opposing concerns. However, we believe the scope for distortion of incentives will be limited when only unsold licenses are to be re-offered after the primary clock auction. Incentives for manipulation may be further reduced if the decision whether to re-offer licenses is left to the discretion of the FCC. We therefore recommend that the FCC preserve the option to re-offer unsold licenses. Revenues generated by such sale should be included in the determination of closing conditions.

We recommend use of another clock auction if unsold licenses are re-offered. As long as the Clock Package Auction is used in the primary auction, we believe this will adequately address issues of exposure risk and needs for frequency contiguity. We therefore believe that the supplemental auction could be implemented using the original MALS forward clock auction design.

4.2 Reverse Auction

Single-Pass Reverse Auction An alternative to the sequence of reverse auctions (at declining targets) proposed by MALS is reverse auction conducted in a single pass. The simple idea is that instead of stopping the auction when prices clearing the first provisional clearing target are reached, the auction would continue and trace out the "supply curve" over the range of potential clearing targets.

In our baseline single-pass proposal, the mechanics of the reverse auction would be identical to that of a single reverse auction in the original design. Suppose that the FCC believes that the feasible range of cleared channels per market is between 8 and 16. The auction

would begin at prices sufficient to ensure that 16 channels were cleared, and continue until only 8 licenses per market were being offered by current TV licensees. The FCC would record bidders' choices at every round of the auction, including intra-round bids, for later use. The interaction between forward and reverse auction would be exactly as originally proposed by MALS. The forward auction would begin with an attempt to satisfy the closing conditions for a quantity Q_1 (say, $16 \times 6\text{MHz} = 96\text{MHz}$ in every market, less whatever is set aside for guard bands or other use). Revenues from the forward auction would be compared to the total costs of clearing Q_1, obtained from the reverse auction. If the net revenues fell short, the target would be reduced to Q_2. However, rather than reconvening the reverse auction to establish the (lower) prices for clearing target Q_2, these new prices would simply be taken from the supply curve obtained from the single-pass reverse auction.

From a bidder's perspective, the single-pass auction is nearly identical to one of the reverse auctions under the MALS proposal. Just as with the MALS proposal, a bidder would need to come prepared with one number (a reservation value) for each possible relinquishment option. A bidder's options during the auction would be identical to those under the original proposal, and the rules determining prices paid to bidders for each relinquishment option would be no different. Just as in the original proposal, bidders' choices between relinquishment options would be binding offers.

The single pass option offers several advantages. One is elimination of the need for a new reverse auction each time a clearing target fails. This would simplify participation in the reverse auction. It would also avoid delay: rather than pausing the forward auction to reconvene reverse auction bidders each time the clearing target is adjusted, the forward auction could proceed without interruption.

The single-pass design also simplifies participation of reverse auction bidders in a "two-sided closing trial" and would further allow the FCC to minimize the likelihood of "overshooting" during a closing trial (see below). This could lead to more cleared spectrum.

Another advantage is that bidders would be assured that all broadcaster offers were chosen the same day; unlike the MALS design, here a bidder need not worry that the final offers of different TV stations might be made days or weeks apart.

A slight variation on our proposal is to conduct the single-pass auction using proxy bidding. This idea was suggested in the NPRM and might offer additional benefits. With proxy bidding, each bidder would report his minimum acceptable price for each relinquishment option to a proxy agent (software). The proxy agent would then bid on his behalf in the clock auction, selecting the profit maximizing option for the bidder at each new set of prices. This would be similar to the proxy bidding system on eBay. A potentially important advantage of proxy bidding is that verification of repacking feasibility (and any other underlying optimization subject to repacking constraints) could be performed offline rather than in real time. Depending on the complexity of the feasibility checking problem, offline feasibility checking may allow more complete solutions of this problem, assuring that maximal spectrum is cleared at the lowest possible cost.

Problem-Specific Constrained Optimization The discussion of computational and algorithmic issues in the NPRM lacks critical detail. The most general lesson one should take from research and practical experience with challenging constrained optimization problems is that good solutions are often problem-specific. It is difficult—often impossible—to prescribe efficient algorithms for solutions for very general classes of problems (e.g., integer linear programming problems). However, specific instances of such problems often have special structure that allow known algorithms to perform well, or that permit the design of new algorithms that perform well by tailoring to this special structure. In some cases this can be shown theoretically, while in others this can be demonstrated convincingly through simulation. Because details on the nature of the actual repacking constraints have not been provided, it is impossible to make specific recommendations, or to draw clear lines between

which proposals under consideration present computational problems, and which do not. We recommend that such information be provided so that industry experts can assist in the evaluation of algorithmic issues and their interaction with the design of the reverse auction rules.

4.3 Closing Rules

Two-Sided Closing Trial We propose an alternative that departs modestly from the MALS "one-sided closing trial" proposal but offers potential for substantial improvement in efficiency. The main idea is that all competitors participate when a closing trial is triggered. This would allow all potential owners of spectrum rights to compete, expressing their willingness to improve upon the provisional prices in the forward and reverse clock auctions when necessary to ensure that their desired trades are consummated.

In the baseline version of our proposal, no change to the main forward or reverse auction is needed. However, if the forward auction reaches a point where excess demand is zero but the nationwide net revenue condition fails, all parties would be told that the clearing conditions have failed. Prices would then be raised in the forward auction while lowered in the reverse auction. For example, in a sequence of rounds, prices in the forward auction could rise by a percentage ρ while those in the reverse auction fall at the same rate. Bidders on each side would express demand/supply at the clock prices, just as in the original forward and reverse auctions. Prices would continue to adjust until either the net revenue condition is satisfied or prices reach a point at which demand falls short of supply.

The advantage of this approach is that it provides both forward and reverse auction bidders the opportunity to express their willingness to accept less favorable prices to ensure that their trades are executed. This can lead to more efficient allocation of spectrum and to outcomes that are preferred by participants in both the forward and reverse markets.

The use of the single-pass reverse auction would allow significant additional efficiency

gains in a two-sided closing trial. This is because a remaining source of potential inefficiency is the miscoordination of the forward and reverse price clocks, which could lead to *overshooting* on one side of the market during a closing trial. The spirit of including reverse auction bidders in the closing trial is that both sides may have some "slack" in the sense that they are willing to accept somewhat less favorable prices if necessary. But it is impossible for the FCC to know which side (or more generally, which bidders) has more slack and, therefore, how quickly to adjust one price relative to another. This leads to the possibility that the clock overshoots valuations on one side before allowing bidders on the opposite side to express their full willingness to adjust the provisional prices. In some cases this could cause a two-sided closing trial to fail when a one-sided trial would have succeeded. With the single-pass reverse auction, much of this inefficiency can be avoided, since the FCC would know the prices at which the clocks would overshoot the valuations of reverse auction bidders. Overshooting on the supply side can be avoided completely, and further adjustments (discussed below) can minimize overshooting on the demand side as well.

5 Conclusion

The FCC and their advisors have developed an ambitious proposal making substantial progress toward design of the incentive auctions. We believe this proposal is an excellent starting point for discussion. Although we see several significant shortcomings, we believe these can be addressed through relatively modest alterations to the MALS design. We have sketched our concerns and proposals above. Below we provide a more extensive discussion of these ideas and others.

Part II

Forward Auction

The purpose of the forward auction is twofold. First, it provides a way for mobile wireless providers to reveal the value they place on spectrum currently allocated for broadcast television use. This is important for assessing how much spectrum has its highest value use in broadcast television vs. mobile wireless service. Second, the forward auction provides a method of determining allocations among mobile wireless providers, and the payments they will make to the FCC. Although the FCC has conducted auctions of spectrum in the past, those auctions served only the second purpose. The interaction between potential buyers (in the forward market) and potential sellers (in the reverse market) is new. In addition, the FCC and its experts seek to take advantage of experience in prior auctions and recent developments in market design.

6 The NPRM and MALS Proposals

6.1 Clock Auction

In the forward clock auction proposed by MALS, the FCC would simultaneously offer licenses in each EA. There will typically be more than one class of license available in each market; e.g., licenses for 10MHz of "paired" spectrum (5 MHz for wireless uplink, 5MHz for downlink), and licenses for 5MHz of unpaired (downlink only) spectrum.[6] Licenses for different combinations of EA and class are treated as distinct *objects* and will have different clocks. Multiple *units* of each object, corresponding to specific frequencies, will typically be

[6] The proposed building block for the forward auction licenses is a 5MHz license. This contrasts with the 6MHz licenses for broadcast television that will be obtained from the reverse auction.

available. However, all units of the same object are treated as generic. At the beginning of the auction, all objects are given low initial (reserve) prices by the FCC. Potential buyers respond to these prices by specifying the number of units of each object that they would wish to purchase at these prices. Prices for objects with excess demand (demand that exceeds the available supply) then rise, and bidders indicate their demands at these new prices. This process continues until the quantity of spectrum demanded in each market is no larger than the associated target quantity. Thus, the forward auction stops at prices just high enough to eliminate excess demand relative to the target quantities.

6.2 SMR Auction

As an alternative, the NPRM mentions the possibility of a Simultaneous Multiround (SMR) ascending auction. The SMR has been used in prior FCC spectrum auctions. In an SMR auction, the FCC would separately identify each license by geography and frequency (there is no generic treatment of licenses). Bidders make price bids on any subset of these specific licenses they desire. The auction proceeds in a sequence of rounds, with prices constrained to move only higher. After each round, the FCC declares a provisional winner for every license. Bidding for all licenses remains open as long as there is bidding activity on any license. The provisional winners become final winners only when bidding activity ceases on all licenses. This feature facilitates aggregation of licenses, but does so most effectively when the bidders regard alternative licenses as substitutes rather than complements.

Although the SMR has a number of virtues, it has a number of significant limitations as well. In an SMR auction bidders must choose which particular license to bid on and how much to raise the current standing bids. This introduces many possible strategies for achieving the same goal, as well as ambiguity in interpreting the behavior of competitors. This inhibits price discovery. Indeed, in early rounds bidders may intentionally "park" their demand on licenses they do not want in order to hide their intentions and inhibit price

discovery. The SMR is also inadequate for guaranteeing efficient aggregation when bidders regard alternative licenses as complements, as will be the case whenever a bidder seeks to assemble a group of licenses covering a region larger than a single EA. Because the bidders make offers for specific frequency blocks in the SMR, a hold out problem can arise: a small bidder can easily win a license that makes it impossible for another bidder to obtain multiple licenses with frequency contiguity. Even worse, a speculator may target such a license for the purpose of reselling for a high price in the resale market (e.g., Pagnozzi (2010)). In this sense, SMR does little to guarantee efficient aggregation and vertical contiguity. Bidders may also attempt to signal or coordinate through bids. Further, the fact that provisional winning bids are identified in each round makes this auction format susceptible to collusion. By contrast, the proposed clock auction eliminates the problem of holdout and enables the FCC to guarantee within-region contiguity. The clock design appears to be less susceptible to collusion.

In what follows we focus on the clock auction proposed by MALS. We believe this is a superior starting point for the forward auction design.

7 Primary Concerns

7.1 Exposure Risk

Our most serious concern with the proposed forward auction design is its treatment of complementarities between licenses. Such complementarities will exist for any bidder who will wish to assemble coverage over regions larger than a single EA. This may be the vast majority of forward auction bidders. The clock auction design allows bidders to pursue packages of licenses, but only by offering to buy each individual license that is part of the desired package. This introduces a substantial exposure risk for bidders.

This risk is especially severe if, as the auction proceeds, each bidder is permitted to

reduce his quantity demanded only for objects whose prices have risen. We believe this is the intended policy in the MALS proposal.[7] However, this rule creates severe exposure risk for bidders whose valuations exhibit complementarities. This point has been emphasized, for example, by Ausubel, Cramton, and Milgrom (2006). We view the proposed rules as creating unacceptable exposure risk to forward auction bidders. This will inhibit efficient aggregation of licenses and lead to conservative bidding, inefficient spectrum allocations, and low revenues. The revenue implications are especially problematic here, due to the role of the net revenue requirement. Unlike prior FCC auctions, issues of revenue and efficiency cannot be separated: low revenues will lead to inefficiently low quantities of spectrum cleared. Further, even ignoring the role of revenues, both large bidders and small bidders (those not themselves subject to exposure risk) can be harmed by the exposure problem. An example illustrates.

Example 1. *Suppose there are 2 licenses, A and B, and three bidders. Bidders' valuations*

$$\begin{aligned} v_1 &= (6, 0, 6) \\ v_2 &= (0, 10, 10) \\ v_3 &= (5, 5, 10 + \beta) \end{aligned}$$

where, for example, bidder 1*'s valuation vector* v_1 *indicates a value of* 6 *for license A alone,* 0 *for license B alone, and* 6 *for the pair. Bidder 3 places positive value on both license, and obtains a complementarity "bonus" of* $\beta > 0$ *if he obtains both, so that his valuation of the pair is* $5 + 5 + \beta$*. Begin with* $\beta = 5$*. In this case the efficient allocation gives license A*

[7] An alternative would be to permit a bidder to reduce his quantity demanded on any license as long as the price rises for some licenses he previously demanded. In the absence of concerns for frequency contiguity (see section 7.2 below), this alternative would avoid the exposure risk arising from geographic complementarities: a bidder interested in a package of licenses could exit the auction if that package becomes expensive, even if that is due to an increase in the price of only one component EA license. However this alternative rule would weaken incentives for straightforward bidding and could lead to substantial undersell.

to bidder 1 and license B to bidder 2. Suppose that bidders use ***straightforward bidding*** *strategies, i.e., at every set of clock prices, each bidder chooses the demand that would yield him the largest profit if the current clock prices turned out to be the final prices. In this case the auction would proceed as follows*[8]

p_A	p_B	*demand*
1	1	A,B,A+B
2	2	"
⋮	⋮	"
6	6	0,B,A+B
6	7	"
⋮	⋮	"
6	10	0,0,A+B

Note that once p_B reaches 9, bidder 3 would like to exit the auction altogether. However, because the auction rules forbid this (only the price of B is rising), the combination A+B is the most profitable demand he is permitted to express. The resulting outcome is bad from all bidders' perspectives: bidder 3 makes a loss; bidders 1 and 2, who should have obtained licenses, obtain nothing.

We might expect bidder 3 to avoid the exposure risk by bidding more conservatively. Suppose he follows a ***conservative straightforward bidding*** *strategy: he uses a straightforward bidding strategy except that he refuses to demand any good whose price exceeds his stand-alone valuation for the good. With such a strategy, the value of β becomes irrelevant to the auction*

[8] In our examples we assume arbitrarily small bid increments, denoted by ϵ when necessary. We show only key "rounds" of the clock auction, listing prices in that round and the demands expressed at those prices. The list of demands in each row of the "demand" column show the objects demanded, with commas separating the demands of each bidder. We write "A+B" to indicate demand for a unit of A and a unit of B.

outcome. The auction will proceeds as follows,

p_A	p_B	*demand*
1	*1*	*A,B,A+B*
2	*2*	*"*
$\vdots$	$\vdots$	*"*
5	*5*	*A,B,0*

Now bidder 3 avoids the exposure problem. Revenues are substantially lower, which may lead to failure of the net revenue requirement. Otherwise, whether the auction allocation is efficient depends on whether efficiency is helped or harmed by eliminating bidder 3 from competition. For small β this is efficient; for $\beta > 6$ it is not.

7.2 Frequency Contiguity

A second major concern is that the NPRM and MALS proposals do not make adequate provisions for bidders to obtain contiguous blocks of spectrum. Two types of frequency contiguity are important. First, within a geographic area, wireless service providers seeking to offer LTE or LTE-Advanced services desire significant blocks of spectrum in adjacent frequencies. We understand that such *vertical contiguity* is essential to optimal performance of these technologies. Second, bidders seeking coverage areas encompassing multiple EAs desire licenses in identical frequencies in each EA. We understand that such *horizontal contiguity* minimizes interference at boundaries and allows use of more efficient network deployment.

The current proposals for assigning individual licenses to winners of generic licenses in each EA may address the need for vertical contiguity within a single EA. But they would not allow bidders to express their broader needs for frequency contiguity.

The MALS proposal suggests the use of a random priority rule for assigning particular

frequencies to winners of the clock auction. The NPRM mentions the possible use of a bidding mechanism for assignment. The currently envisioned version of the random priority rule is problematic if bidders care about horizontal contiguity. Assuming that the generic auction is held for each EA, a random priority rule would work as follows: 1) Each winner rank-orders all possible sets of frequency blocks that equal to the number of licenses he won in the clock auction. 2) The FCC randomly orders all the winners. 3) The winner first on the list is assigned his most preferred blocks; the second on the list is assigned his most preferred block of those remaining, and so on. This procedure will generate inefficient allocations when bidders value horizontal contiguity. This can be illustrated by a simple example.

Example 2. *Suppose there are two EAs, EA_1 and EA_2, and suppose each EA_i has three frequency blocks: A_i, B_i, C_i for $i = 1, 2$. Assume that in the reverse auction all three blocks are cleared in EA_1. In EA_2, only two of them are cleared. Suppose there are three bidders, 1, 2, 3 in the forward auction. Bidder 1 and bidder 2 each won 1 license in each EA, whereas bidder 3 won only one license in EA_1 in the forward generic auction. Suppose 1 and 2 rank: $A_i - B_i - C_i$ in that order in each EA_i, for $i = 1, 2$. And suppose 3 ranks: $C_1 - B_1 - A_1$. Then, bidder 3 gets C_1 in EA_1, but 1 and 2 get (A_1A_2, B_1B_2), (A_1B_2, B_1A_2), (B_1A_2, A_1B_2), (B_1B_2, A_1A_2) with equal probability, 1/4. If it is more valuable for a bidder to win the same frequency block across the EAs, this outcome is inefficient.*

Further, there is no dominant strategy for bidders in the random assignment phase. To illustrate, return to the example and suppose winning A_1A_2 is not much more valuable than winning B_1B_2. It is an equilibrium for 1 to rank $A_i - B_i - C_i$ in each EA $i = 1, 2$ and for 2 to rank $B_i - A_i - C_i$ in each EA_i, $i = 1, 2$. This leads to an efficient assignment of (A_1A_2, B_1B_2, C_1) for bidders 1, 2, and 3, with probability one. While this may suggest that bidders may be able to coordinate on an efficient outcome in equilibrium, in practice such coordination may be difficult to achieve. The lack of strategy-proofness is a drawback. Of

course, if both 1 and 2 value A_1A_2 sufficiently more than B_1B_2, then the above inefficient allocation will be the unique equilibrium.

7.3 The Overflow Problem

The MALS forward auction provides no language for bidders to express whether their demand for a particular license is driven by interest in a larger group of licenses. Without such language, bidders seeking small groups of licenses can face rising prices even when their own demands are not a source of scarcity, leading to bias against small bidders and inefficient allocations.

An example will illustrate the problem. Consider the Boston MEA, which includes the Bangor, Portland, and Boston EAs. Suppose that six 10MHz paired licenses are available in Bangor and Portland, but only five in the Boston EA. This implies that at most five bidders could obtain MEA-wide coverage. Suppose that at some point in the auction "regional bidders" seeking MEA-wide coverage (or coverage in a larger area that includes the MEA) are demanding seven licenses, while there is only one Portland EA license demanded by a firm seeking coverage in Portland alone. Suppose the regional bidders have an all-or-nothing strategy in this MEA: they are not interested in any strict subset of the 3 EAs. In such a situation, we would like the auction to "hold on" to the offer of the Portland-only bidder: we know that only five units of demand from the regional bidders can be satisfied. So selling all licenses requires allocating to the Portland-only bidder. However, under the MALS design, the auction will count eight units of demand for the Portland license, conclude that this license is in excess demand, and raise its price. This will force the Portland-only bidder to either pay a higher price or exit, even though his demand is not a source of scarcity. This will tend to force such a bidder out of the market unnecessarily.

We term this phenomenon the *overflow problem*. With a richer bidding language, the auction design could account for feasibility constraints and limit the extent to which demand

for large packages "flows down" to be counted as demand for the smaller packages and individual licenses nested in the larger package. Without such a language, too much demand flows down. This creates artificial competition for smaller bidders. This bias against smaller bidders will lead to undersell and/or inefficient allocations of licenses.

Within the simple clock auction design proposed by MALS, we see no easy fix. Indeed there is a tension between avoiding the inefficiency introduced by the exposure problem and avoiding those introduced by the overflow problem. The following example illustrates.

Example 3. *Suppose there are two markets, with two licenses available in market A but only one license in market B. Suppose there are six bidders with valuations for A, B, and the pair A+B given by*

$$\begin{aligned} v_1 &= (1,0,1) \\ v_2 &= (3,0,3) \\ v_3 &= (0,6,6) \\ v_4 &= (0,8,8) \\ v_5 &= (2,3,7) \\ v_6 &= (3,5,12). \end{aligned}$$

This type of configuration is highly plausible: markets in which less spectrum can be cleared will tend to be those where licenses are more valuable. The unequal clearing across markets limits the feasible supply of the "package" AB desired by bidders 5 and 6 to one unit. The efficient allocation involves assigning 1 unit of each object to bidder 6, and the remaining unit of object A to bidder 2.

Under the MALS proposal we may expect bidders 5 and 6 to bid cautiously to avoid the

exposure problem. If bidders use conservative straightforward bidding strategies, the auction will proceed as follows:

p_A	p_B	*demand*
1	1	0,A,B,B,A+B,A+B
2	2	0,A,B,B,A+B,A+B
2+ϵ	2+ϵ	0,A,B,B,B,A+B
2+ϵ	3	0,A,B,B,0,A+B
$\vdots$	$\vdots$	$\vdots$
2+ϵ	5+ϵ	0,A,B,B,0,A
2+ϵ	6	0,A,0,B,0,A

The allocation is inefficient. Further, the magnitude of this inefficiency can be made arbitrarily large by changing bidder 6's package valuation.

We might hope that package bidders would bid less cautiously, so that the implications of exposure risk are not so dire. If they do, this will introduce the overflow problem. Supposing that all bidders follow straightforward bidding strategies, the auction will proceed as follows:

p_A	p_B	*demand*
1	1	0,A,B,B,A+B,A+B
2	2	0,A,B,B,A+B,A+B
3	3	0,0,B,B,A+B,A+B
3	4	0,0,B,B,A,A+B
3	5	"
3	6	0,0,0,B,A,A+B
3	7	"
3	8	0,0,0,0,A,A+B

Revenue is higher but the allocation is still inefficient. This time the inefficiency is due to the overflow problem. Although only one A+B pair is feasible, bids by the package bidders drive bidder 2 out of the market, leading to misallocation of one of the market A licenses. This is undesirable, but the MALS auction design does not allow for any distinction between demand for A alone and demand for A as part of the AB package. In addition to the misallocation, bidder 5 falls prey to the exposure risk he ignored and is forced to pay more than his valuation for the license he wins.

7.4 Other Sources of Inefficiency

Nonexistence of Market Clearing Prices

As pointed out by Ausubel and Milgrom (2002), market clearing prices need not exist when some licenses are complements. Suppose for example that there are two licenses (A and B) available and two bidders with valuations

$$\begin{aligned} v_1 &= (4, 5, 15) \\ v_2 &= (7, 9, 9)\,. \end{aligned}$$

Here bidder 1 obtains a significant complementarity when obtaining both licenses, whereas bidder 2 does not. The efficient allocation gives both licenses to bidder 1. For a pair of prices (p_A, p_B) to yield no demand from bidder 2 requires $p_A \geq 7$, $p_B \geq 9$. But at such prices bidder 1 demands no licenses. In the MALS auction, with conservative straightforward

bidding, the auction will proceed as follows:[9]

p_A	p_B	demand
1	1	A+B,B
1	1+ϵ	A+B,B
$\vdots$	$\vdots$	$\vdots$
1	3	A+B,A
1+ϵ	3	A+B,B
1+ϵ	3+ϵ	A+B,A
$\vdots$	$\vdots$	"
3	5	A+B,A
3+ϵ	5	A+B,B
3+ϵ	5+ϵ	A,A
3+2ϵ	5+ϵ	A,B

The allocation is inefficient, and revenues are low relative to the surplus available. With straightforward bidding, the allocation would be worse, with one of the two licenses failing to sell.

We emphasize that the potential lack of market clearing prices is a limitation not just of a clock auction, but of any mechanism in which the same prices are offered to all potential buyers. Anonymity of prices is an attractive feature and may be essential if bidders are to view the auction as fair. However, this feature may lead to some inefficiency, sometimes in the form of undersell.

[9] We assume bidders resolve indifferences between licenses by choosing A. This has no effect on the final allocation and an arbitrarily small effect on revenue.

Miscoordination of Price Clocks

Synchronization of price clocks can be important in any clock auction. A simple example illustrates.

Example 4. *Suppose there are two licenses available, A and B. There three bidders with valuations*

$$\begin{aligned} v_1 &= (5, 0, 5) \\ v_2 &= (0, 9, 9) \\ v_3 &= (3, 6, 12) \end{aligned}$$

where, for example, bidder 3 places value 3 on license A alone, 6 on license B alone, and 12 on the "package" AB. Here the efficient allocation excludes bidder 3. Depending on the synchronization of clocks, the MALS auction could proceed as follows under straightforward bidding:

p_A	p_B	*demand*
1	1	A,B,A+B
⋮	⋮	″
5	5	0,B,A+B
5	⋮	0,B,A+B
5	7	0,B,A+B
5	8	0,B,A+B
5	9	0,B,A

The allocation is inefficient (and bidder 3 faces a loss).[10]

[10]Note that bidder 3 would like to exit the auction entirely at the prices (5,7) but is not permitted to, since only p_B is rising at this point. The most profitable option available to bidder 3 at this point is to continue demanding A+B.

However, if the clocks moved at different speeds (that for B moving twice as fast), efficiency could be achieved with straightforward bidding:

p_A	p_B	*demand*
1	*2*	*A,B,A+B*
2	*4*	*"*
3	*6*	*"*
4	*8*	*A,B,0*

This gives the efficient allocation.[11]

Of course, optimal coordination of clocks depends on the realized valuations and the strategies used by bidders. Perfect synchronization is therefore infeasible. Inefficiency may arise no matter how the price clocks are controlled. However, there may be general principles for synchronization of clocks that can enhance efficiency. For example, clock speeds might be calibrated based on expected final prices, perhaps based on prices in prior FCC spectrum auctions. This issue should be investigated further.

8 Clock Package Auction

MALS mentions the possibility of adding packages to the forward auction. Two ideas are suggested: holding a full Combinatorial Clock Auction ("CCA") as explored in Ausubel, Cramton, and Milgrom (2006), or adding a limited number of packages to the clock auction. We prefer the latter.

The key elements of the CCA are a clock phase used for price discovery, followed by a sealed bid phase that determines winners. We refer readers to Ausubel, Cramton, and

[11] With conservative straightforward bidding, both clock speeds yield the efficient allocation.

Milgrom (2006) and Cramton (2012) for details. Although the CCA has a number of attractive features, it has several others we view as problematic for the FCC forward auction. One concern is the fact that all licenses remain "up for grabs" at the end of the clock auction, with winners not determined until after a sealed bid phase. A second is that the "VCG-nearest core" pricing rule used for the critical sealed-bid phase is opaque, making it difficult for bidders to understand the strategic environment they face. Finally, we are uncertain what effect the sealed bid phase might have on bidding behavior in the clock phase of the auction, particularly given the substantial complementarities between licenses. In the worst case this might lead to poor price discovery, substantial uncertainty for bidders, low revenues, and inefficiently low quantities of spectrum cleared.

We believe that substantial gains can be obtained following the simpler option of adding packages to the clock auction. Here we provide a detailed proposal for doing so, using a simple hierarchical structure to define the set of packages offered. We propose offering packages that cover each Major Economic Area (MEA), each Regional Economic Area Group (REAG), as well as the entire nation. This particular choice is not essential, and our formal description below incorporates the possibility of other "multi-tree" structures. But the EA-MEA-REAG-nationwide structure is natural, and we believe it would capture most of the significant geographical complementarities between licenses.

The introduction of packages to the clock auction is motivated by the issues of exposure risk, need for horizontal contiguity, and the overflow problem, all discussed above. Each is a problem that, if left unaddressed, could lead to inefficient allocations of cleared spectrum, low revenue, and inefficient reduction in the quantity of spectrum traded in the combined forward and reverse auctions. The inclusion of packages in the forward clock auction can address all three issues.

Before proceeding with the details, we emphasize that our proposal

- involves a very modest change to the original proposal;
- does not introduce significant complexity to the auction from the perspective of bidders or the FCC;
- does not set aside any spectrum for packages;
- does not require equalized clearing of spectrum across markets;
- results in no thinning of competition for any license;
- creates no advantage (or disadvantage) for package bidders;
- will not lead to violation of the property that identical licenses sell for identical prices, except when feasibility constraints and excess demand for packages requires superadditive package prices;
- does not appear to introduce new opportunities for undesirable strategic bidding behavior.

8.1 Objects for Sale

As with the original MALS clock auction, the auction is a multi-*unit* multi-*object* auction. An *object* is class of generic license covering a particular geographic area. Typically there will be more than one license of each such class, i.e., more than one *unit* of each object.

For simplicity we assume here that all licenses covering a particular geography are generic. Our proposal easily extends to allow multiple mutually exclusive classes of licenses (e.g., paired vs. unpaired) that are generic within each class. Objects are then defined by their geographic coverage. The elementary geographic building block is the EA. A package object

is a collection of single-EA objects; for example, an MEA license for Philadelphia consists of one EA license in each of the three EAs comprising this MEA .

Let $\mathcal{E}$ denote the set of EAs and $\mathcal{S}$ the set of packages offered. Then

$$\mathcal{O} = \mathcal{E} \cup \mathcal{S}$$

represents the set of objects for sale. Complexity considerations dictate that $\mathcal{O}$ not include all possible subsets of $\mathcal{E}$. Rather, $\mathcal{S}$ should include the packages of greatest importance to bidders. We will assume that $\mathcal{S}$ is chosen so that $\mathcal{O}$ can be placed in a hierarchical structure defined below.

A notion of (sufficient) horizontal contiguity is defined in advance. All objects are specified as consisting of horizontally contiguous allocations of spectrum.[12] No spectrum is set aside for package licenses. Competition in the auction (and feasibility constraints) will determine how much spectrum, if any, is to be allocated to package licenses.

8.2 Hierarchical Structure

For objects k and j in $\mathcal{O}$, we write $k \subset j$ (equivalently, $j \supset k$) if the set of EAs included in object k is a strict subset of those included in j. When $k \subset j$ we will say that j *contains* k. We will say that object j is a *parent* of object k (equivalently, k is a *child* of j) if both (i) $k \subset j$ and (ii) $\nexists \ell \in \mathcal{O}$ such that $k \subset \ell \subset j$. An object may have no parent, one parent, or multiple parents. Let π_j denote the set of j's parents and let χ_j denote the set of j's children.

We represent the parent-child relationships with a directed graph Γ containing one vertex for each object $j \in \mathcal{O}$. For $j, k \in \mathcal{O}$, Γ has a directed edge from j to k if j is a parent of k.

[12] Alternatively, smaller packages (say, MEAs and REAGs) could be specified with a guarantee of horizontal contiguity, with larger packages (say, a national package) coming only with the promise of contiguity when possible.

Figure 1 illustrates with a simple example in which seven objects are for sale: one for each of four EAs, one for each of two MEAs, and one for the "nation" as a whole.

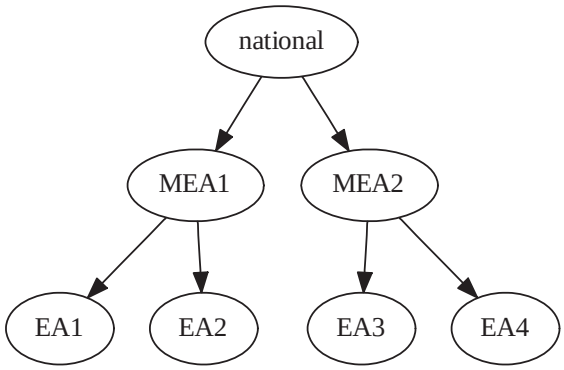


Figure 1: A simple multitree structure.

Because the parent-child relationship is defined based on strict subsets, there can be no directed cycles in Γ. We will further require that Γ be a *multitree,* i.e., that there be at most one undirected path between any two vertices in Γ.[13] The structure in Figure 1 satisfies this restriction. Another example is given in Figure 2, where Regional Economic Area Groups (REAGs) are included as well. Both examples generate a *tree* structure for Γ, which is a special case of a multitree. Another possible multitree structure is one identical

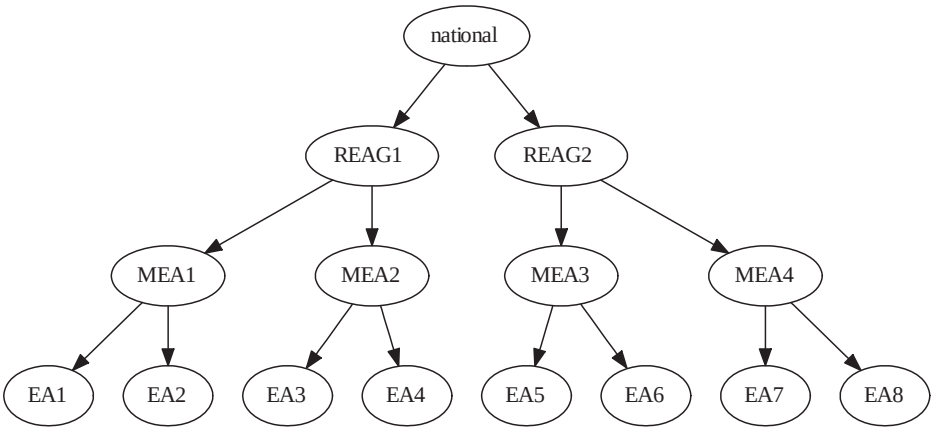


Figure 2: A larger multitree structure.

[13]Equivalently, the set of vertices reachable from any given vertex forms a tree.

to that in Figure 2, but without the national license. For the forward auction, the multitree structure is likely to cover the types of packages needed. As shown below, a key feature of the multitree structure is a lack of ambiguity about which objects are in excess demand.[14]

Each object can be assigned to a unique *tier* in Γ. This assignment can be constructed iteratively as follows: objects which are single-EA licenses are assigned to tier 1; parents of tier-1 objects are assigned to tier 2; parents of tier-2 objects to tier 3; etc. Let $\tau^{\max}$ denote the maximum non-empty tier. In the prior examples the assignments to tiers are simple: for example, tier 1 corresponds to the EA objects, with tier $\tau^{\max}$ corresponding to the national object.

8.3 Overview of the Clock Package Auction

The auction includes price clocks for each object. Initial (reserve) prices $p_k^{\min}$ are set for each EA license. Reserve prices for packages are additive:

$$p_j^{\min} = \sum_{\substack{k \in \mathcal{E}: \\ k \subset j}} p_k^{\min}. \tag{1}$$

The auction begins at these prices and proceeds through multiple rounds with progressively higher prices. In each round, bidders express nonnegative integer quantities demanded for each object at the current clock prices. Bidders' expressed demands are binding offers. A bidder expressing positive demand for multiple objects is agreeing to purchase all of those objects if the auction ends at the current prices. Prices continue to rise until there is no excess demand (defined below) for any object, at which point the auction terminates. As

[14] It may be useful to consider an example of a structure that violates the multitree restriction. Let there be three EAs: A,B, and C, and suppose the packages offered are AB,BC, and ABC. The graph of this structure is not a multitree because there are two directed paths from ABC to B. This could be accommodated (imperfectly) in our design by defining only one of the packages AB or BC to be a child of ABC, yielding a modified graph that is a multitree. The choice of the child would be arbitrary and could affect the outcome of the auction. Further, the CPA avoids the overflow problem entirely when Γ is a multitree, but only partially when Γ must be modified to obtain a multitree.

suggested in the MALS proposal, intra-round bidding can be used to minimize overshooting due to discrete price increments.

8.4 Feasible Supply and Feasible Allocations

For each $j \in \mathcal{O}$, let q_j^f denote the *feasible supply* of object j. This is the maximum number of units of the object that could be allocated. For objects consisting of a single EA license, this is just the number of available licenses in that EA. Because every package object is a collection of smaller objects, the feasible supply of a package object will be limited by the minimum feasible supply among its components (i.e., its children). In particular, for any object j such that $\chi_j \neq \emptyset$,

$$q_j^f \leq \min_{k \in \chi_j} q_k^f.$$

With package licenses specified as horizontally contiguous, the feasibility of horizontal contiguity might further constrain the feasible supply, yielding a strict inequality.

The set of quantities $\{q_j\}_{j \in \mathcal{O}}$ is a *feasible allocation* if for all $k \in \mathcal{O}$,

$$q_k + \sum_{\ell \supset k} q_\ell \leq q_k^f. \tag{2}$$

Typically the set $\left\{q_j^f\right\}_{j \in \mathcal{O}}$ will not be a feasible allocation.

Example 5. *Suppose there are 4 EAs, labeled A,B, C, and D. Let $\mathcal{O}$ be comprised of the singleton EA objects, two regional objects AB, CD, and a national object ABCD. Suppose sufficient spectrum has been cleared to allow allocation of up to 3 licenses in EAs A,B, and*

C but only 2 licenses in EA D. If there are no other feasibility constraints, we have

$$
\begin{aligned}
q_A^f &= 3 \\
q_B^f &= 3 \\
q_C^f &= 3 \\
q_D^f &= 2 \\
q_{AB}^f &= 3 \\
q_{CD}^f &= 2 \\
q_{ABCD}^f &= 2
\end{aligned}
$$

An example of a feasible allocation is

$$
\begin{aligned}
q_A &= 1 \\
q_B &= 1 \\
q_C &= 2 \\
q_D &= 1 \\
q_{AB} &= 1 \\
q_{CD} &= 0 \\
q_{ABCD} &= 1.
\end{aligned}
$$

This feasible allocation also utilizes all the available licenses.

To avoid incentives for manipulation, we require that the expressed demand of a bidder at any price be a feasible allocation.[15] This constraint is easily imposed: if quantities $\left\{q_{ij}^d\right\}_{j\in\mathcal{O}}$

[15] Demands for infeasible allocations cannot be filled. Thus, attempts to distort the outcome of the auction with such bids have no cost. The same concern would arise in the MALS auction, where ruling out demands for infeasible allocations is also simple.

are demanded by a bidder i, the auction interface can verify that

$$q_{ij}^d + \sum_{k \supset j} q_{ik}^d \leq q_j^f \quad \forall j \tag{3}$$

before entering the bid, asking the bidder for a corrected demand vector if (3) is violated.

8.5 Total Demand, Excess Demand

Critical to the forward clock auction is the determination of which objects are in excess demand at a given set of prices. Without packages this is simple: the total number of units of an object demanded is compared to the total number of units available. With packages, we must account for the fact that demand for a package implies demand for the objects contained in the package. With the multitree structure this is straightforward. Further, because bidders express demand for package objects separately from demand for smaller objects, we can now avoid the overflow problem (see section 7.3).

Begin by defining the *first-order demand* for object j to be the quantity demanded of the object alone at the current prices. For example, first-order demand for an EA license is the quantity of this license demanded alone (not as part of a package object). Let $d_j^1(p)$ denote the first-order demand for object j.

Object j's *second-order demand,* denoted $d_j^2(p)$, and *total demand*, denoted $d_j^T(p)$ are then defined iteratively. Second-order demand for an object j represents the demand for j embedded in the feasible demand for objects that include j. Total demand for j is simply the sum of the first-order and second-order demand. The iterative definition starts from the top (tier $\tau^{\max}$) of the graph Γ and proceeds down. For each object j in tier $\tau^{\max}$ let

$d_j^T(p) = d_j^1(p)$. We then proceed to tier $\tau^{\max} - 1$. For each object j in this tier, let

$$d_j^2(p) = \sum_{k \in \pi_j} \min\left\{q_k^f, d_k^T(p)\right\} \tag{4}$$

$$d_j^T(p) = d_j^1(p) + d_j^2(p). \tag{5}$$

We take the minimum of q_k^f and $d_k^T(p)$ in (4) to account for the fact that in some cases not all demand for a parent can flow to its children, due to feasibility constraints. For example, in Example 5 above, at most two units of demand for the package CD would ever be counted as demand for C.[16] This process continues through tier 1, applying equations (4) and (5) at each tier.

Finally, object j has *excess demand* at prices p if total demand for j exceeds its feasible supply, i.e., if

$$d_j^T(p) > q_j^f.$$

8.6 Price Clocks

If no object has excess demand at the current clock prices, the clock auction terminates. Otherwise prices rise for all objects that (i) have excess demand or (ii) contain objects with excess demand. For specificity only, we assume bid increments are specified as a constant percentage increase.

Whereas the determination of total demand works from the top down in the graph Γ, determination of new clock prices works from the bottom up. Let p_j denote the current price of an object j; the new price p_j' is to be determined. For each tier-1 object j such that $d_j^T(p) > q_j^f$, the price will be incremented to $p_j' = (1+\delta)\, p_j$. Moving then to tier 2, the price of an object j in this tier will be incremented if either

[16] One way to represent this is to assign capacities to the edges in the graph Γ. The edge from j to any child $k \in \chi_j$ would have capacity q_j^f. The maximum demand that can flow down from parent to child is determined by the capacity of the relevant edge.

(a) the price of some object $k \in \chi_j$ has already been incremented; or

(b) $d_j^T(p) > q_j^f$.

If condition (a) holds,

$$p'_j = \max\left\{p_j, \sum_{k \in \chi_j} p'_k\right\}$$

regardless of whether condition (b) also holds.[17] If only condition (b) applies—i.e., if $p'_k = p_k$ for all $k \in \chi_j$, but there is excess demand for j—the new price is $p'_j = (1+\delta)\, p_j$. Only in this latter case is the price of a package *not* additive in the prices of its components (children).

This process continues through each of the higher tiers until all price adjustments have been determined. The new prices are then offered to bidders in the next round. As in the MALS proposal, bidders would be allowed to reduce the quantity they demand only for objects whose prices have risen.

8.7 Examples

Example 6 (Elimination of Exposure Risk). *Our first example illustrates the elimination of the exposure problem when the clock package auction is used and $\mathcal{O}$ includes all packages relevant to bidders. Let there be two markets, A and B, with two identical licenses*

[17] Alternatively, the price increment could be made larger if both conditions hold. Whether this aids efficiency is ambiguous in general under straightforward bidding (recall our discussion of clock synchronization). However, we believe that minimizing deviations from additive package price is desirable for encouraging straightforward bidding, as a bidder will know that he cannot slow down the rise in a package price by withholding demand for the package until later rounds and bidding instead on its components in early rounds.

available in each. There are five bidders with valuations

$$\begin{aligned} v_1 &= (5,0,5) \\ v_2 &= (4,0,4) \\ v_3 &= (0,5,5) \\ v_4 &= (0,4,4) \\ v_5 &= (3,3,11). \end{aligned}$$

Here the CPA proceeds under straightforward bidding as follows:

p_A	p_B	p_{AB}	*demand*
1	*1*	*2*	*A,A,B,B,AB*
2	*2*	*4*	*"*
3	*3*	*6*	*"*
4	*4*	*8*	*A,0,B,0,AB*

This yields the efficient allocation. Compare this to what may arise without including packages in the auction. Suppose the clock auction proposed by MALS were held. If bidder 4 avoids the exposure problem by adopting a conservative straightforward bidding strategy, that auction would proceed as follows:

p_A	p_B	*demand*
1	*1*	*A,A,B,B,A+B*
2	*2*	*"*
$\vdots$	$\vdots$	*"*
$3+\epsilon$	$3+\epsilon$	*A,A,B,B,0*

All units sell, but the exposure problem leads to inefficiency and low revenue: total revenue is 25 percent lower and total surplus (ignoring the potential adverse effect of revenue losses on closing conditions) is 14 percent lower.

Example 7 (Elimination of the Overflow Problem). *Return now to Example 3 (page 29). Previously we saw that the MALS auction design leads to inefficiency and/or undersell and there was a tension between addressing the needs of large bidders (facing the exposure problem) and those of small bidders (facing the overflow problem). Adding package clocks to the auction eliminates both problems. With the same setup considered in Example 3, the CPA would proceed as follows:*

p_A	p_B	p_{AB}	*demand*
1	1	2	0,A,B,B,AB,AB
1	2	3	"
⋮	⋮	⋮	"
1	5+ϵ	6+ϵ	0,A,B,B,A,AB
1+ϵ	5+2ϵ	6+3ϵ	"
2-ϵ	6	8-ϵ	0,A,0,B,A,AB
2	6+ϵ	8+ϵ	0,A,0,B,0,AB
2	7	9	"
2	8	10	0,A,0,0,0,AB

This yields the efficient allocation. Notice that the price of object A pauses once the sum of its first-order demand and the feasible second-order demand falls to 2 units (in the first

round displayed). At this point

$$\begin{aligned} d_A^T &= d_A^1 + \min\left\{q_{AB}^f, d_{AB}^T\right\} \\ &= 1 + \min\{1, 2\} \\ &= 2 \\ &= q_A^f. \end{aligned}$$

The total demand equals the feasible supply; thus, there is no excess demand for A. This illustrates how the CPA allows the excess demand calculation to distinguish between demand for A alone and demand for A that is embedded in demand for a package. This distinction is impossible in the simple (MALS) clock auction, but is essential if we are to obtain efficiency. Stopping the price at 1 allows the auction to "hold on" to the demand of bidder 2 while still raising the price to the package bidders. Of course, if one of the package bidders later drops its demand for the package and instead demands a unit of A, p_A will rise again. This occurs in the example when p_B reaches $5+\epsilon$ and bidder 5 finds license A more profitable than the package.

Example 8 (Superadditive Package Prices). *Let there be two markets, A and B, with two identical licenses available in each. However, interference constraints limit the number*

of feasible horizontally contiguous AB packages to 1. There are six bidders with valuations

$$\begin{aligned} v_1 &= (5,0,5) \\ v_2 &= (6,0,6) \\ v_3 &= (0,5,5) \\ v_4 &= (0,6,6) \\ v_5 &= (3,3,11) \\ v_6 &= (4,4,14)\,. \end{aligned}$$

Complementarities in the two package bidders' valuations are contingent on horizontal contiguity. With straightforward bidding, the CPA would proceed as follows:

p_A	p_B	p_{AB}	*demand*
1	*1*	*2*	*A,A,B,B,AB,AB*
$\vdots$	$\vdots$	$\vdots$	*"*
5	*5*	*10*	*0,A,0,B,AB,AB*
5	*5*	*11*	*0,A,0,B,0,AB*

The price clocks for the single-market licenses stop at 5, even though three units of each are demanded. This is because only 1 of the 2 package units demanded can be part of a final allocation. For example

$$\begin{aligned} d_A^T &= d_A^1 + \min\left\{q_{AB}^f, d_{AB}^T\right\} \\ &= 1 + \min\{1,2\} \\ &= 2 = q_A^f. \end{aligned}$$

However, there is excess demand for the package at this point, so the package price p_{AB} continues to rise. This yields a package price that exceeds the sum of the component prices p_A and p_B. Note that the degree of superadditivity, the total revenues, and the total surplus could be made arbitrarily high in this example by driving up the package valuations of bidders 5 and 6. With the original MALS proposal and conservative straightforward bidding, the exposure problem (this time the exposure of obtaining packages that lack horizontal contiguity) leads to a worse outcome

p_A	p_B	*demand*
1	1	A,A,B,B,A+B,A+B
⋮	⋮	"
3+ϵ	3+ϵ	A,A,B,B,0,A+B
4+ϵ	4+ϵ	A,A,B,B,0,0

Revenue is nearly 25 percent lower, while total surplus is 15 percent lower. Both losses can be made arbitrarily large by driving up the complementarities in the two package bidders' valuations.

8.8 Properties of the CPA

Success

The CPA is guaranteed to "succeed" in the sense that it will terminate at a feasible allocation. We show this with the following two results.

Theorem 1. *If the clock package auction terminates at price vector p^*, the implied allocation $\left\{d_j^1\left(p^*\right)\right\}_{j\in\mathcal{O}}$ is feasible.*

Proof. Since the auction terminates when there is no excess demand

$$d_j^T(p^*) \leq q_j^f \quad \forall j \in \mathcal{O}. \tag{6}$$

Recall that for all objects j in tier $\tau^{\max}$, $d_j^T(p^*) = d_j^1(p^*)$. Now consider an object j in tier-$(\tau^{\max} - 1)$. Any object $k \supset j$ must be in a higher tier. So by (4), (5), and (6), $d_j^T(p^*) = d_j^1(p^*) + \sum_{k \supset j} d_k^1(p^*)$. Continuing this iteration through tier 1, we obtain

$$d_j^T(p^*) = d_j^1(p^*) + \sum_{k \supset j} d_k^1(p^*) \quad \forall j \in \mathcal{O}.$$

By (6) this implies

$$d_j^1(p^*) + \sum_{k \supset j} d_k^1(p^*) \leq q_j^f \quad \forall j \in \mathcal{O}$$

i.e., $\left\{d_j^1(p^*)\right\}_{j \in \mathcal{O}}$ is a feasible allocation. □

Theorem 2. *Suppose that (i) the bid increment is bounded from below by $\delta > 0$, (ii) bidder valuations are finite, and (iii) there exists $L < \infty$ such that no bidder expresses demand which, if accepted, would yield the bidder a loss greater than L. Then the clock package auction will terminate in a finite number of rounds.*

Proof. Suppose to the contrary that for every round $r = 1, 2, \ldots, \infty$ there is excess demand. This requires that there be at least one object j that is in is excess demand in an infinite number of rounds. Because the bid increment is bounded from below by δ, the price of j (and any object containing j) must diverge to infinity. Because valuations are finite, this requires that there be some bidder demanding units of j (or an object containing j) who would face an arbitrarily large loss if his demand were accepted. This contradicts part (iii) of the hypothesis. □

No Exposure Problem

As long as the set $\mathcal{S}$ includes all of the types of packages desired by bidders (i.e., all those involving complementarities or the need for horizontal contiguity), the exposure problem is absent.

No Overflow Problem

As illustrated in the examples, the overflow problem and its bias against small bidders is eliminated. A bidder's price rises only when his own demand is a source of scarcity.

Simplicity for the FCC

The form and complexity of the proposed clock auction is essentially the same as that in the MALS proposal. We have added a relatively small number of package licenses to the auction: if there are K EAs and L packages, the number of objects in the auction is $K + L$ vs. K in the original proposal. Operation of the auction involves only the calculation of excess demand and adjustment of price clocks. Our description of these calculations translate directly to an algorithm for controlling the price clocks. The complexity of this algorithm is linear in the total number of objects for sale.

Simplicity for Bidders

The addition of packages to the ascending clock auction leaves the fundamental decisions for bidders unchanged. As in the original MALS proposal, a bidder merely indicates its most preferred purchases at each round of prices. The price of a package license is never less than the sum of prices for each component EA license. This keeps bidders' decisions simple (there are no tempting arbitrage opportunities that involve exposure risk) and aids price discovery. With the restriction to bids that are themselves feasible allocations, we see

no new opportunities for strategic bidding behavior created by the addition of packages to the clock auction.

Fairness

The clock package auction as we have described it creates no advantages or disadvantages for large bidders (e.g., those bidding for packages) or small bidders (e.g., those bidding for individual licenses). The allocation of spectrum to package vs. single licenses is not preset but is determined by prices. A package bidder has no advantage because it must always pay a price at least as large as the sum of the component prices for the elements of its package. It is not disadvantaged either: although package prices may be superadditive, this happens only when this is necessitated by excess demand for the package itself. Similarly, the elimination of the overflow problem removes a bias against small bidders that is present in the MALS design.

Efficiency and Revenue

The discussion and examples above reveal that adding packages to the clock auction can eliminate some sources of inefficiency in the clock auction proposed by MALS, and can enhance revenues as well. However, there is no strict dominance relation: one can construct examples in which adding package clocks may reduce efficiency, depending on how clocks are synchronized and how package bidders handle the exposure problem in the auction without packages.

Example 9. *Suppose there are two licenses (A and B) and three bidders with valuations*

$$\begin{aligned} v_1 &= (3, 0, 3) \\ v_2 &= (0, 6, 6) \\ v_3 &= (2, 2, 7). \end{aligned}$$

The efficient allocation gives license A to bidder 1 and license B to bidder 2. In the MALS auction, conservative straightforward bidding will yield the efficient allocation, proceeding as follows:

p_A	p_B	*demand*
1	1	A,B,A+B
2+ϵ	2+ϵ	A,B,0

In the CPA, under straightforward bidding the auction may proceed as follows:

p_A	p_B	p_{AB}	*demand*
1	1	2	A,B,AB
2	2	4	"
3	3	6	0,B,AB
3	4	7	0,B,0

Although revenue is the same, good A goes unsold.[18] *This undersell can be seen as arising from miscoordinated price clocks (recall section 7.4). For example, if the clock for license B moved at twice the speed of that for license A, the CPA would instead proceed as follows:*

p_A	p_B	p_{AB}	*demand*
1	2	3	A,B,AB
2	4	5	"
$\frac{7}{3}$	$\frac{14}{3}$	7	A,B,0

The allocation is now efficient. Further, revenues are now 75 percent higher than in the MALS auction.

To provide some comparisons of outcomes under alternative auction rules we have run

[18] To obtain strictly higher revenue from the MALS auction, modify the example so that $v_3 = (2+\epsilon, 2+\epsilon, 7)$.

a set of simulations using a stylized representation of the forward auction. We discuss the details of the simulation design in Appendix A. At a broad level, however, we generate many randomly drawn bidding environments capturing key qualitative features likely to be present in the forward auction. We use these to simulate actual bidding behavior in both the original MALS auction design and in the CPA. This enables us to compare the potential performance of the two auction designs in terms of efficiency and revenue.

Our results are presented in detail in Appendix A. They suggest that substantial efficiency and revenue gains from the CPA may be typical. For example, in our baseline simulation design, total surplus and total revenue are higher under the CPA in the vast majority of our 1,000 replications. Average revenue (across all replications) is 70% higher under the CPA. The average surplus is 17% higher. The CPA achieves an average of 97 percent of the (infeasible) first-best efficiency. Compared to the infeasible first best (fully efficient) allocation, the CPA achieves at least 90 percent efficiency in 91 percent of the replications, whereas the MALS auction achieves this level in only 37 percent of the replications. Results in alternative specifications are qualitatively similar, with larger gains when complementarities for package bidders are stronger.

9 Supplementary Bidding

As discussed before, both the Clock auction proposed by the NPRM and MALS and the CPA proposed here could leave some items unallocated. It should be an option, if the FCC finds it necessary, to resell the unsold items immediately following the main clock auction. We imagine this option to be triggered only if the FCC finds significant undersell to have resulted from the main round. Should the FCC decide to resell the unsold items, an important consideration in the auction format design is to minimize possible adverse effects it may have on the main clock auction. For instance, if the unsold items were sold in a "pay-

as-you-bid auction," bidders may have incentives to signal low values in the clock phase in an attempt to lower the prices they face in the supplementary round.

For this reason, a clock auction, which is relatively simple and has a transparent pricing rule, is preferred. We do not envision package bids to be allowed for this round, in light of the fact that package bidding in the main round will have treated much of the exposure problem. We do not envision package bids to be allowed for this round, in light of the fact that package bidding in the main round will have addressed much of the exposure problem. A proxy version of the clock auction could be used if a speedier resolution of the forward auction is an important concern.

An alternative more comprehensive approach would put all licenses, including those sold in the initial clock phase, back into sale in the supplementary round. This is the approach prescribed by the Combinatorial Clock Auction (CCA), mentioned as an option in the NPRM (for package bidding). CCA begins with a clock phase (with a different bid withdrawal rule than the MALS clock auction), but adds a supplementary round of proxy bidding for packages following the clock phase. In the (supplementary) proxy phase, all clock bids (i.e., prices for winning quantities) are added as default package bids, but bidders are allowed to submit additional sealed bids for these packages and to bid, with some limitation, for other packages. Winners are then determined to maximize the total bids, and are charged with the VCG-nearest core prices.[19]

There are several concerns with such a comprehensive supplementary bidding approach. First, the pricing rule (i.e., the VCG-nearest core pricing) means that the final clock bids and the prices winners eventually pay would differ substantially (even when the winning

[19]The VCG rule charges each winning bidder the social opportunity cost associated with his winning licenses—the net social value that was foregone due to the winning by the bidder of these licenses. A core pricing rule is a profile of prices that would leave no profitable deviation either by an individual or by a group of individuals through reallocation of licenses within them or through their non-participation. A VCG-nearest core pricing selects the VCG prices if they are in the core, and selects the core point that is the closest to, and in equal distance across all winning bidders away from, the VCG in case the VCG is not in the core. See Ausubel, Cramton, and Milgrom (2006) and Cramton (2012) for detail.

allocation does not change across the two phases),[20] and the relationship between the two phases and the activity rule governing it are complex and may be perceived as opaque by the bidders.

Second, the outcome of the proxy phase is unpredictable in the sense that the winners of the clock phase may not secure the licenses they have won from the clock phase. The prevailing activity rule provides some protection in this regard, for each winner of the clock phase may reclaim the winning package from the the clock phase by raising his bid for that package by the final clock prices of the unsold items (see Cramton (2012) and Ausubel and Cramton (2011)). But that may prove too expensive for this option to be of practical value to the bidders.

Third, when all items are sold by the end of the clock phase, the allocation remains unchanged, but the prices the bidders pay depend on their opponents' bids only. Since their winning licenses remain unchanged and their payments do not depend on their bids, the bidders become indifferent among all feasible package bids (allowed by the standard revealed preference activity rule). As explained in detail in Appendix B, this ambiguous bidding incentive in the proxy phase could lead to excessively low revenue for the seller, susceptibility to collusion, and distorted incentives in the clock phase and inefficiencies.

Overall, the feature that "everything is up for grabs again in the supplementary round" can be perceived as introducing too much complexity/uncertainty into the process for the participants. Such uncertainty may in turn make it difficult for the bidders to form a valuation for the clock phase. And this could hinder price discovery (of even individual items) and may entail underbidding in the clock phase.

Limiting the scope of supplementary bidding to only those items that have not been sold by the clock phase makes the procedure much simpler and more predictable and transparent

[20] In the UK 10-40 GHz auction which used a version of CCA, the final prices of licenses were 20-30% of the winning clock bids in the initial phase, even though the relative prices were stable across the two phases (see Cramton (2008)).

in terms of the consequence of the bidding behavior in the clock phase. In particular, those items that are sold in the initial clock phase will not be subject to any further uncertainty in terms of allocation and prices. The fact that the items sold in the clock phase will be unavailable and the uncertainty on whether the FCC will opt to resell the unsold items immediately will also encourage more sincere bidding in the clock phase, contributing to the efficient allocation of the licenses through the clock phase.[21]

10 Improved Assignment Phase

As noted earlier, the current procedure for assignment does not allow bidders to express preferences for horizontal contiguity across licenses won in different EAs. Here, we propose simple modifications of the MALS assignment procedure that can enhance efficient assignment and horizontal contiguity. Obviously, the problem of allocational efficiency and horizontal contiguity can be treated most effectively by introducing package bids, as envisioned by our Clock Package Auction proposal. The methods discussed here will be most useful if such a comprehensive bidding approach is not adopted, but may be useful even with its use, to the extent that the number of packages allowed may be limited, or when bidders desire vertical contiguity between a package and single EA license in an area covered by the package.

[21] Some demand that would be present if all units are available for sale may not be present if only some items are available for sale, and this may make the supplementary bidding not as competitive as it could be, and in principle this may create incentives for bidders to strategically reduce demand in the clock phase. We do not believe that this is a significant issue. The risk of the desired items being sold in the clock phase (and thus not being available for the supplementary phase), and the uncertainty regarding the FCC's exercise of the option for immediate resale will make such strategic behavior very costly.

10.1 Random Priority with Enriched Preferences

The NPRM suggests a possibility of a Random Priority ("RP") assignment of specific frequency blocks. Efficiency could be enhanced by enriching the preference language for alternative frequency blocks across multiple EAs, and applying the Random Priority rule with respect to these preferences. More precisely, instead of rank-ordering alternative frequency blocks in each EA separately, the FCC would allow bidders to rank-order alternative *combinations* of frequency blocks across different EAs. To illustrate, recall Example 2 introduced earlier: there are two EAs, EA_1 and EA_2; each EA_i has three frequency blocks: A_i, B_i, C_i for $i = 1, 2$; all three blocks are cleared in EA_1 but only two of them are cleared in EA_2; and the remaining station in EA_2 can be moved to any block. There are three bidders, 1, 2, 3 in the forward auction. Bidder 1 and bidder 2 each won 1 license in each EA, whereas bidder 3 won only one license in EA_1 in the forward auction.

Suppose bidder 1 ranks: $A_1A_2 - B_1B_2 - A_1B_2 - B_1A_2 - \cdots$. Bidder 2 may rank similarly: $A_1A_2 - B_1B_2 - B_1A_2 - A_1B_2 \cdots$. One can then define the random priority rule analogously but over both EAs. To illustrate, suppose that bidder 3 ranks $C_1 - B_1 - A_1$. In this case, again bidder 3 will get C_1 in EA_1. And bidders 1 and 2 will get (A_1A_2, B_1B_2) and (B_1B_2, A_1A_2) with equal probability 1/2. Hence, in this way, we achieve full horizontal contiguity.

The example was (deliberately) simple. Matters become more complicated if bidder 3 ranks: $A_1 - B_1 - C_1$, and the remaining station in EA_2 must keep C_2, or C_2 is too impaired to be of any value to the bidders. In that case, with probability 1/3, bidder 3 goes first and will pick A_1 in EA_1, in which case the next bidder will get B_1B_2, and the last bidder will get C_1A_2. More precisely, each of the following six assignments,

$$(A_1A_2, B_1B_2, C_1), (B_1B_2, A_1A_2, C_1), (A_1A_2, C_1B_2, B_1)$$
$$(C_1B_1, A_1A_2, B_1), (B_1B_2, C_1A_2, A_1), (C_1A_2, B_1B_2, A_1)$$

will be selected with probability 1/6 (where again the first component denotes bidder 1's assignment, the second denotes bidder 2's assignment, and the third denotes bidder 3's).

In this case, the new version of the RP assignment does not work as well in preserving horizontal contiguity.[22] A further improvement can be made if the FCC restricts the set of admissible assignments to be those that guarantee (or optimize on) horizontal contiguity. For instance, if it is known that bidder 3's gain from having A instead of B is not very large whereas the loss from not having inter-EA contiguity is very large, then the FCC may declare only two assignments, (A_1A_2, B_1B_2, C_1) and (B_1B_2, A_1A_2, C_1), to be admissible. In this case, horizontal contiguity can be guaranteed, although bidder 3 may be worse off. Of course, the FCC may take a middle ground by declaring C_1A_2 or A_1C_2 to be too inefficient to be a part of an admissible set of assignments. In that case, the RP will be run so that each winner at his turn can only choose from the set of assignments that does not include these two outcomes.

More generally, the improved version of the RP assignment procedure can be stated as follows.

- The FCC picks an extended area $\mathcal{X}$ (which could be the entire nation or one or multiple MEAs or REAGs) which contains multiple EAs. The extended area $\mathcal{X}$ should be chosen to be the minimal region such that a failure to attain horizontal contiguity across different EAs within $\mathcal{X}$ would entail a nontrivial loss to a bidder.

- The FCC next picks the set of "admissible" ways of allocating the cleared blocks in the EAs contained in $\mathcal{X}$ to the winners of the corresponding objects. For instance, the FCC could first impose vertical contiguity (to the extent this is guaranteed, as with the NPRM and MALS) and horizontal contiguity for the packages (for which hori-

[22] Nevertheless, this rule does a better job of accounting for bidders' preferences for horizontal continuity than does the NPRM proposal. In fact, the new version produces an assignment that is Pareto efficient, whereas the outcome from simple the RP assignment fails to be Pareto efficient. Furthermore, the procedure is strategy-proof, making it a weakly dominant strategy for each bidder to reveal his preferences truthfully.

zontal contiguity is guaranteed) and identify the set of feasible assignments satisfying these guarantees. Next, the FCC may impose a suitably-chosen degree of horizontal contiguity it deems as desirable based on an appropriate metric. For instance, the FCC may require that each admissible assignment should satisfy horizontal contiguity over a certain minimal fraction of areas over which each bidder has won licenses (e.g., measured by the number of pairs of adjacent EAs in which a bidder has won licenses).

- Each winner of any license within $\mathcal{X}$ ranks his possible allocations from the set of admissible allocations.
- The FCC next runs the RP assignment procedure based on the preference rankings submitted by the bidders.

The next result is standard:

Theorem 3. *The generalized RP is strategyproof and produces an assignment that is Pareto efficient within the set of admissible allocations.*

Vertical contiguity and horizontal contiguity may sometimes be in conflict with each other, and it may be impossible to satisfy both. The current proposal will resolve the tradeoff in three ways: (1) through the contiguity guarantee that comes with a package, (2) through the set of admissible assignments determined by the FCC, and (3) through the rich preferences submitted by the winners.

To illustrate, suppose there are three EAs: EA_1, EA_2 and EA_3. EA_1 and EA_2 have each 3 blocks, A, B and C, cleared from the reverse auction. EA_3 has 2 blocks: A and B. Suppose all three EAs are pairwise adjacent. Two bidders have won in these EAs. Bidder x won two licenses in EA_1 and one license in each of EA_2 and EA_3. Bidder y won two licenses in EA_2 and won one license in each of EA_1 and EA_3.

Let us first see that it is impossible to satisfy both vertical and horizontal contiguity of assignments. Vertical contiguity for bidder x in EA_1 means that he should win either AB

or BC in EA_1. For the same reason, bidder y should win either AB or BC in EA_2. In case bidder x wins AB in EA_1, horizontal contiguity between EA_1 and EA_2 demands that bidder y should win BC in EA_2. Finally, horizontal contiguity for bidder x between EA_1 and EA_3 means that he should get A in EA_1. But then bidder y must get B in EA_3, violating the contiguity between EA_1 and EA_3 for that bidder. The case in which bidder x gets BC has a similar violation of horizontal contiguity.

The proposed assignment scheme would resolve the conflict in the following way. First, horizontal contiguity guaranteed for a package must be respected. Second, the FCC may ensure vertical contiguity within each EA for the winners (to the extent it can). Third, the FCC may maximize the number of pairs of adjacent EAs for which horizontal contiguity of licenses (won as single licenses and between single licenses and package of licenses) is satisfied.

To illustrate, assume that the three EAs form a single MEA. Suppose first that each of the two bidders won one MEA package and one single EA license (one in EA_1 for x and one in EA_2 for y). Then, the above procedure results in two admissible assignments.

Table 1: Admissible Assignments with Two Package Winners

	A	B	C	A	B	C
EA_1	x	y	x	y	x	x
EA_2	x	y	y	y	x	y
EA_3	x	y		y	x	

Notice that vertical contiguity must be violated for one bidder, since the horizontal contiguity guarantee that comes with each MEA package must be respected first. Of these two admissible assignments, one will be chosen by the RP rule. Unless the specific frequency block matters much, the first assignment will be chosen if bidder y is selected to go first (since it ensures vertical contiguity for y but not for x) and for the same reason, the second assignment will be chosen if bidder x is selected to go first.

Suppose next that only bidder x has won MEA package (and two single EA licenses), and bidder y won all licenses as single EA licenses. In this case, the assumed procedure yields a unique admissible assignment.

Table 2: Admissible Assignment with One Package Winner

	A	B	C
EA_1	x	x	y
EA_2	x	y	y
EA_3	x	y	

Bidder x enjoys vertical contiguity across licenses within each EA and horizontal contiguity across EAs. Bidder y attains vertical contiguity of licenses within each EA, but the horizontal contiguity between EA_1 and EA_3 is not satisfied.

10.2 Assignment Auction

The random priority assignment is sensible only when the bidders do not find the value differences across particular frequency blocks to be large, and the FCC can limit the set of admissible assignments to guarantee contiguity of frequency assignments across regions for the winners of geographically adjacent licenses. An alternative would be to hold an auction to determine the assignment. One possibility is to use the assignment auction prescribed by Cramton (2012), also used in the UK 10-40 GHz auction. According to this method, winners of the principal auction stage bid for preferred assignments. The winners can submit multiple (or possibly no) bids for their preferred assignments that are consistent with their winning awards of the principal auction, and the auction manager selects a collection of bids, at most one bid from each bidder, that are maximal among all possible collections that produce feasible assignments. The winning bidders are then charged the VCG-nearest core prices for their assignments.

In the example from Section 10.1, even without the FCC limiting the admissible assignments, such an auction is likely to produce contiguous assignments across the regions for bidders 1 and 2. If bidder 3 has weak preferences over alternative frequencies in EA_1, then he will bid very little, if any, for his preferred frequency block, and bidders 1 and 2 will bid seriously for A_1A_2 and B_1B_2 (to the extent that they value contiguous assignments), so they will outbid bidder 3 and secure a contiguous assignment. At the same time, the need to respect the horizontal contiguity for the package items will still limit the set of admissible assignments.

While there may be potentially many assignments a bidder can bid for, the auction will be relatively straightforward from the perspective of bidders since important matters such as how many licenses they win in each region will have been already settled. In particular, a bidder can, and will typically, bid for a small number of select assignments (as was the case with the UK auction). The pricing rule also limits the incentives for non-truthful bidding and is envy free.

11 Other Concerns and Recommendations

11.1 Generic Licenses

The treatment of licenses as generic within market and class of license is essential to the MALS design and our CPA proposal. This feature has a number of desirable properties as long as licenses designated as generic actually are equivalent. It is essential that the band plan be designed to minimize interference or other impairment of licenses, so that genericity of licenses is genuine. If in limited cases licenses do unavoidably differ substantially, they must be treated as non-fungible in the forward auction. Failure of the auction design to distinguish adequately between heterogeneous licenses would lead to a significant exposure problem, conservative bidding, and inefficient allocations.

11.2 Bidding Credits

The NPRM proposes offering bidder credits of 15 percent to "small businesses" and 25 percent to "very small businesses." Bidding credits have been used toward this end in past FCC spectrum auctions, and the FCC proposes to do so again in the forward auction.[23]

However, an important difference from past auctions is the interaction between the forward and reverse auctions. Consequently, the result of favoring designated entities through discounts will not merely be to favor designated entities in the allocation of spectrum for wireless services. It will also favor the status quo, i.e., allocation of spectrum to current broadcast television licensees. Discounts offered to designated entities may result in a failure of closing conditions for a target quantity of spectrum, even when bidders in the forward auction are offering prices sufficient to meet the net revenue requirement.[24] The result will not be the intended one: instead of tilting the allocation toward designated entities in the mobile wireless industry, the quantity of spectrum made available to mobile wireless—including to designated entities—will be reduced.

What is needed is an alternative that preserves the desired preferential treatment of designated entities when it comes to the question of *how* mobile wireless spectrum is allocated, but does so without adversely influencing the question of *whether* spectrum is allocated to mobile wireless. This is possible with a simple modification of the NPRM proposal. Bidding credits could be made contingent on satisfaction of the net revenue requirement, and phased in gradually to allow the maximum feasible bidding credit (up to the 15 and 25 percent

[23] Ayres and Cramton (1996) point out that bidding credits could sometimes enhance revenues by creating competition for licenses attracting few large bidders. This outcome may be less likely with the proposed auction design due to the use of generic licenses. Nonetheless, our proposal below would not affect any revenue enhancing feature of bidding credits.

[24] Consider an example with one license and two bidders: a *very small business* with valuation 65 and a non-designated entity with valuation 80. Suppose that the net revenue requirement is 62. The designated entity's 25% bidding credit allows it to become the provisional winner in the clock auction at a price of 80. However, its payment would be only 60. Thus the net revenue requirement fails. Here this occurs even though both bidders would be willing to pay more than the required net revenue of 62 for the license.

levels) that can be accommodated without leading to a revenue shortfall.[25] This need not introduce uncertainty for designated entities. They can be told the bidding credit they are eligible for at each price vector. Nor would the auction be disrupted when the bidding credits "kick in," since the only effect would be an increase in demand. This modification of the bidding credit program would require only relaxation of the activity rule for designated entities, allowing them to take advantage of the credits. This should be straightforward.

This proposal is a sharply targeted remedy to the problem that bidding credits could lead to net revenue failure. Under straightforward bidding, the proposed modification would have no effect when the net revenue requirement would have been satisfied under the original proposal. Likewise, if the net revenue requirement fails under our proposed bidding credit system, it would also fail under the original system. Thus the only cases in which our proposed change would have an effect is when the net revenue condition would be satisfied under our proposal but would have failed under the original proposal.

11.3 Activity Rule

The purpose of the Activity rule is to prevent bid sniping[26] and encourage straightforward bidding, both of which are important for effective price discovery. The basic idea behind such an activity rule is to constrain bidding behavior to be consistent with straightforward bidding. Traditionally, the activity rule used by the FCC in past auctions has been a "monotonicity rule," requiring that the aggregate quantity demanded by a bidder—typically measured by

[25] In the simple example above, bidding credits would kick in as soon as the price reached 62. At a price of 65, for example, the very small business could receive a bidding credit of 3; at a price of 70, a bidding credit of 8.

[26] Bid sniping refers to the strategy of waiting (i.e., bidding low or insincerely) until the last minute of the auction to bid seriously. When permitted, bidders have incentives to engage in such behavior in order to conceal their preferences and thereby increase their chances to win desired items at low prices.

MHz $\times$ Population—not increase over the course of the auction.[27] This rule works well when the items are homogeneous, but not well when they are heterogeneous. For instance, the prices of different EA licenses may vary widely on a per MHz $\times$ Pop basis. In that case, straightforward bidding behavior may require switching to a larger package when its price becomes relatively cheaper, but this behavior will not be allowed by the monotonicity rule. This activity rule is also susceptible to "parking," a strategy of bidding initially on underpriced or low-value objects with high quantity so as to keep the the prices on desired objects from rising quickly. Such behavior inhibits price discovery, and may distort prices and hinder efficient allocation.

An alternative "revealed preference" activity rule proposed by Cramton (2012) and Ausubel, Cramton, and Milgrom (2006) is more flexible and is immune to parking behavior. In words, the revealed preference requirement would allow a bidder to switch to a larger package as long as that package has become relatively cheaper than the package she demanded at the previous round. The hybrid version suggested by Ausubel and Cramton (2011), which uses the traditional eligibility monotonicity rule but allows bidders to switch to large packages as allowed by the revealed preference requirement,[28] appears to offer further flexibility to the bidders. These rules appear to be sensible for both the clock auction proposed by the NPRM and the CPA proposed here.

[27] Specifically, according to this rule, each bidder i must bid within his eligibility point E_t^i, which is set initially (say at E_0^i) based on the deposit posted by the bidder, and evolves over time to equal the smaller of his bidding activity $e \cdot q_t^i$ at round t and the eligibility point E_{t-1} at the previous round (where e refers to the vector of eligibility points for the products the bidder is bidding on, q_t^i refers to the quantity bidder i demands or bids at round t.)

[28] More precisely, under the Simplified Revealed Preference rule, at any round in the Clock Phase a bidder can bid on a larger package than would be permitted by the bidder's current eligibility, provided that the package satisfies "revealed preference" with respect to each prior round's bid in which eligibility was reduced (Ausubel and Cramton (2011)). The rule states that in Clock round t, bidder i can bid an package q_t if

$$e \cdot q_t \leq E_t^i,$$

or

$$(p_t - p_s) \cdot (q_t - q_s) \leq 0,$$

for each previous round s at which her eligibility was reduced.

Part III

Reverse Auction

12 The NPRM and MALS Proposals

Broadcast television bands currently occupy 294 MHz of spectrum in five different bands allocated for broadcasting use. The density of broadcast television licensees varies significantly across markets, and licensees themselves differ substantially in their geographic coverages ("contours"), depending on such factors as location, transmitter power, antenna height, local terrain, etc. In many markets, substantial spectrum in the broadcast television allocation is unused. Because television and mobile wireless uses are incompatible, reallocating portions of the spectrum to mobile wireless uses requires relocating television licensees. By shifting broadcasters to a single portion of the spectrum, sufficient bandwidth may be cleared to permit viable mobile wireless services to be offered in the remaining portion.

Although legislation gives the FCC authority to relocate ("repack") broadcast television licensees within or across the broadcast television blocks, this must be done in a way that does not unduly affect licensees' contours. The ease of meeting this requirement will vary considerably across markets and across incumbent licensees within markets. Further, in some large metropolitan markets there are many television licensees. In such markets, even after repacking there might be relatively little spectrum available for wireless services. Such markets may, however, also be some of the most valuable markets for mobile wireless services.

The Spectrum Act authorizes the FCC to resolve the competing demand for the scarce spectrum through voluntary participation in "incentive auctions" in which television licensees can offer to relinquish their licenses. The market design problem for the FCC is to provide

an auction mechanism that selects voluntary offers to relinquish while also accounting for the constraints on repacking broadcasters in a way that adequately respects their contours. This need to repack without introducing interference introduces significant complications to the design of the reverse auction. Repacking constraints are "global," in the sense that placing a broadcaster in one market in a particular frequency can affect the feasibility of placing broadcasters in the same or nearby frequencies in other markets. For example, Washington, D.C. and Philadelphia, PA are sufficiently proximate that use of a UHF television channel in one may preclude use of the same channel in the other market. For the same reason, decisions regarding channel usage in Philadelphia may affect New York City, which then may affect Bridgeport, CT, and then Boston, MA. Similarly, a Washington D.C. assignment may affect feasible assignments in Baltimore, MD and possibly Richmond, VA. Thus, channel usage can have a "daisy-chain" effect that can link major metropolitan areas—as well as smaller communities—that are hundreds of miles apart.

12.1 Descending Clock Auction

MALS proposes a simultaneous descending clock design for the reverse auction. The reverse auction would begin with provisional target quantities of spectrum to be cleared in each market. Although there would be a single nationwide reverse auction, it will utilize different clocks for each market and each *relinquishment option*—e.g., go off the air, share with another station, or move to a lower band. The option to "remain in the current band" (i.e., to be repacked) is always available as well. Bidders who do not participate in the auction are automatically assigned to this option. Participation in the auction is strictly voluntary. Clock prices may differ across bidders within a market and may move at different speeds, due to differences in coverage areas, in the feasibility of each option, in the costs of repacking, or in the effect of repacking one station on the ease of repacking others.

The auction clocks begin with high initial ("reserve") prices chosen by the FCC for each

feasible relinquishment option in each market. Each bidder selects the option he finds most attractive at these prices. Roughly speaking, prices are then lowered, bidders again express their preferences, and the process iterates until prices reach a level just low enough that the quantity of spectrum offered in each market equals the target quantity.

Complicating this simple description is the fact that feasibility considerations will limit repacking options. Each clearing target determines the amount of spectrum available for repacking bidders who choose to stay on the air. Before prices are adjusted during the auction, the feasibility of repacking each remaining bidder (i.e., the feasibility of adding that bidder to the set to be repacked) must first be checked. If it becomes infeasible for a given bidder to be repacked, his current relinquishment offer will be provisionally accepted at the current clock price for that option. The feasibility checking iterates until it is the case that each remaining bidder could feasibly be repacked. Only at this point do clock prices decline for these remaining bidders.

A significant virtue of the clock design is its simplicity from the perspective of bidders. Although complicated repacking constraints operate in the background, the rules of the auction are transparent, making it easy for bidders to see how their actions determine outcomes and payments. Further, given appropriate rules for controlling clock prices,[29] bidders have clear and strong incentives to follow a straightforward bidding strategy—i.e., always to select the option that would maximize one's own profit if the current clock prices were to be the final prices.

Theorem 4. *Consider the MALS reverse auction and assume that clock prices decline continuously and with speeds that do not depend on the actions of bidders. Then straightforward bidding is a weakly dominant strategy for all bidders.*

Proof. See Appendix C. □

[29] The NPRM and MALS are not explicit about the rules that will govern adjustment of clock prices for feasible relinquishment options. As Theorem 4 suggests, we see some potential for distortion of incentives if the rates at which prices adjust depend on bidder offers.

12.2 Other Reverse Auction Designs

The NPRM also suggests an alternative to the descending clock auction design. Details are not provided, but broadly the proposal involves collecting price offers from reverse auction bidders and choosing winners (or, perhaps, provisional winners in each of a sequence of rounds) to minimize payments to bidders subject to repacking constraints.

13 Primary Concerns

13.1 Computational Complexity

Constraints on repacking broadcasters cause issues of auction design and computational complexity to be intertwined here in a way that has not previously been well explored. As already noted, two types of auction design have been proposed by MALS and the NPRM. One is a descending clock auction, using real-time feasibility checking. The other is an unspecified sealed bid auction design in which optimization over relinquishment offers (subject to feasible repacking) might play a prominent role.

In general the types of feasibility checking and constrained optimization problems involved in such auction designs can present severe computational challenges. The NPRM is vague about the nature of the repacking constraints and imprecise about the amenability of the constrained optimization problem to solution using standard or specialized algorithms. In some cases the NPRM discusses use of approximate solutions. In the worst case, approximation approaches can perform extremely poorly. Further, here the quality of an approximation depends not only on proximity to the true solution, but also on how the optimization affects the performance of the auction as a whole.

Without details on the repacking constraints, it is impossible to evaluate the likely performance of potential full solution or approximate solution algorithms. Although certain

auction designs may ease or worsen the computational complexity or performance of approximate solutions, similar issues are likely to arise in any of the contemplated reverse auction designs.

We elaborate on these issues in section 15 below.

13.2 Delay and Uncertainty Due to Target Failures

If the FCC chooses initial clearing targets appropriately,[30] these will be quite high, reflecting an attempt to maximize opportunities for efficient trade. This will almost certainly lead to multiple clearing targets being tried before one is found that allows satisfaction of closing conditions for the grand auction.

Under the current rules, each time the target is reduced, the forward auction must pause while reverse auction bidders are reconvened in order to obtain new "supply" prices for the reduced target quantities. In addition to the burden this creates for bidders, this feature of the auction design will delay completion of the grand auction. It may also introduce uncertainty for reverse auction bidders, since truthful bidding would require some broadcasters to take actions that commit them to assignments days or weeks ahead of other bidders.

14 Single-Pass Reverse Auction

An alternative to the proposed sequence of reverse auctions contemplated by MALS is to conduct the reverse auction in a single pass. The simple idea is that instead of stopping the auction when prices for the most optimistic target Q_1 are reached, the auction would continue and trace out the "supply curve" over the entire range of potential clearing targets. We describe two variations of the basic idea. These differ in whether bidder optimization over the alternative relinquishment options is done by bidders themselves or by proxy.

[30] MALS propose to set initial clearing targets based on the supply offered at high initial reserve prices.

We see at least four potential gains from the single-pass option:

1. greater simplicity for reverse auction bidders;

2. avoidance of delay and inconvenience for bidders when a closing target fails;

3. enabling improved efficiency in a two-sided closing trial (see section 18);

4. avoiding real-time feasibility checking.

The first three gains can be achieved with our baseline proposal. The last takes advantage of proxy bidding.

14.1 Single-Pass: Baseline

Our baseline proposal would alter the reverse auction design only slightly. Instead of conducting a sequence of reverse auctions, each with a progressively smaller clearing target, just one reverse auction would be held. Let $Q_1, Q_2, \ldots, Q_T$ represent all possible clearing targets entertained by the FCC, listed in descending order. In the single pass reverse auction, the FCC would start the auction at prices more than sufficient to clear Q_1, just as it would in the first of its sequence of reverse auctions under the MALS proposal. But instead of stopping when prices for this clearing target are reached, the auction would continue with prices falling until the quantity of spectrum offered in each market reaches Q_T. Bidders' exit prices would be recorded, allowing the FCC to "replay" the reverse auction from the beginning to any desired clearing target. These "replayed" auctions would be used to reveal the payments required for any possible clearing target.

The interaction with the forward auction would then be exactly as originally proposed. The clearing target Q_1 would be tried first in the forward auction. If the revenues obtained there exceeded the total cost implied by the reverse auction bids for the target Q_1, the grand auction would end. Otherwise the forward auction would continue with the lower

clearing target Q_2. However, rather than reconvening the reverse auction to establish the (lower) prices for the new target, these new prices would simply be reconstructed from the single-pass reverse auction.

The single-pass option changes bidding in the reverse auction very little. A bidder must still come to the auction with a reservation value in mind for each of the possible relinquishment options. A bidder's options during the auction would be identical to those under the original proposal, and the rules determining prices paid to bidders for each relinquishment option would be no different. Just as in the original proposal, bidders' choices between relinquishment options would be binding offers. We also see no change in a bidder's incentive for straightforward bidding.[31]

The single pass option offers several advantages. One is elimination of the need for a new reverse auction each time a clearing target fails. This would simplify participation in the reverse auction. It would also avoid delay: rather than pausing the forward auction to reconvene reverse auction bidders each time the clearing target is adjusted, the forward auction could proceed without interruption.

The single-pass design also simplifies participation of reverse auction bidders in a "two-sided closing trial" and would further allow the FCC to minimize the likelihood of "overshooting" during a closing trial (see section 18 below). This could lead to more cleared spectrum. Another advantage is that bidders would be assured that all broadcaster offers were chosen the same day; unlike the MALS design, here a bidder need not worry that the

[31] Consider a simple example with 3 bidders in a market where the clearing target may be 1 or 2 licenses. Suppose that the only options for bidders are to go off the air or remain in their original band (exit). We can divide the auction into two phases: phase 1 covers the period before any bidder exits, and phase 2 is the period between the first and second exits. Suppose that exits are revealed during the reverse auction, so that bidders know the current phase. Consider phase 1. Exiting implies obtaining zero profit (zero gain over the value of remaining on the air). So by standard arguments, exiting at a price above one's valuation is weakly dominated. Further, since the price will only decline further in phase 2, standard arguments imply that remaining in the auction at prices below one's valuation is weakly dominated. Now consider phase 2. The price for clearing 2 licenses has already been determined. So what remains is a single-unit descending auction, where standard arguments imply that bidding one's reservation value is weakly dominant.

final offers of different TV stations might be made days or weeks apart. Such concerns could adversely affect participation and bidding in the auction if bidders believe that new information affecting valuations might arrive in the period between the first MALS reverse auction and the last.

A possible concern is that reverse auction bidders might be reluctant to reveal information unnecessarily. For example, consider a bidder with a reservation value for going off the air that is well below what turns out to be the final market clearing price. Under the MALS design, such a bidder would have no need to reveal just how low a price he would have been willing to accept, whereas a single-pass reverse auction may collect this information.[32] However, we understand that the FCC has well established procedures for protecting confidential information.

14.2 Single-Pass with Proxy Bidding

Conducting the single-pass auction by *proxy* may offer additional benefits. With proxy bidding, bidders would be asked once to report reservation values for each relinquishment option through proxy-agent software. The rules of the auction for a given target Q_t would be identical to that originally proposed. However all bidding would be done by the proxy agent. The proxy agent would implement a straightforward bidding strategy for each bidder. Specifically, at each vector of prices offered by the auction's descending price algorithm, the proxy agent for bidder i would choose the relinquishment option (or "exit") that is most profitable to i according to i's reported reservation values. The proxy auction would stop when prices for the target Q_T are reached.

The primary gain from proxy bidding is that there would be no need for real-time feasibility checking or other optimization. This will ensure that the auction will not stall between

[32] Any such bidder is one who ends up accepting an offer to clear, and bidders giving up their licenses may be less concerned about revealing their reservation values.

rounds due to computational difficulties. It may also allow more complete solutions of the underlying repacking problems, leading to more efficient clearing, i.e., assurance that the most favorable supply offers are accepted.

15 Addressing Algorithmic Issues

Stepping back from any particular reverse auction design, optimal clearing of a given target quantity of spectrum would minimize the total costs of clearing (i.e., the value of relinquished spectrum allocations) and of repacking television broadcasters who remain on the air. Reaching this fully optimal solution is certainly infeasible. One problem is that of *incentive compatibility*: current licensees cannot be compelled to reveal the values they place on their current spectrum allocations and must voluntarily agree to the terms of any relinquishment. This alone makes it impossible to pay each cleared television licensee the lowest price it would accept for its license. A second problem is the computational complexity involved in finding a cost-minimizing allocation. This complexity arises from the effect of repacking one station on the feasibility (or cost) of repacking others. Even if bidders' reservation values were known to the FCC, the cost minimization problem is an integer programming problem of a type known to be computationally hard in general. The unique challenge in the reverse auction design is to handle adequately both incentive compatibility and computational feasibility while also keeping the rules sufficiently simple and transparent. Here we discuss this challenge in further detail.

The MALS clock auction offers an approach in which each bidder has a strong incentive to offer to relinquish whenever the price exceeds his true reservation value (recall Theorem 4). Taking these strategies as given, the MALS clock auction design replaces minimization of total cost with minimization of payments to cleared licensees, subject to sequential verification of repacking feasibility. As long as more bidders than necessary are volunteering to

be cleared, prices fall, leading to repacking of bidders with the highest reservation values. In the simplest form of the proposed design, repacking constraints would enter only through verification that it is feasible to repack a bidder before he is offered a new set of prices. This approach puts priority on the cost of clearing relative to the cost of repacking. Only when it is infeasible for a bidder to be repacked would the auction allow repacking costs to affect the choice of which broadcasters are to be cleared. Possible variations include using repacking constraints to adjust relative clock speeds or to score bidders' offers. This would allow repacking costs to play a larger role, but repacking would still be done sequentially, possibly leading to suboptimal choices.

Of course, the clock auction design is also what leads to the simple and transparent incentives for bidders. Other auction designs might improve on the repacking optimization *given* a set of price offers from bidders, but these offers may be systematically different from those in a clock auction. How such tradeoffs could affect the overall efficiency of the MALS design relative to other options may depend on the nature of the repacking constraints, about which the FCC has thus far released little information.

Further, the MALS clock auction does not avoid significant computational challenge. Formally, feasibility checking takes the form of a "graph coloring problem," which is known to be computationally hard in the worst case. Without knowing the fine details of repacking constraints, it is impossible to determine whether the feasibility checking required by the MALS proposal is itself computationally feasible.

The NPRM also entertains other types of reverse auction designs, where full optimization over bids and repacking costs might play a more prominent role. Few details are provided, making a careful analysis of such options difficult.

Below we elaborate on these issues. However, our overriding message is that by releasing more detailed specifications of the repacking constraints involved, the FCC would enable outside experts to better assess the likely performance of the proposed reverse auction design

and alternatives. Such analysis could clarify which of the mechanisms under consideration may be vulnerable to the computational concerns we discuss, and allow development of new specialized algorithms for the repacking problem that might yield substantial improvements in performance.

15.1 Background and Context

Both the NPRM and the MALS proposal discuss several variations for the structure of the reverse auction. The overarching goal of the reverse auction is to clear a targeted amount of broadcast spectrum in an efficient manner, ideally while minimizing overall costs (in the form of direct payments to the broadcasters and costs associated with repacking broadcasters remaining on-air). Both documents correctly emphasize that the primary computational challenge in meeting this goal arises from the *repacking constraints*. In the absence of such constraints, the reverse auction would require nothing more than selecting those broadcasters demanding the lowest prices (regardless of the auction mechanism details), and paying them to clear their spectrum (up to the targeted amount), while repacking the highest bidding broadcasters. In the presence of repacking constraints, minimizing costs for clearing the desired spectrum may become computationally intractable, and force consideration of various heuristic and suboptimal algorithms.

The repacking constraints are physical, engineering and policy constraints that are exogenous to broadcaster prices, bids and valuations. Broadly speaking, they arise from interference considerations due to the physical and frequency proximity of broadcasters — i.e. if two broadcasters are close enough geographically, and are assigned the same or adjacent channels, interference may occur. Geographic terrain also influences the strength of broadcaster signals. Such sources of interference already exist within the current assignments of broadcasters to frequencies, and define the current "coverage area" or "contour" of a given broadcaster. The repacking constraints arise from the regulatory requirement that

any broadcaster choosing to remain within their current band must be repacked in a way that adequately respects the broadcaster's current coverage area or service contour.[33]

To a first approximation, then, repacking constraints can be thought of as constraints between certain *pairs* of broadcasters: if broadcasters A and B are geographically proximate, and currently on sufficiently different channels that neither interferes with the other's service area, but relocating them on the same or adjacent channels would create too much new interference (as defined by the regulatory requirements), then they cannot be repacked together in this way.

We can view these pairwise constraints as forming a *network* or *graph* in which there is a node or vertex representing each broadcaster in the nation, and there is an edge or link between any pair of vertices whose corresponding broadcasters are constrained in the above manner (i.e. cannot be relocated on the same or adjacent channels without creating too much new interference). This is a large, complex and dense network, and its meaning for the repacking process is clear: once we have decided to repack broadcaster A on channel c, we are then unable to repack any network neighbor of A on any of channels $c-1, c, c+1$. Repacking decisions thus have consequences that *propagate* in both the spatial and frequency dimensions: repacking A on channel c not only constrains repacking geographically proximate broadcasters on c (spatial propagation), but also on channels $c-1$ and $c+1$ (frequency propagation). In other words, "local" decisions can have "long-distance" effects.

It is such long-distance influences through the repacking constraint network that give rise to a computationally challenging repacking problem for *any* proposal for the reverse auction mechanism. The simplest version of the repacking problem is referred to as *feasibility checking* in the NPRM and MALS documents, and can be formulated as follows: *Given the repacking constraint graph G over n broadcasters (vertices) described above, and a subset R*

[33] The NPRM discusses several different possible interpretations of this requirement, none of whose details materially alter the subsequent discussion.

of the broadcasters to be repacked, determine if there is an assignment of the broadcasters in R onto k contiguous channels in a way that obeys all the repacking constraints in G. In an *optimization* version of the problem, there is a price or valuation associated with each broadcaster, and the goal is to find the set R of size k that can be feasibly repacked whose sum of prices or valuations is maximized (e.g. thus minimizing the cost for clearing the set of winning broadcasters).

As we shall discuss, depending on the details of the particular reverse auction mechanism under consideration, one of these variants of the repacking problem arises.[34] But the computational complexity of all of these problems is that they are all provably intractable on worst-case inputs.[35] This means that if the graph G is arbitrary, then the best algorithm for solving these problems will require computation time that scales *exponentially* with the number of broadcasters; in practice, this would mean that these problems could be feasibly solved only for very small instances, much smaller than the number of broadcasters who will participate in the reverse auction.

Given this worst-case computational intractability of repacking problems, there are three broad approaches that can be considered:[36]

1. Employ general-purpose algorithms known to find optimal or exact solutions, even though their worst-case running time may be computationally infeasible, and hope that the actual running times on the "real data" (most importantly, the actual repacking constraints, but also potentially including clearing targets, prices, etc.) will in reality be manageably modest.

[34] The first variant arises in the descending clock auction, while the second arises in sealed-bid mechanisms.

[35] This can be proven via a reduction from the well-known graph coloring problem.

[36] It is worth remarking that some variations of the mechanisms under consideration could greatly ease the real-time computational burdens of the reverse auction. For example, the single-pass clock auction with proxy bidding discussed in Section 14.2 would permit feasibility checking computations to be performed "offline" (that is, not during the auction itself, but after the fact), which might allow slower algorithms that find better solutions.

2. Employ general-purpose algorithms known to be computationally efficient, but which may find suboptimal or approximate solutions.

3. Design special-purpose algorithms that exploit the structure of the actual repacking constraints, hopefully achieving fast computation time and near-optimal solutions.

Approaches 1 and 2 require no advance knowledge of the repacking constraints (though knowledge of them may permit simulations that shed light on the efficacy of these approaches, which we discuss later), while Approach 3 inherently assumes such knowledge. Note further that hybrids of the three approaches are also possible, and may yield the most appealing tradeoffs.

We now proceed to discuss the computational challenges presented by repacking in the context of the specific reverse auction mechanisms under consideration, concentrating primarily on the descending clock auction of the MALS proposal. Our primary intent is again to show that the release by the FCC of considerably more detailed data on and models for the repacking constraints could allow (a) the assessment of how likely drawbacks are to arise in the actual auction, via computational simulations; and (b) the development of new, specialized approaches to repacking that may yield considerably better outcomes in terms of the amount of spectrum cleared, and the expenditures to do so.

15.2 Computational Complexity in a Descending Clock Auction

The NPRM and MALS documents both describe a descending clock auction, which in its simplest form gradually reduces the price offered to each broadcaster to clear their spectrum.[37] Once a broadcaster declines the current clock offer and exits the auction, it must be repacked. Since it is a weakly dominant strategy for each broadcaster to remain in the auc-

[37] Throughout we shall simplify the discussion by assuming the only options available to broadcasters are to clear their spectrum entirely, or to be repacked in their current band. The NPRM discusses a number of other possible options as well, none of which would ease the computational challenges we are discussing.

tion until its clock offer falls below its private valuation for remaining on-air, this auction can be thought of as processing broadcasters in descending order of valuations (since this is the order in which they will choose to exit the auction under their weakly dominant strategies), and is thus mathematically equivalent to a setting in which the broadcaster valuations are known and we use a "greedy" algorithm that attempts to repack higher-valuation bidders first.

In this mechanism or algorithm, we must ensure the invariant that at each point, each broadcaster currently remaining in the auction could be feasibly repacked, given the set of broadcasters we have already committed to repack. Thus, upon adding a new broadcaster b to the current feasible set R of repacked broadcasters, we must check that each remaining broadcaster b' could be added to R and still obey all repacking constraints. If not, then in the language of the proposals, b' must be *frozen* at its current clock price and paid this price to clear its spectrum, since it can no longer be repacked. The version of the repacking problem that is thus relevant to this mechanism is *feasibility checking* — we must determine whether the given set $R \cup \{b'\}$ can be feasibly repacked — and under weakly dominant strategies, the broadcaster valuations determine the sequential construction of a set of $k = n - t$ broadcasters to repack, where t is the clearing target.

As noted, the major source of computational complexity in the clock auction is the repeated feasibility checks to determine which bidders must be frozen as the repacking set R is gradually expanded; this problem is computationally intractable in general. As per the algorithmic approaches mentioned above, one approach is to solve each feasibility check exactly — that is, employ an algorithm guaranteed to correctly answer each feasibility check, and to produce an assignment of the repacked set R to the targeted number of contiguous channels.

There are indeed a number of general-purpose algorithms for solving such problems, including what are broadly known as *satisfiability* or *constraint satisfaction problem* algo-

rithms.[38] While many such algorithms yield fast computation times on various large-scale, real-world problems and benchmarks, the question of how well they would perform in the context of the actual reverse auction is an empirical one that can only be approached via simulation and detailed knowledge of the repacking constraints.

The NPRM and MALS proposals seem to suggest the intention to use such a general-purpose, exact algorithm for feasibility checking in the clock auction. An alternative approach would be to employ an algorithm for feasibility checking that is ensured to be computationally efficient, but may find suboptimal or inexact solutions. We describe one simple such algorithm here. Suppose that for the current repacking set R we have already found an assignment of each broadcaster in R to one of the k contiguous channels $1, \ldots, k$, in a way that violates no repacking constraint. Then to decide if broadcaster b is a feasible addition to R, and to extend the assignment to channels, we can simply consider assigning b to the first free (not already assigned) channel for which no neighbor of b in the repacking constraint network has already been assigned to an adjacent channel. If no such channel exists, we declare that b cannot be repacked given the current R and assignment. The difference between this algorithm and an exact feasibility check is that once a repacked broadcaster is assigned to a channel, the algorithm never considers changing that assignment in order to accommodate later repackings. For this reason we shall refer to this as the *myopic* feasibility checking algorithm, since it makes short-term repacking decisions without regard for later or global consequences.

While it is not difficult to find xamples where this myopic procedure produces suboptimal

[38] `http://en.wikipedia.org/wiki/Constraint_satisfaction_problem`

results, in the sense of being forced to clear more than the desired number of broadcasters,[39] it is an empirical question whether this heuristic, or some other one, would badly underperform in the actual auction. With enough knowledge about the repacking constraints, it is possible that a feasibility checking procedure balancing performance with computational efficiency could be designed.

Repacking Inefficiency in the Descending Clock Auction

In addition to the computational challenges and trade-offs discussed so far, the descending clock auction format may limit the ability to reach near-optimal solutions as measured by repacking efficiency (that is, the sum of valuations of the repacked bidders), because repacking decisions are made sequentially. In its simplest form the FCC would process the broadcasters "greedily" by descending valuation in a completely myopic fashion, without regard to the constraints on later repacking such greedy decisions might impose. A simple example can illustrate the issue.

Example 10. *Suppose there are 5 broadcasters A, B, C, D, E, currently broadcasting on channels 2, 4, 6, 8 and 10 (thus there are no current interferences at all, since no pair is on adjacent channels), and that the target is to clear three of them and to repack the other two onto channels 1 and 2, thus freeing up channels 3 through 10 for wireless spectrum. Suppose that the geographical proximities of the broadcasters transmissions are such that the following pairs of broadcasters* cannot *be repacked together: AB, AC, and AD. We can think of A as a high-power, wide-area broadcaster who would have interference with the nearby broadcasters*

[39] For example, let there be five broadcasters A, B, C, D, E to be considered in turn for repacking on 5 channels, and assume that the geographical proximities are such that the following pairs of broadcasters *cannot* be repacked together: AB, AC, BC, BD. We first add A to R, assigning it to channel 1. When we next consider B, we must repack it on channel 3, since the constraint AB prevents assignment to channel 2. Broadcaster C is assigned to channel 5 due to the constraints AC and BC. At this point, D cannot be added to this assignment: only channels 2 and 4 are free, and B is adjacent to both, and BD is a constraint. E can be placed on channel 2, giving a final ordered assignment of $AEB * C$, where $*$ denotes an unused channel, and we have failed to repack all broadcasters. However, it is easily verified that there *is* a way to repack all five: the assignment $ADCEB$ violates no constraints.

B, C and D; whereas E is sufficiently distant (or low power) that it can be repacked with any of the others.

Table 3: Bidder Values from Repacking

Broadcasters	A	B	C	D	E
Values of being on air	100	99	99	1	1

Suppose the bidders' values for remaining on air are as shown in Table 3.[40] *Given the repacking constraints, the clock auction proceeds as follows. Suppose the price clock is initially set at 100 and descends gradually. Again, it is a weakly dominant strategy for each bidder to drop out when the clock price reaches their valuation. At the initial price of 100, A is first to drop out, so is added to the repacking set R. But once A is added to R, broadcasters B, C and D cannot be added to R due to repacking constraints. This leaves only E, which can be added to R, so the price clock runs down until E drops out. Hence, we get $R = \{A, E\}$, $W = \{B, C, D\}$. If we evaluate the clock auction by the sum of the valuations of the repacked broadcasters, in this example that sum is $100 + 1 = 101$. However, there is a much better solution: we could instead choose $R = \{B, C\}$, $W = \{A, D, E\}$, which yields a total repacked valuation of $99+99 = 198$, almost twice as much as for the clock auction. The problem in this example is that while A has the highest valuation, it also represents the greatest constraints on subsequent repacking.*

Other simple examples (see for instance Example 11) also show that the actual *expenditures* of the clock auction for clearing the desired amount of spectrum can be much more than under other mechanisms such as VCG.

This is an extreme example intended to illustrate a point. We emphasize that the excess

[40] The great variation in valuations in this and subsequent examples is deliberate, and simply intended to show the extent to which different mechanisms can yield very different outcomes, expenditures, etc. Of course, it is worth noting that such variation in broadcaster valuations must be the primary source of any such differences.

expenditure of the clock auction presented in this example is not meant as a critique of the mechanism, but simply to illustrate the potential for suboptimal results, and the way in which it may depend on repacking constraint details.

Hybrid Algorithms, Discounting, and Variable Clock Rates

Of course, there are other algorithms for feasibility checking that could give different tradeoffs than an exact or optimal algorithm which may take exponential time, or a suboptimal or approximate algorithm guaranteed to run efficiently. In particular, it is quite common in such situations to consider various *hybrid* algorithms. For example, we could implement some form of *lookahead* in creating the channel assignment which tried to determine whether repacking a broadcaster will cause severe constraints on further repackings within the next few steps.[41]

The NPRM suggests the possibility of modifying broadcaster bids to exit their spectrum through the use of *weights* or *scores* that would combine the actual bids with a variety of other factors, including the potential difficulties posed by repacking a broadcaster. In particular, one proposal is to score or reweight the bids of broadcasters whose repacking could greatly constrain further repacking, thus making the optimization problem more difficult. Scores would be used for determining the greedy order in which broadcasters are considered for repacking, while the original (unscored) bids would still be used to determine prices for clearing.

Similarly, in the context of a descending clock auction, the analogous idea would be to have the clock prices of "difficult to repack" broadcasters descend more slowly, thus making

[41] Various types of lookahead are quite common, as one example, in chess-playing computer programs, where rather than simulate all possible future trajectories of play after a contemplated move (which would be computationally infeasible), one simulates just the next few possible moves, and chooses moves based on the "quality" of these intermediate states. The idea is to balance near-term reward with longer-term consequences — in the same way we may want to defer repacking a high-valuation broadcaster now because of the future constraints that would impose, we may want to sacrifice capturing a pawn on this move if it could put us in danger of checkmate several moves from now.

them less likely to exit the auction early and thus constrain the repacking process. While the specific goals of introducing such schemes are not discussed at length in the NPRM, presumably one hope is that such scored or modified bids might elicit more computationally and economically efficient behavior from the repacking algorithms.

Another simple example demonstrates the difficulty of designing such scoring or variable clock rate schemes in a way that would have the intended effects, and that actually circumvent the algorithmic problems we have already highlighted. The example also shows a case where the expenditures for clearing are much higher for the clock auction than for VCG.

Example 11. *Let there be the seven broadcasters A, B, C, D, E, F, G whose valuations are as shown in Table 4.*

Table 4: Bidder Valuations

Broadcasters	A	B	C	D	E	F	G
Values of being on air	100	99	3	1	1	1	1

Suppose we wish to clear 5 broadcasters and repack 2. Let the pairs of broadcasters who cannot be repacked on the same or adjacent channels be AB, AC, BD, CE. Then similar to an earlier example, this is a case where the greedy (or clock auction) approach will find a suboptimal solution: First A drops out at price 100*. Then B and C can no longer be repacked, so their clock prices are frozen at* 100*. We then repack D and clear E, F and G at their valuations. The total expenditure is thus* $100 + 100 + 1 + 1 + 1 = 203$*. But a better feasible solution is to repack B, C, and clear A, D, E, F, G, and the associated total expenditure (under VCG) is:* $101 + 2 + 2 + 2 + 2 = 109$*.*

In order for some scoring scheme to avoid this excess expenditure when a greedy algorithm or clock auction is applied, it would need to make the scored price (or clock rate) of A less (or slower) than that of B and C, since it is the first step of choosing A that dooms greedy in this

example. But on what principle would such a scoring or varying rate be based? Notice that all of A, B and C occur in exactly two constraints each, so a simple "constraint counting" scheme will not suffice. Furthermore, this example can be easily modified to actually have B and C have many *more* constraints than A, and yet still elicit the same suboptimal behavior from the greedy or clock approach. It thus seems quite difficult to imagine a simple scheme of this type that eradicates the drawbacks of this approach. The basic problem is that the mere number of constraints a broadcaster appears in, or even information about the more detailed structure and interaction of these constraints, may not help in designing scoring schemes, since one cannot know in advance which constraints will actually matter in (that is, affect the choices of) the greedy repacking process. In this example, the constraints BD and CE were irrelevant once B and C had to be cleared.

15.3 Computational Complexity in Sealed-Bid Auctions

In addition to the descending clock mechanism, the NPRM raises the possibility of some form of sealed-bid reverse auction. In a sealed-bid mechanism, broadcasters are asked to each submit once a price or bid offered for going off-air and clearing their currently used spectrum. Let $B = \{1, \ldots, n\}$ denote the set of n broadcasters or bidders, and for simplicity let us suppose that there is only a single option on which to bid — vacating broadcast spectrum entirely, or not at all. Let $V = \{v_1, \ldots, v_n\}$ denote the *private valuations* the broadcasters assign to remaining on air — that is, the lowest payments they would accept in order to go off-air. Depending on the mechanism, the broadcasters may bid differently than their valuations — for instance, in a pay-as-bid mechanism, there will be an incentive to bid higher than one's valuation, whereas in VCG it is a weakly dominant strategy to bid one's valuation. Thus we also introduce *prices* or *bids* $P = \{p_1, \ldots, p_n\}$ submitted by the broadcasters.

In the same way that the descending clock auction encounters the feasibility checking

variant of the repacking problem, sealed-bid approaches entail a distinct but related computational problem. More precisely, for a targeted number $t \leq n$ of channels to be cleared, we now have an easily stated optimization problem with a well-defined objective function: find that subset W of t "winning" broadcasters to be cleared such that the total expenditure $E(W) = \sum_{i \in W} p_i$ is minimized, *subject to the constraint* that the remaining $n - t$ broadcasters in the set $R = B - W$ can be repacked together. Again, it is this complex combinatorial constraint that makes the computation of the optimal W intractable in general. Note that in the special case of a VCG auction, broadcasters bid their private values as a weakly dominant strategy, so the expenditure $E(W)$ coincides with the *value function* $V(W) = \sum_{i \in W} v_i$, whose minimization corresponds to maximizing the sum of valuations in R.

The NPRM outlines two classes of algorithmic approaches to this problem: *global* algorithms that are generally guaranteed to find an optimal (cost-minimizing) or approximately optimal solution, but that may require inordinate computation time to do so; and what the NPRM refers to as *sequential* (but which could instead be termed *local* or *greedy*) approaches whose solution may be far from optimal, but whose computation time is more modest.

The NPRM further suggests that the repacking constraints are such that the optimization problem falls into the well-known class of Integer Linear Programming (ILP) programs — that is, a linear objective function optimization (in our case, the expenditure function $E(W)$) subject to linear constraints over both continuous and discrete variables. The discreteness arises from presumably multiple sources, including but not limited to the fact that broadcasters must either vacate or not, as opposed to vacating "fractionally," and certain pairs or sets of broadcasters being either mutually exclusive for repacking purposes, or entirely

compatible, but not "partially repackable."[42]

The NPRM discusses[43] taking standard algorithmic approaches to the ILP problem. There exist a wide variety of both open-source and commercial software packages for encoding and solving (integer) linear programming problems.[44] In the case of large scale ILP, none of these packages can guarantee rapid convergence (computation time scales polynomially with the number of variables and constraints) to an optimal or even approximately optimal solution. Since presumably the number of constraints defining the feasibility function F_C is almost certainly in the thousands (possibly even tens or hundreds of thousands), we cannot claim that we have a "small" instance of ILP and argue that brute-force search for the optimal solution would succeed in a reasonable amount of time. The NPRM suggests, without providing any supporting evidence or detail, that existing ILP packages might suffice for finding good approximately optimal solutions. This conjecture is an empirical one that cannot be evaluated without simulation studies using specific ILP packages and specific ILPs based on the actual repacking constraints (or at least constraints broadly similar in their number, size and structure).

15.4 Empirical Evaluations of Reverse Auction Mechanisms

The discussion and examples above emphasize the problems of computational and expenditure inefficiency that *could* arise under the reverse auction designs in the NPRM and MALS proposals. But these examples were obviously based on hypothetical repacking constraints

[42] For example, suppose for each broadcaster i and channel c, we introduce a binary variable $x_{i,c}$ that assumes value 1 if and only if i is relocated to c under repacking, and is 0 otherwise. Then if broadcasters i and j are connected to each other in the repacking constraint graph, in an ILP approach we could introduce, for all channels c, the linear constraints $x_{i,c} + x_{j,c} \leq 1$, $x_{i,c} + x_{j,c+1} \leq 1$, and $x_{i,c} + x_{j,c-1} \leq 1$. These constraints, along with the restriction that the variables $x_{i,c}$ are integer-valued (more precisely, binary), encode the fact that i and j cannot be assigned the same or adjacent channels. (To satisfy each inequality, only one of its two variables may assume value 1.) In this way we can simply represent the repacking constraint network as an ILP.

[43] NPRM, para. 45

[44] See e.g. `http://en.wikipedia.org/wiki/Linear_programming`

of the type suggested in the NPRM, and were designed to exhibit worst-case behaviors of various kinds (though they were simple and did not require complex or unrealistic constructions). The extent to which such difficulties would be encountered in the actual auction depends on a variety of unknown factors, including the detailed structure of the repacking constraints and the likely valuations and bidding behavior of broadcasters.

While eliciting or accurately estimating broadcaster valuations and behavior may be infeasible, doing so for the repacking constraints is not, and would alone permit a variety of activities that could shed significant light on the likely outcomes and potential problems with the various reverse auction designs. Even in the absence of full specification of all repacking constraints, crude approximations — such as identification of which pairs of broadcasters are likely to create interference if repacked on the same or adjacent channels (the aforementioned repacking constraint network) — would allow much better assessment of the proposed auction designs than is currently possible.

The two main activities that would be permitted by having model repacking constraints are simulation studies and the design of specialized algorithms and mechanisms. We discuss each in turn.

Simulation Studies

With model repacking constraints, one could extensively simulate the main proposals for the reverse auction — the descending clock auction and its variants employing algorithms for repacking feasibility checking, and sealed-price mechanisms combined with global optimization using Integer Linear Programming for winner determination. Of course, in both cases one would have to also have a model for broadcaster valuations and bidding behavior, but one could run simulations over a wide variety of assumptions on broadcasters. For example, the simplest model for bidder behavior in the descending clock auction (and the one that in fact motivates that design) is staying in the auction until the clock drops below

the broadcaster's valuation. Armed with models for repacking constraints and valuations, we could thus run large-scale simulations that answered some of the key questions we have raised here:

- For a greedy or descending clock approach, how difficult is the exact feasibility checking problem? How effective are heuristic repacking solutions, such as the myopic feasibility algorithm discussed above? And for these and other variants, how suboptimal are the solutions found in terms of expenditures and amount of spectrum cleared?

- For the sealed-bid/ILP approach, is the computation of winning bids subject to repacking likely to be impractically difficult and slow? If so, is the ILP approach able to at least find acceptable approximately optimal solutions quickly? How much worse are these approximations than the global optimal solution?

To illustrate the kinds of simulation studies that could be performed, the questions they could help investigate, and the benefits of more detailed repacking constraint information, we have implemented a very preliminary simulation framework that allows us to compare various quantities (such as clearing expenditures, computation time, and many others) for the main reverse auction mechanism proposals (as well as potential future variants thereof), and for mechanisms that provide useful economic benchmarks. For example, our framework (which is currently implemented in a mixture of Matlab code and open-source optimization algorithm software) permits the simulation of the following mechanisms:

- The descending clock auction, using either an ILP or constraint satisfaction solver for feasibility checking, under the assumption that broadcasters remain in the auction until their offer falls to their valuation for remaining on-air.

- The descending clock auction, but with the exact solution for feasibility checking replaced by the aforementioned and much faster myopic construction of the repacked set and assignment to channels.

- The sealed-bid VCG mechanism, again under truthful bidding, using an ILP solver for the selection of the expenditure-minimizing set of broadcasters to clear.
- A sealed-bid pay-as-bid (first price) reverse mechanism, evaluated under full-information Nash equilibrium bidding, and again employing ILP for the selection of broadcasters to clear.

Essentially any other variant or proposed mechanism could be incorporated into our simulation framework. Our framework also permits the specification of essentially any set of pairwise repacking constraints and broadcaster valuations. For instance, this allows us to simulate varying numbers of broadcasters, with varying density or number of repacking constraints; varying distributions (parametric forms, variances and means, etc) of broadcaster valuations, etc.

In Appendix D, we provide some very preliminary sample simulation results, which highlight the ways in which different reverse auction mechanisms are influenced by repacking constraints and broadcaster valuations, and the fact that which mechanism is "best" (in several senses) depends strongly on these constraints and valuations, thus emphasizing the need for real data. We expect the scale and sophistication of our simulations to improve with such data and the development of our framework.

Design of Specialized Algorithms

The second activity enabled by model repacking constraints would be the design of specialized mechanisms and algorithms that exploit the special structure of these constraints. The majority of algorithmic work in computer science is devoted to finding good algorithms for special cases of problems that are intractable in the general case. A classic example of this is the Traveling Salesman Problem (TSP), which is NP-hard without any assumptions on the network of "cities" and "distances" between them, but for which there is a very efficient

algorithm yielding very good approximations to the optimal solution if the network corresponds to a physical, 2-dimensional map. TSP is more generally an excellent example of a hard problem on which tremendous practical progress has been made through a combination of simulation studies and designs for special cases.[45]

Armed with model repacking constraints, one could similarly investigate whether a specialized algorithm for cost-minimizing winner selection in a sealed-bid auction could be considerably faster than with a generic ILP approach. The same could be done for the previously discussed problem of feasibility checking in the descending clock auction. Fast and (near-)optimal algorithms for these problems could materially change the assessment of the corresponding mechanism proposals.

15.5 Specific Requests for Repacking Constraint Data

In light of the discussion, examples, and simulations above, it is clear that repacking complexity is a central concern in any reverse auction mechanism, and that the details of the actual repacking constraints and broadcaster valuations will significantly impact the potential computational complexity, costs for clearing, and other properties of the reverse auction. We therefore now discuss various types of information that could greatly aid the study of reverse auction proposals, and lead to the development of better repacking algorithms specialized to the actual constraints.

An ideal along these lines would be a complete mathematical description of all the known repacking constraints, for all broadcasters across the nation, specified in some formal, machine-readable language or notation (e.g. a network of pairwise incompatibilities for adjacent channels, an integer linear program or constraint satisfaction program, etc.) Related, but slightly more general (and thus less informative about the actual specific constraints) would be a program or parametric model that permits the generation of such complete

[45] See e.g. `http://en.wikipedia.org/wiki/Travelling_salesman_problem`

descriptions under varying assumptions (e.g. power and interference assumptions, service contours, acceptable degradations of service, etc.)

It would also be extremely valuable to have a simple network or networks giving pairwise repacking constraints over broadcasters (i.e. the repacking constraint network), or again, parametric mathematical models for the repacking constraint network under varying assumptions. Related data of value would be geographical (latitude and longitude coordinates) for the transmission location(s) of every broadcaster eligible for participation in the reverse auction.

Part IV

Closing Rules

16 The NPRM and MALS Proposals

An important component of the grand auction design is the integration of the forward and reverse auction. This is where "supply" and "demand" meet to determine how much spectrum will be allocated to TV stations, and how much to wireless carriers. Of course, there are important differences from the classic supply and demand setting. One is that prices paid by forward auction buyers must cover not only payments to reverse auction sellers, but costs of repacking and of the auction itself. Another is that the forward and reverse auction prices do not reflect the valuations of bidders on the margin.

Example 12. *Suppose there are two bidders on each side of the market. One of the forward auction bidders ("buyer H") has valuation 100 and the other ("buyer L") has valuation 50. Likewise, one of the reverse auction bidders ("seller H") has valuation 100, and the other ("seller L") has valuation 50. Suppose the target is to clear one license and that there are no repacking constraints. The reverse auction will end at a price of* 100*, the second lowest seller valuation. Seller L will be provisionally assigned to sell his license. The forward auction will end at a price of* 50*, with bidder H the provisional winner. Clearly the net revenue requirement fails: the provisional forward auction revenue is only half the reverse auction cost. This is not because the transfer of spectrum from seller L to buyer H is inefficient; indeed, this trade would double the surplus created by the spectrum. The problem is that instead of comparing buyer H's willingness to pay with seller L's valuation, the auction rules compare buyer L's willingness to pay to seller H's valuation. This comparison has nothing to do with whether trade should occur.*

The fundamental problem is the separation of the forward and reverse auction markets. Although the purpose of the incentive auctions is to allocate scarce spectrum competitively, a clock auction in the forward market induces competition only between mobile wireless carriers; these bidders compete to be among the provisional winners, but do not compete with television stations for final ownership of spectrum. Likewise, a reverse clock auction creates competition only between current broadcast television licensees. Reverse auction bidders compete to be provisional sellers, but the two sides never compete directly with each other to resolve the question of how much spectrum should be transferred from potential sellers to potential buyers. The result is that both the forward and reverse auction will tend to stop too soon, i.e., at prices that are unnecessarily low in the forward auction and unnecessarily high in the reverse auction. Uncorrected, this could undermine efficiency, just as in the example above.

This limitation is recognized by MALS and underlies their proposal that when net revenue falls short the forward auction clock prices would continue rising until either the revenue condition is satisfied or demand falls short of the current target. This can be interpreted as a one-sided *closing trial* for the grand auction at the current target. It allows forward auction bidders to express their willingness to pay prices above the provisional forward auction prices if necessary to achieve satisfaction of closing conditions at the clearing target.

17 Primary Concerns with the One-Sided Closing Trial

The one-sided closing trial contingency still leaves more room for inefficiency than necessary. This is easily seen in Example 12. A price anywhere strictly between 50 and 100 would result in trade. However, no trade will occur even with the closing trial because buyer H will not be willing to beat the provisional reverse auction price of 100. The problem is that while a one-sided closing trial allows forward auction bidders to express their willingness to

offer better prices when necessary to ensure that they are allocated the licenses they seek, there is no such provision for the supply side. Reverse auction bidders lack the opportunity to improve their price offers in the event that closing conditions fail. Thus, even if there are reverse auction bidders who would like to offer prices substantially below those obtained in the reverse auction (recall that these are the maximum prices that clear exactly the target), those bidders will have no opportunity to express this. Put differently, with a one-sided closing trial there is still a barrier to full buyer-seller competition for ownership of the marginal units of spectrum. The result will be unnecessary inefficiency. Some trades that buyers and sellers would all prefer will not take place, not due to the inherent constraints of incentive compatibility, but due to the auction design.

18 Two-Sided Closing Trial

One possible solution to the limitations of a one-sided closing trial seems clear: allow both sides of the market to participate in the closing trial when this phase is required.

18.1 Baseline Proposal

In the baseline proposal, no change to the main forward or reverse auction is needed. However, if the forward auction reaches a point where excess demand is zero but the net revenue condition fails, all parties would be told that the clearing conditions have failed. Prices would then be raised in the forward auction while lowered in the reverse auction. For example, in a sequence of rounds, prices in the forward market could rise by a percentage ρ while those in the reverse auction fall at the same rate. Intra-round bids could be used to avoid overshooting. Bidders on each side would express demand/supply at the clock prices, just as in the original forward and reverse auctions.

Let p_D and p_S denote vectors of clock prices in the forward and reverse auctions, respec-

tively. Let $D(p_D)$ denote the vector of total quantities (e.g., MHz) demanded of each object at the forward market prices, with $S(p_S)$ denoting the vector of total quantities offered for supply at the reverse auction prices. Let Q_t denote the current target clearing quantities.[46] At the beginning of the closing trial we have

$$D(p_D) = S(p_S) = Q_t.$$

The two-sided closing trial would end as soon as either

(a) the revenue requirement is satisfied, or

(b) $\min\{D(p_D), S(p_S)\} < \alpha Q_t$ for some $\alpha \in (0, 1]$.

Condition (b) corresponds to the case in which the closing trial fails. Here $<$ represents the component-wise strict partial order. Thus, if $D^m(p_D)$, $S^m(p_S)$ and Q_t^m are the components of $D(p_D)$, $Q_S(p_S)$ and Q_t corresponding to market m, the condition

$$\min\{D(p_D), Q_S(p_S)\} < \alpha Q_t$$

holds iff *both*

$$\min\{D^m(p_D), S^m(p_S)\} \leq \alpha Q_t^m \ \forall m$$

and

$$\min\{D^m(p_D), S^m(p_S)\} < \alpha Q_t^m \ \exists m.$$

Thus, if $\alpha = 1$, part (b) stops the auction as soon as one bidder (from either side of the market) exits the closing trial. Smaller values of α (for example, $\alpha = \frac{Q_{t+1}}{Qt}$, if clearing targets are uniform across markets) would allow a degree of incomplete clearing of the current target Q_t before triggering a nationwide adjustment to the target to Q_{t+1}. Variations on this rule

[46] Recall that we denote the sequence of clearing targets, beginning with the first, as $Q_1, Q_2, \ldots$.

are possible. For example, one might set the trigger threshold in condition (b) based on nationwide or regional clearance levels rather than by the "worst" market.

If the closing trial ends with condition (a) above, the closing trial succeeds. The grand auction would then terminate. If condition (b) terminates the closing trial, the attempt to clear the target Q_t would fail, the target would be reduced to Q_{t+1}, and the forward and reverse auctions would continue from this point as envisioned in the original MALS proposal.

As long as the clocks in auction $t+1$ are started from the final prices in the auction t closing trial (i.e., strict continuation from the closing trial), incentives for reverse auction bidders are identical to those in the original reverse auction design. The proposed modification does not appear to change incentives in the forward auction either.

The following example illustrates the two-sided closing trial.

Example 13. *Consider a one-market example in which the FCC is attempting to clear 90MHz of spectrum (fifteen channels) in the reverse auction and sell 80MHz of this spectrum in the forward auction in the form of eight 10MHz (5+5) paired licenses (the remaining 10 MHz is reserved for guard bands or other uses). Suppose that the reverse auction stops at a price of 75, whereas each of the 15 stations electing to go off the air at this price values its license at only 50. In the forward auction, prices stop at 100 per license, although the 9 provisional winners each place a value of 130 on a license. Comparing the provisional forward auction revenue of 800 to the provisional clearing cost of 1125, we have a shortfall. Furthermore, a one-sided closing trial is certain to fail: the maximum willingness to pay among the 8 provisional winners in the forward auction is 1040 (i.e., 8×130). Thus, with the MALS auction design, this target will fail and the target quantity will shrink. A two-sided closing trial could avoid this inefficient outcome. Suppose that in the closing trial, prices rise in the forward auction and fall in the reverse auction at equal speeds, adjusting by 1 unit per round. After 15 such rounds, the forward auction revenue* ($8 \times 115 = 920$) *would (more than) cover the reverse auction cost* ($15 \times 60 = 900$). *Thus the closing conditions*

can be satisfied. Note that all bidders should be happy to accept these prices in the closing trial: exiting the closing trial implies moving to a lower target, where the reverse auction price will fall to 50 and the forward auction price will rise to 130. Thus, there will be many information structures in which bidders will voluntarily participate in the closing trial.

18.2 Closing Trial with Proxy Bidding

Including reverse auction bidders in the closing trial would require them to be called back to the auction when the original MALS proposal would not have required this. This would be required only when net revenue falls short and would be required under the MALS proposal as well unless the one-sided closing trial succeeded. Nonetheless, under the proposal for a single-pass reverse auction (see section 14), this could be avoided altogether, potentially simplifying the closing trial contingency. With the single-pass reverse auction, each bidder will have indicated his willingness to relinquish his license across the full range of prices consistent with the possible clearing targets. This means that the FCC could serve as a proxy bidder for TV stations in a closing trial, keeping a bidder in the auction as long as necessary if the price remains above the minimum price acceptable to the bidder.

We emphasize that taking advantage of this does *not* require that the single-pass auction itself be conducted with proxy bidding.

As long as reverse auction bidders trust the proxy system, this would not alter reverse auction bidders' incentives in the single-pass reverse auction. And up to the inherent ambiguities created by the repacking optimizer, it would be possible for bidders to verify the actions of the proxy agent ex post.

The next section will demonstrate an additional advantage of the single-pass reverse auction in promoting efficiency in the closing trial.

18.3 Avoiding Overshooting

A remaining source of inefficiency in the closing trial arises from potential miscoordination of price clocks. For example, consider a market in which one license is to be cleared. Normalize the net revenue requirement to zero. Suppose the provisional prices and valuations of provisional winners are as follows:

	Forward	Reverse
provisional price	6	9
valuation of provisional winner	10	8

In the closing trial, if the forward and reverse auction clocks move at equal absolute speeds, the closing trial will fail when the forward auction clock reaches a price of 7 and the reverse auction reaches a price of 8. This causes the target to fail even though there are substantial gains to trade remaining. Here, in fact, two-sidedness of the closing trial harms the outcome: a one-sided closing trial would have cleared the target at a price of 9.

Ideally, the clocks would by synchronized in a way that reflected the relative gaps between prices and valuations. In the example above, if the forward price moved at a speed proportional to $(10 - 6)$ while the reverse clock moved at a speed proportional to $(9 - 8)$, the closing trial would end successfully with forward and reverse prices equated at 8.4. Even imperfect coordination can improve outcomes. For example, if the forward clock moves at twice the reverse clock speed, the auction again ends successfully, this time at prices equated at 8. Unfortunately, whether it is better to speed up or slow down one clock relative to another depends on bidders' (unknown) valuations.

Note, however, that the key to efficiency is not actually that the relative clocks speeds be coordinated perfectly, but that the clock does not *overshoot* valuations on one side before allowing bidders on the opposite side to express their full willingness to adjust the provisional prices. With the single-pass reverse auction, substantial progress toward this goal can be

achieved using variable clock speeds, exploiting the fact the supply at any possible price vector is already known. As a simple example, forward and reverse auction clocks could be adjusted at identical speeds in the closing trial as long as this does not cause the closing conditions to fail due to a drop in supply, i.e., as long as at the new prices p_S

$$Q_S(p_S) \geq \alpha Q_t.$$

When the proposed change in the clock prices would violate this condition, the reverse auction clocks would stop, and only the forward auction clocks would continue. Variations on this example could achieve the same goal. The key is that, with a single-pass reverse auction, overshooting on the supply side can be avoided.

This modification does not prevent overshooting in the forward auction during the closing trial. Of course, the risk of such overshooting is only worse in a one-sided closing trial. Further, by beginning the two-sided closing trial with the forward auction clock moving more slowly than the reverse auction clock (the latter controlled to avoid overshooting as described above), one could minimize the chance of any overshooting.

One possible concern with our proposed strategy for avoiding overshooting is that it creates incentives for reverse auction bidders to manipulate their bids, exiting at prices a bit above their reservation values. However, because there will be many reverse auction bidders, the expected gain to a single bidder from such behavior may be small relative to the cost of forgoing profitable selling opportunities.

Appendices

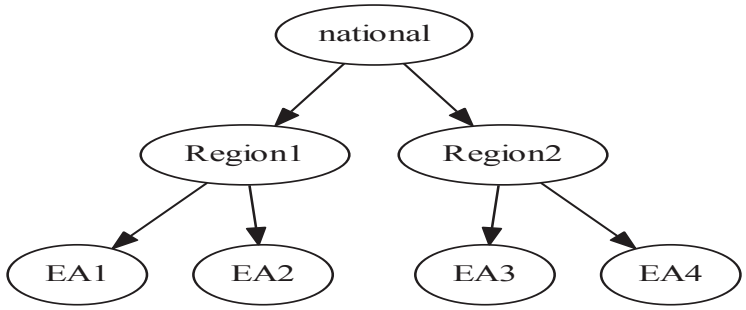
A Clock Package Auction Simulations

The goal of these simulations is to explore the potential performance of the CPA relative to the simple clock auction proposed by MALS. The simulations are not intended to be "realistic" in all aspects. For example, we consider a small number of EAs and do not attempt to create valuations that are realistic in terms of dollar values. Rather, our goal is to illustrate relative performance of the CPA design in a variety of settings aimed at capturing the essential qualitative features likely to be present in the forward auction. The code is written in Matlab and is sufficiently flexible to allow a wide range of further modifications.

A.1 Simulation Design

Licenses and Objects

We specify a three-tier hierarchical structure in which the objects for sale are EA objects, regional objects, and national objects. The scale of the hierarchical structure is controlled by a parameter m. There are $4m^2$ EAs and $2m$ disjoint regions. For our baseline specification we set $m = 1$, yielding the structure illustrated below



The feasible supply of each object is controlled by a parameter k. In our baseline specification we model the case of partially unequal spectrum clearing across EAs. For three quarters of the EAs, we set the feasible supply equal to k; for the remaining quarter, we set the feasible supply to $k-1$. For package objects j, $q_j^f = \min_{k \in \chi_j} q_k^f$ (recall that χ_j represents the children of object j). We set $k = 4$ in the baseline specification.

Bidders

We model three types of bidders: *national bidders*, *regional bidders*, and *local bidders*. National bidders value all objects and obtain additional value (complementarities) when they can obtain a regional license or nationwide license with a guarantee of horizontal contiguity. Each regional bidder is associated with a single region. A regional bidder values the EA licenses in "his" region, and obtains complementarity when he can obtain the regional license with its guarantee of horizontal contiguity. Each local bidder is associated with a single EA and desires one only a license for that EA.

For our baseline specification we have 4 nationwide bidders. We start with 3 regional bidders for each regional license and 2 local bidders for each EA license. However, we use randomization to reduce the numbers of regional and local bidders in each replication, creating variation in the level of competition. This is explained below.

Valuations

Valuations are generated randomly for each replication. The valuations of bidder i are characterized by a vector $V_i = (V_{i1}, \ldots, V_{iJ})$ with one component for each object. We construct the components of each bidder's valuation as

$$V_{ij} = V_{ij}^{+} \times \tilde{V}_{ij}$$

where V_{ij}^{+} is either zero or one (indicating which objects bidder i may place positive value on) and $\tilde{V}_{ij}$ is a random variable reflecting the valuation itself.

For a nationwide bidder i, we set $V_{ij}^{+} = 1$ for all objects j. For a regional bidder i, $V_{ij}^{+} = 0$ for all j with probability α_1. With probability $(1 - \alpha_1)$, $V_{ij}^{+} = 1$ for j corresponding to his regional package and the EAs contained in that package. The randomization has the effect of creating variation across simulations in the number of regional bidders, since assigning a bidder to have no positive valuations is equivalent to eliminating this bidder. Similarly, for a local bidder i, $V_{ij}^{+} = 0$ for all j with probability α_2. With probability $(1 - \alpha_2)$, $V_{ij}^{+} = 1$ for the EA j with which i is associated. All other V_{ij}^{+} are zero. In our baseline simulations we set $\alpha_1 = 1/3$ and $\alpha_2 = 1/2$. This leads to an average of 1 local bidder for each EA license, and an average of 2 regional bidders for each regional package.

For EA objects j, we let

$$\tilde{V}_{ij} = \begin{cases} 0 & \text{w.p. } \alpha_3 \\ \text{u}[0,1] & \text{w.p. } 1 - \alpha_3 \end{cases}$$

for each bidder i (equivalently, for each i such that $V_{ij}^{+} = 1$), where u$[0,1]$ indicates a random draw from a standard uniform distribution. The parameter α_3 is used to create random variation in the number of local bidders, but also introduced additional heterogeneity in package bidders' valuations. These valuations for EA licenses are the building blocks of all valuations. We set $\alpha_3 = 0.1$ in the baseline simulations.

For regional objects j, we let

$$\tilde{V}_{ij} = (1 + \beta_1) \sum_{k \in \chi_j} \tilde{V}_{ik}$$

where β_1 is a random parameter determining the degree of complementarity. For our baseline

specification we let β_1 =u$[0, 1/2]$. Similarly, for the nationwide object, we specify

$$\tilde{V}_{ij} = (1 + \beta_2) \sum_{k \in \chi_j} \tilde{V}_{ik}$$

where β_2 is a random parameter. For our baseline specification we let β_2 =u$[0, 1]$.

Observe that the vectors V_i have length equal to the number of objects. From V_i we construct valuations for all possible subsets of objects i might purchase. For simplicity, we allow bidders to value at most one unit of each object and at most one unit of each EA, whether purchased alone or in a package. To obtain valuations for bundles, when these bundles are not themselves objects, we assume additive valuations. Thus, for example, a national bidder i who purchases a regional license j and an EA license k, where $k \not\subset j$, has valuation for this bundle equal to $V_{ij} + V_{ik}$. Similarly, a regional bidder who obtains two EA licenses j and k without the guarantee of horizontal contiguity provided by the package is assumed to value the component EA licenses with no complementarity, so that his valuation is $V_{ij} + V_{ik}$ for the pair. We let $\bar{V}_i$ denote the resulting extended vector of valuations, which now includes valuations for all objects and for all bundles of objects consistent with the restrictions above.

Note that the costs of the bundles which are not themselves objects in the package auction can be constructed from clock prices in the same way as done for the valuations. For example, if $P = (P_1, \ldots, P_J)$ denotes the current clock prices associated with each object, the cost of purchasing two objects j and k (for example, the regional license and excluded EA license described above) is $P_j + P_k$. We let $\bar{P}$ denote the resulting extended price vector.

Clock Package Auction

The auction begins at a reserve price $r = 10^{-6}$ for each EA object. Reserve prices for package objects are additive in the reserve prices of the EAs they contain We use a negligible bid

increment of 10^{-4}.

We run the CPA with straightforward bidding. At each new vector of prices, for each bidder i we construct the vector

$$\bar{\Pi}_i = \bar{V}_i - \bar{P}$$

which is a list of profits the bidder would obtain from each possible choice of demand if the current prices turned out to be the final prices. Bidder i expresses 1 unit of demand for the profit-maximizing choice from this list. Once the straightforward demands of all bidders are constructed, we calculate the excess demand for each object as described in the text. Clock prices then adjust on objects with excess demand until we reach prices at which there is no excess demand for any object.

MALS Clock Auction

Using the same valuations, we also run the clock auction without packages. The setup is the same, but there are no package objects for sale. Because straightforward bidding in the MALS auction involves significant exposure risk to bidders who have complementary valuations,[47] we assume conservative straightforward bidding. For purposes of generating bids, this is equivalent to setting the complementarity parameters (β_1 and β_2) to zero and having bidders follow straightforward bidding strategies. Thus, given this modification of valuations (and the elimination of package objects in the auction), we generate bidders' profit maximizing demands at each price vector exactly as described above. However, we do not eliminate the complementarities when assessing the value bidders obtain from the final allocation. Thus, if a bidder ends up with all components of a package, we assume he receives a payoff reflecting his full complementarities. This gives a potentially significant "unfair" advantage to the MALS clock auction, since it ignores the fact that complementarities may

[47] Further, in some cases—for example, with symmetric information in Example 1—it requires such bidders to follow strategy that is certain to lead to a loss.

depend on frequency contiguity. Thus the performance gains we find for the CPA will tend to be understated.

A.2 Results: Baseline Specification

We begin with the results under the baseline specification described above. Table 5 summarizes the parameters of our baseline specification.

Table 5: Baseline Parameters

m	=	1
k	=	4
α_1	=	0.33
α_2	=	0.5
α_3	=	0.1
β_1	=	u[0,0.5]
β_2	=	u[0,1]
increment	=	10^{-4}
reservation price	=	10^{-6}
n simulations	=	1000
national bidders	=	4
regional bidders	=	6
local bidders	=	8

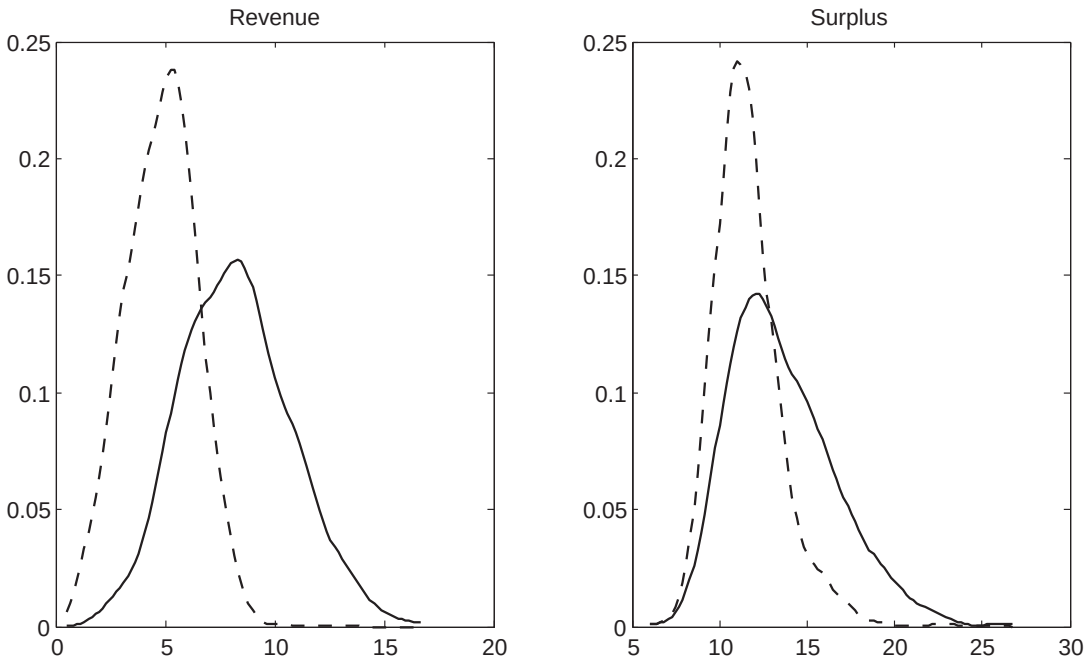
Note that we use the same simulation draws for both the CPA and MALS auction. This avoids introducing simulation error into comparisons and will allow us to make pointwise (replication by replication) comparisons between the two types of auction.

We first examine the performance of the CPA and the MALS clock auction in terms of revenue and efficiency. We measure efficiency by total surplus, i.e., the sum of winning bidders' valuations for the objects they win. This ignores the potential influence of revenues on efficiency via the quantity of spectrum ultimately cleared. Because the CPA consistently generates higher revenue in our simulations, this implies that our comparisons of efficiency are (again) likely to understate the gains from the CPA. We also do not consider re-offering

of unsold licenses when undersell occurs. As seen below, there is slightly more undersell in the CPA, so allowing the re-offer of unsold licenses would only further strengthen the relative performance of the CPA.

Figure 3 illustrates the revenue and surplus outcomes using kernel density estimates applied to the realized revenue and surplus across all 1000 replications.[48] The left panel shows a significant rightward shift in the distribution of revenue when moving to the CPA, indicating significant gains in revenues. There is a similar but smaller rightward shift in the distribution of surplus.

Figure 3: Distribution of Revenue and Surplus



Note: This figure shows kernel density fits to the realized revenue (left panel) and surplus (right panel) across 1000 replications. Solid curves = CPA; dashed curves = MALS auction.

Table 6 shows key summary statistics for these outcomes. Here we report the mean, standard deviation, median, 25th percentile, and 75th percentile of each outcome measure.

[48] Kernel density estimates can be thought of as smoothed histograms. Thus, they illustrate the relative "frequencies" (more precisely, estimates of the relative "likelihoods") of outcomes across the sample.

On average the CPA produces 70 percent higher revenues than the MALS auction, and surplus that is 17 percent larger. In both cases the standard deviation of outcomes is somewhat higher under the CPA. However, much of this is can be accounted for by a change in scale corresponding to better outcomes under the CPA. In particular, the coefficient of variation for revenue is only slightly higher under the CPA than under the MALS design, and the coefficient of variation for surplus is smaller under the CPA.

Table 6: Summary Statistics

	Revenue		Surplus		% Units Sold		Surplus/Optimal	
	CPA	MALS	CPA	MALS	CPA	MALS	CPA	MALS
Mean	8.2	4.8	13.6	11.6	96.8%	99.7%	97.2%	84.3%
Std	2.5	1.6	3.0	1.9	5.1%	1.5%	4.4%	11.1%
Median	8.1	4.9	13.0	11.4	100%	100%	100%	85.5%
q25	6.4	3.7	11.4	10.4	93.3%	100%	95.0%	76.5%
q75	9.9	5.9	15.4	12.6	100%	100%	100%	94.2%

Note: This table reports summary statistics for the baseline simulations. The labels "q25" and "q75" indicate the 25th and 75th (respectively) percentile values of each outcome measure.

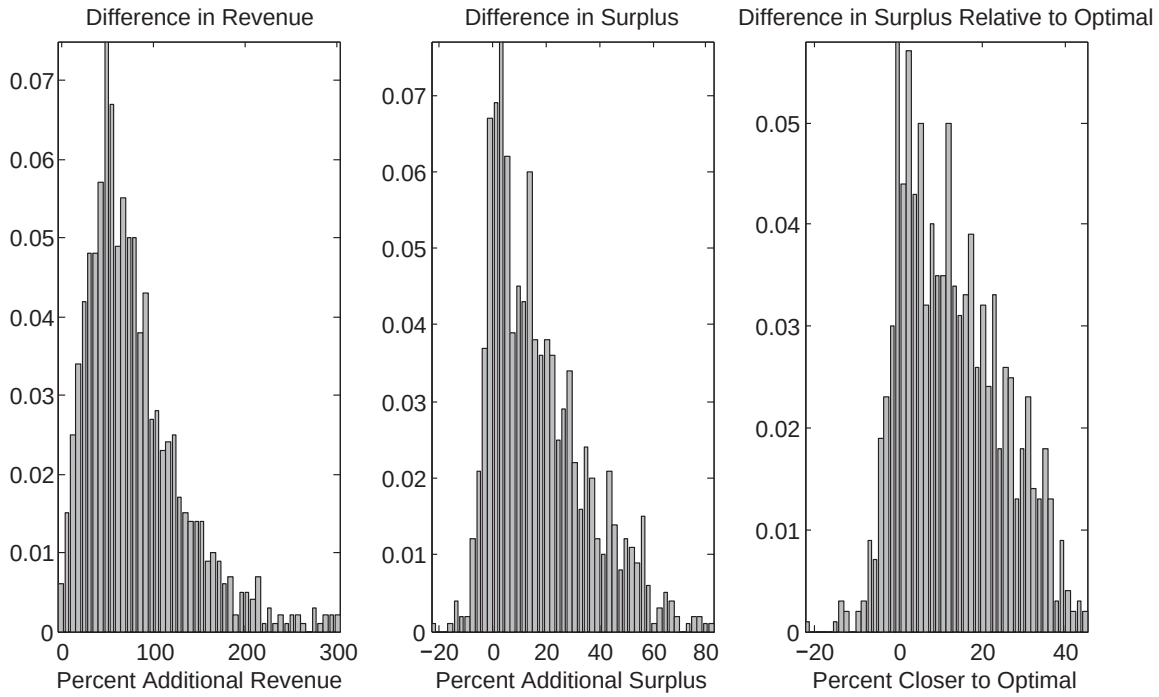
Table 6 also shows the share of licenses sold. The CPA sometimes results in undersell, typically a failure to sell one unit of one EA license. This undersell is occasionally due to lack of demand for some EA object (recall that the number of regional and local bidders with positive valuations is stochastic), but most often due to imperfect coordination of price clocks (recall Example 9). Nonetheless, the degree of undersell is small, with 97 percent of licenses selling on average, and 100 percent of license selling in more than half the replications. Undersell occurs rarely in the MALS auction under conservative straightforward bidding.

Table 6 also reports the surplus achieved as a share of that in the efficient (i.e., first-best) allocation. This comparison shows that the gains in efficiency simply could not be much

greater than what is achieved by the CPA. The CPA significantly outperforms the MALS auction, achieving 100 percent of the efficient surplus more than half the time, and 97 percent on average. The MALS auction achieves full efficiency much less often and yields only 84.3 percent of the efficient surplus on average.

Figure 4 provides another way of looking at the same outcomes. Here we show histograms of the differences in revenue, surplus, and share of the efficient surplus *replication by replication*. We knew that there was no strict dominance relation between the two auction designs. Further, even if the CPA outperforms the MALS auction with high probability, there could in principle be replications in which the CPA does much worse. Figure 4 reveals that this is not the case. Each panel summarizes the pointwise (replication by replication) differences in performance. These difference can be interpreted as the gains from the CPA, although the "gains" can be negative. The first panel shows that the CPA generates higher revenues in virtually all (99.6 percent) of the replications. The magnitude of the gap is often quite large. As shown in Table 7, the median percentage gain in revenue from the CPA is 67.1 percent, and the 75th percentile gain is more than 100 percent.

Figure 4: Distribution of the Percent Difference



Note: This figure shows the histogram of the pointwise (replication by replication) differences between the CPA and MALS auction designs in terms of revenue, surplus, and share of first-best surplus achieved.

The second panel of Figure 4 shows that CPA also generates strictly greater efficiency than the MALS auction in a large majority (85.9 percent) of the replications. Table 7 shows that the median efficiency gain is 13.5 percent. In 11.7 percent of the replications the CPA yields lower surplus, but on average the CPA yields a 17.5 percent gain.

Table 7: Summary Statistics : Pointwise CPA Gains

	Revenue	Surplus
Mean	82.8%	17.5%
Std	70.0%	18.0%
Median	67.1%	13.5%
q25	42.7%	3.2%
q75	105.1%	28.0%

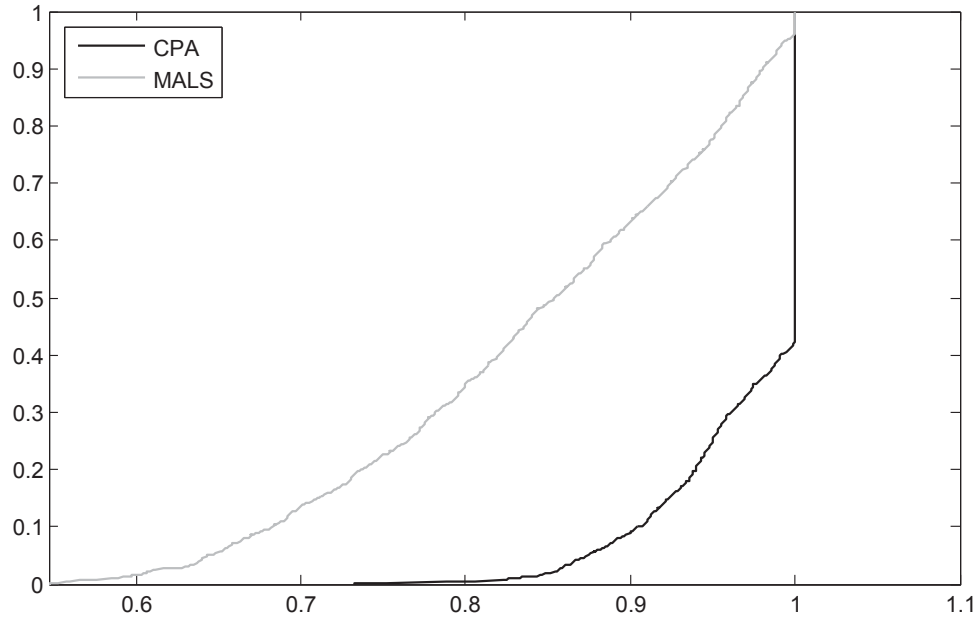
Note: This table summarizes the distribution of outcomes obtained across 1000 simulations. The numbers represent the percent differences between the outcome in the CPA and that in the MALS auction.

In the third panel of Figure 4 we normalize (divide) the surplus outcomes by the first-best surplus, showing the distribution of differences in the share of the efficient surplus achieved (i.e., share under CPA minus share under MALS). As already shown, there are some replications in which the MALS auction is closer to full efficiency. However the gap in these cases is typically small, and a preponderance of replications demonstrate significant efficiency gains from the CPA design. As already shown in Table 6, these gains reach full efficiency in more than half the replications.

Figure 5 illustrates the efficiency outcomes in yet another way, showing the empirical distribution of total surplus achieved normalized by the first-best surplus.[49] Here we see the substantially stronger performance of the CPA. For example, the CPA achieves at least 90 percent efficiency in over 91 percent of the replications. The MALS auction achieves this level of efficiency in only 37 percent of the replications.

[49] The *empirical distribution* plots the share of replications (on the vertical axis) in which the efficiency achieved is *lower* than the level indicated by the horizontal axis. For example, at 100 percent efficiency (horizontal axis equal to 1) the figure shows that fewer than 42 percent of the replications yielded less than full efficiency. Put differently, the vertical segment of the CPA empirical distribution at 100 percent efficiency indicates that more than 58 percent of replications achieved the first-best allocation.

Figure 5: Empirical Distribution of Surplus Relative to the Optimal



A.3 Sensitivity Analysis

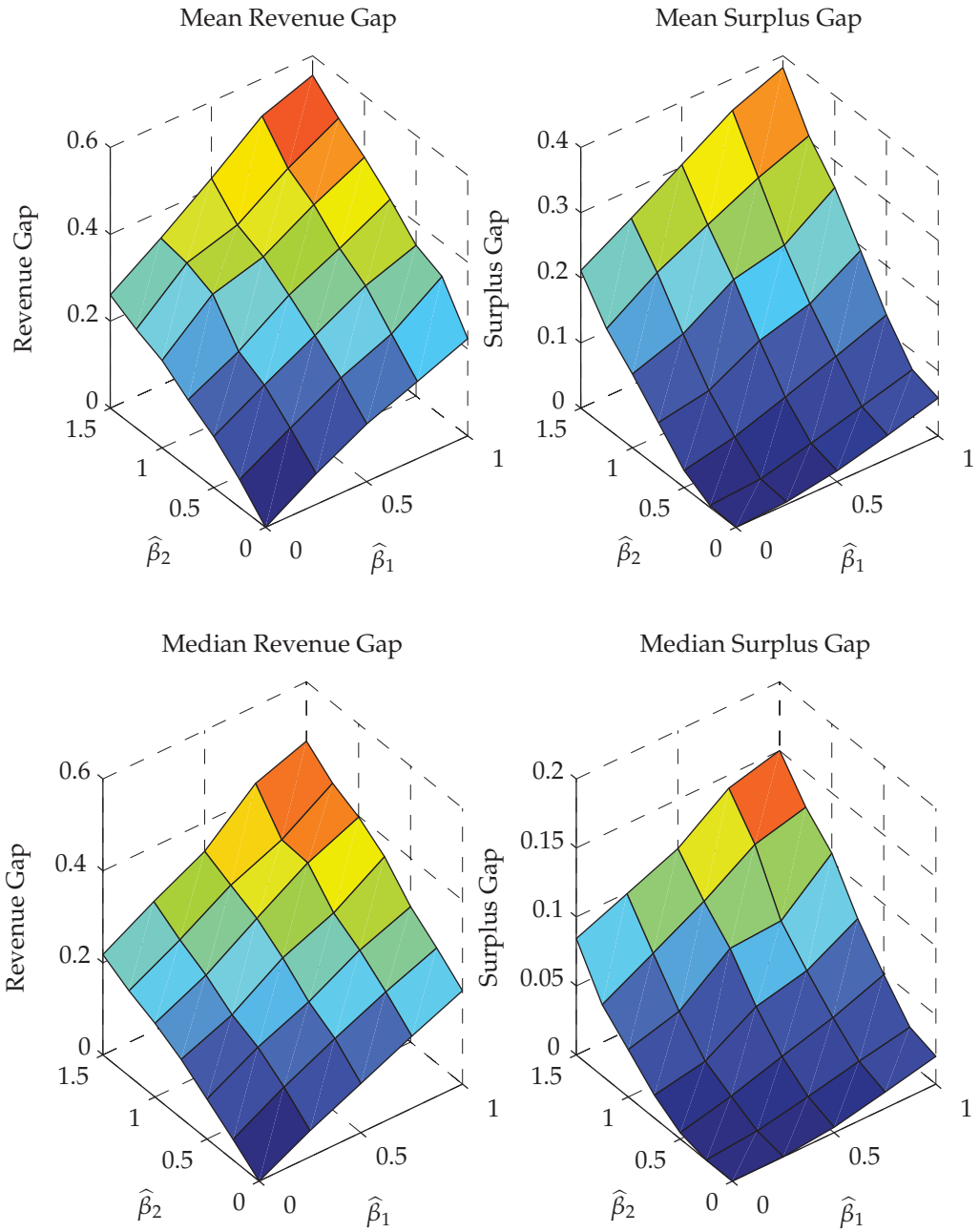
Strength of Complementarities

We first consider the sensitivity of the simulation results to the strength of the complementarities, as determined by the distributions of the parameters β_1 and β_2. We do this by altering the supports of the uniform distributions. Specifically, we let $\beta_1 \sim u[0, \hat{\beta}_1]$ and $\beta_2 \sim u[0, \hat{\beta}_2]$ and re-run the simulations using different combinations of values for the parameters $\hat{\beta}_1$ and $\hat{\beta}_2$. We let $\hat{\beta}_1$ vary between 0 and 1, while $\hat{\beta}_2$ varies between 0 and 1.5. At each pair of values $(\hat{\beta}_1, \hat{\beta}_2)$ we run 500 simulations.[50]

We summarize our findings in Figure 6, where we show the mean and median gains in revenue and surplus from the CPA at each combination of parameters. As we would expect, larger values of the complementarities lead to larger gains from the CPA. However, the qualitative findings remain consistent with those in our baseline specification.

[50] Results change very little with a larger number of draws.

Figure 6: Sensitivity Analysis



Note: These figures show the percent difference (CPA minus MALS) in revenue and surplus of the mean and the median comparison over 500 simulations. For each set of simulations, β_1 and β_2 are drawn randomly for each auction from uniform distributions with supports $[0, \hat{\beta}_1]$ and $[0, \hat{\beta}_2]$, respectively.

Within-Auction Complementarity Heterogeneity

In our baseline specification the complementarity parameters β_1 and β_2 were drawn once for each auction replication. Thus the same complementarity parameter applied to every regional and national bidder. Because these parameters interact multiplicatively with valuations, this implies different levels of complementarities for each bidder. Nonetheless, it may be more reasonable to treat the complementarity parameters as themselves varying across bidders. We have therefore re-run the baseline simulations drawing β_1 and β_2 randomly for each bidder in each simulated auction. We summarize the results in Tables 8 and 9. Comparing the results to those in Tables 6 and 7, we see that the outcomes are nearly identical to those in the baseline specification.

Table 8: Summary Statistics

	Revenue		Surplus		% Units Sold		Surplus/Optimal	
	CPA	MALS	CPA	MALS	CPA	MALS	CPA	MALS
Mean	8.1	4.9	13.7	11.6	96.2%	99.7%	97.0%	82.6%
Std	2.0	1.6	2.4	1.8	5.9%	1.6%	4.8%	8.9%
Median	8.1	4.8	13.5	11.5	100%	100%	100%	82.7%
q25	6.8	3.8	12.1	10.5	93.3%	100%	95.0%	76.3%
q75	9.5	6.0	15.3	12.5	100%	100%	100%	89.2%

Note: This table summarizes outcomes obtained across 1000 simulations using random draws of β_1 and β_2 for each bidder.

Table 9: Summary Statistics : Pointwise Comparison

	Revenue	Surplus
Mean	77.9%	18.9%
Std	55.0%	15.4%
Median	66.2%	17.8%
q25	44.3%	7.4%
q75	96.9%	29.1%

Note: This table summarizes the distribution of outcomes obtained across 1000 simulations using random draws of β_1 and β_2 for each bidder. The numbers represent the percent differences between the outcome in the CPA and that in the MALS auction.

B Other Concerns with CCA Supplementary Bidding

We provide further details on the concerns associated with a combinatorial clock auction (CCA) approach to supplementary bidding in Section 9.

First, bidders in the proxy phase may not have appropriate incentives for bidding for all relevant packages, and clock bids that are used to impute for the missing package bids may not accurately price the "social opportunity costs." To illustrate, suppose there are four units of a (homogeneous) license, and there are two bidders 1 and 2, each of whom values his i-th unit at $5 - i$, for $i = 1, 2, 3, 4$. Suppose the clock price rises in small increments each round from zero. If bidders bid straightforwardly and truthfully, then the clock auction ends with each bidder winning two units at the price of 2. All four units are sold, and this means that under the suggested activity rule (e.g., Ausubel and Cramton (2011)) the allocation is not changed, and more importantly, any profile of feasible strategies by the bidders forms an equilibrium, meaning that each bidder is indifferent across all feasible package bids (see Levin (2011) for instance). It is then conceivable that the bidders may not bid at all or only bid for their winning packages. Suppose the bidders make no supplementary bids.[51] In that case, the "proxy agent" uses the clock bids to impute the bidder's package bids, so the bids of 4, 6 and 4 will be entered as bids for packages of 4, 3 and 2 units, respectively.[52] Notice that these package bids understate the bidder's true values, which are $10(= 4+3+2+1), 9(= 4+3+2)$ and $7(= 4+3)$, for 4, 3 and 2 units, respectively. Since the preferences are substitutable, the prices charged for the winning bidders are VCG, but importantly they are computed based on the "imputed" package bids. Consequently, each bidder pays $2 = 6 - 4$,[53] below the true VCG payment, $3 = 10 - 7$.

[51] A similar result holds if they bid only for the winning package of the clock phase.

[52] Interestingly, the package bids can be non-monotonic. Of course, the non-monotonicity may arise even if the bidders do make supplementary bids, given their indifferences. Incidentally, such a non-monotonicity has been observed in the UK 10-40GHz auction.

[53] That is, the price is the value of the most profitable package for the opponent, which is no more than 6, minus the value of the opponent's winning package, which is 4.

Second, the ambiguous bidding incentives in the proxy phase may make CCA susceptible to collusion. Bidders have a relatively simple way to support a collusion. They can (tacitly) agree to divide the licenses among themselves, and they can drop their demands quickly (but dropping one unit at a time for each increment) to their agreed-upon levels. In the proxy phase, they can simply go "quiet" and not make any supplementary bids, unless some bidder has deviated in the clock phase, in which case they all bid truthfully for the packages in the proxy phase.[54] This behavior can be supported as an equilibrium due to the feature that bidders become indifferent over all of their feasible bids in case all license are sold; the indifference means that a bidder has no obvious incentive to deviate from a collusive agreement. More importantly, even bidding straightforwardly during the clock phase can lead to a collusive outcome, as illustrated above.

Third, the ambiguous bidding incentives in the proxy phase could compromise bidders' incentive for bidding truthfully in the clock phase and could lead to an inefficiency, as pointed out by Levin (2011). To see this, consider the above example again. There exists an equilibrium in which bidder 1 bids slightly more than 3 for the third unit to win 3 units and bidder 1 bids true marginal values to win only 1 unit, and thereafter in the proxy phase bidder 1 bids truthfully and bidder 2 goes "quiet" and makes no bid. As noted, since all items are sold in the clock phase, any strategy profile, including the described behavior, is an equilibrium in the proxy phase. Given this behavior in the proxy phase, the described behavior of the bidders in the clock phase is supported as an equilibrium.[55] Clearly, the resulting allocation is inefficient.

[54] This is possible if they had demanded such packages in the clock phase.

[55] Against the truthful bidding by bidder in the proxy phase, bidder 2 can do no better than bidding true marginal values in the clock phase. Against the "quiet" behavior by bidder 2, bidder 1 pays only $2 = 6 - 4$, whereas if he wins only 2 units, he will still pay $2 = 6 - 4$ (as observed earlier).

C Proof of Theorem 4

Theorem 4. *Consider the MALS reverse auction and assume that clock prices decline continuously and with speeds that do not depend on the actions of bidders. Then straightforward bidding is a weakly dominant strategy for all bidders.*

Proof. Consider an arbitrary bidder i. Let $v_{i0}, v_{i1,} \ldots, v_{iK}$ denote i's valuations of each option, where option 0 is "exit" (remain in one's currently assigned band) and options $1, \ldots, K$ are relinquishment options. Let $p_i = (p_{i0}, \ldots, p_{iK})$ denote the clock prices offered to bidder i at a given instant in the auction. The price p_{i0} is always zero. The price of an option k that is infeasible for bidder i is specified as $p_{ik} = -\infty$. For each $k = 0, \ldots, K$ let

$$\pi_{ik}(p_i) = v_{ik} + p_{ik} - v_{i0}.$$

Thus, $\pi_{ik}(p_i)$ represents the gain (relative to the "exit" option) i would realize at the current clock prices by choosing option k. Of course, $\pi_{i0}(p_i) = 0$. Let

$$\bar{\pi}_i(p_i) = \max_k \pi_{ik}(p_i).$$

We will need to consider three possible types of deviations from the straightforward bidding strategy (the strategy of choosing option $k^*(p_i) \in \arg\max_k \pi_{ik}(p_i)$ at every price vector p_i). (i) Suppose i exits when $\bar{\pi}_i(p_i) > 0$. Since exit is irreversible, this deviation has no effect on i if he would ultimately have been assigned option 0 by following straightforward bidding. So this deviation can affect i only when it changes his final assignment from some $k > 0$ to 0. Since straightforward bidding guarantees i a payoff of at least v_{i0} and could have led to strictly higher payoff (e.g., if all others exited immediately at their current price offers), exiting when $\bar{\pi}_i(p_i) > 0$ is weakly dominated at p_i. (ii) Now suppose i chooses an option $k > 0$ even though $\bar{\pi}_i(p_i) < 0$. Relative to straightforward bidding when the price

vector is p_i, the only way this choice could change i's payoff is if i ends up assigned to some option $k > 0$. But in such cases i's payoff is strictly less than v_{i0}. Since v_{i0} is the lowest payoff i can receive under straightforward bidding, this deviation is weakly dominated. (iii) The remaining possible deviations from straightforward bidding involve choosing an option $j \notin \arg\max_{k>0} \pi_{ik}(p_i)$ when $\bar{\pi}_i(p_i) > 0$. Because this choice does not change the subsequent price offers to i or other bidders, the only way this deviation from straightforward bidding can change i's payoff is when p_i turns out to be the final price vector i is offered. In this case, he would have been strictly better off following the straightforward bidding strategy. Thus, at any p_i, straightforward bidding is weakly dominant.

D Reverse Auction Simulations

In this section we describe simulation results for the following four reverse auction mechanisms:

- The descending clock auction, using either an ILP or constraint satisfaction solver for feasibility checking, under the assumption that broadcasters remain in the auction until their offer falls to their valuation for remaining on-air. In the figure legends below, this mechanism is referred to as *descending clock*.
- The descending clock auction, but with the exact solution for feasibility checking replaced by the much faster myopic construction of the repacked set and assignment to channels. In the figure legends below, this mechanism is referred to as *myopic clock*.
- The sealed-bid VCG mechanism, again under truthful bidding, using an ILP solver for the selection of the expenditure-minimizing set of broadcasters to clear. In the figure legends below, this mechanism is referred to as *VCG*.
- A sealed-bid pay-as-bid (first price) reverse mechanism, evaluated under full-information Nash equilibrium bidding, and again employing ILP for the selection of broadcasters to clear. In the figure legends below, this mechanism is referred to as *pay-as-bid full-info Nash*.

For these four mechanisms and equilibrium concepts, we consider all six pairwise comparisons of expenditures for clearing 7 broadcasters out of 10 and repacking 3. In Figure 7, the repacking constraint network is generated randomly at various edge densities (0.25, 0.5, and 0.75) over the 10 broadcasters, and the valuations of broadcasters are independent random values between 0 and 100. Each point in Figure 7 corresponds to a single such random trial, and shows the expenditure for clearing three broadcasters for each method on that trial. Points above the diagonal are a win for the mechanism+equilibrium concept on the

x-axis, while points below are a win for the one on the y-axis. In general, the problems become harder with higher edge density (more repacking constraints). Figure 8 is similar in spirit, but instead shows comparisons at the fixed edge density 0.5, but with the number of broadcasters k to be repacked varying from 2 to 4.

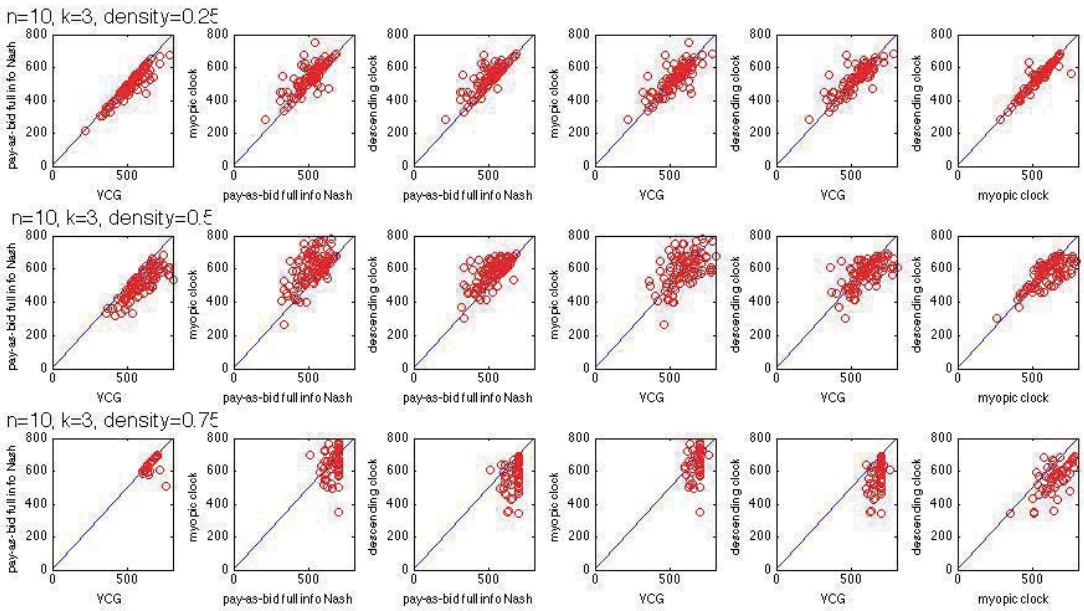


Figure 7: Comparison of mechanism expenditures with varying repacking constraint network edge density.

The main takeaways from these preliminary plots are:

- Even within this artificial family of generated networks, valuations, etc., there are significant differences between the expenditures and other properties of the solutions found by the various mechanisms, and these differences depend on the parameters.
- For example, the clearing expenditures of the clock auction are generally higher than those of pay-as-bid Nash at low edge density, but are generally lower at high edge density. The clock auction expenditures are generally comparable to those of VCG, except at high edge density, where the clock auction tends to spend less.

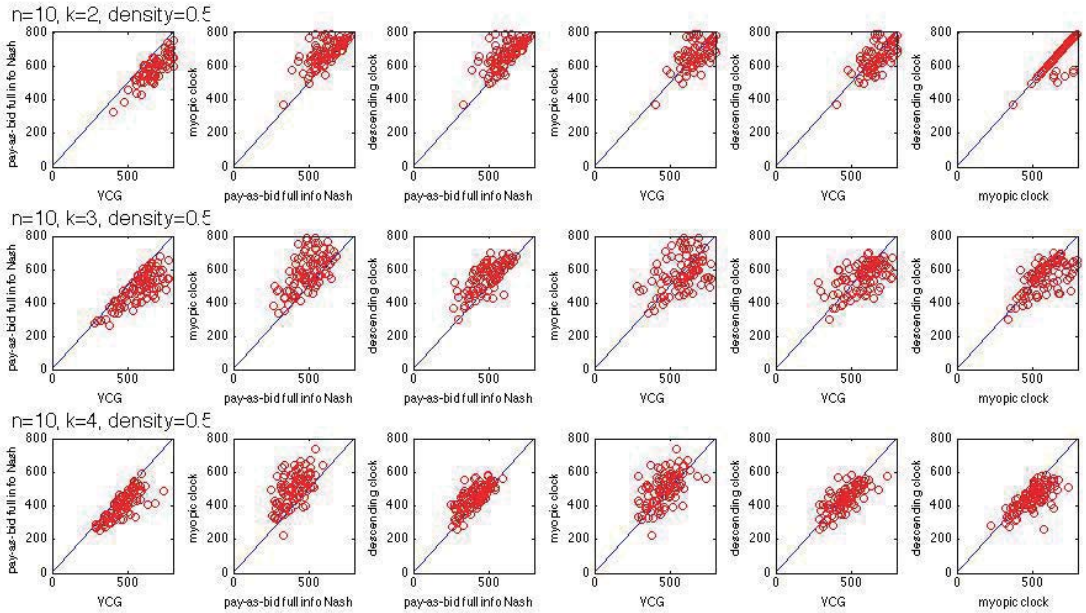


Figure 8: Comparison of mechanism expenditures with varying clearing targets.

- The myopic clock auction — the version of the clock auction where exact feasibility checking is replaced by the computationally efficient myopic assignment algorithm — competes well with the standard clock auction at low to moderate edge density. At high edge density, it starts to underperform due to its clearing more stations than necessary.

- Related observations can be made for varying numbers of broadcasters to repack.

Figure 7 and 8 compare the mechanism expenditures in absolute ("dollar") terms, but perhaps more relevant are the relative expenditures, as measured by the ratio of expenditures for each pair of mechanisms as we vary edge density or clearing target. The maximum and minimum ratios for each pair of mechanisms is thus shown in Figure 9 for each setting of the parameters.

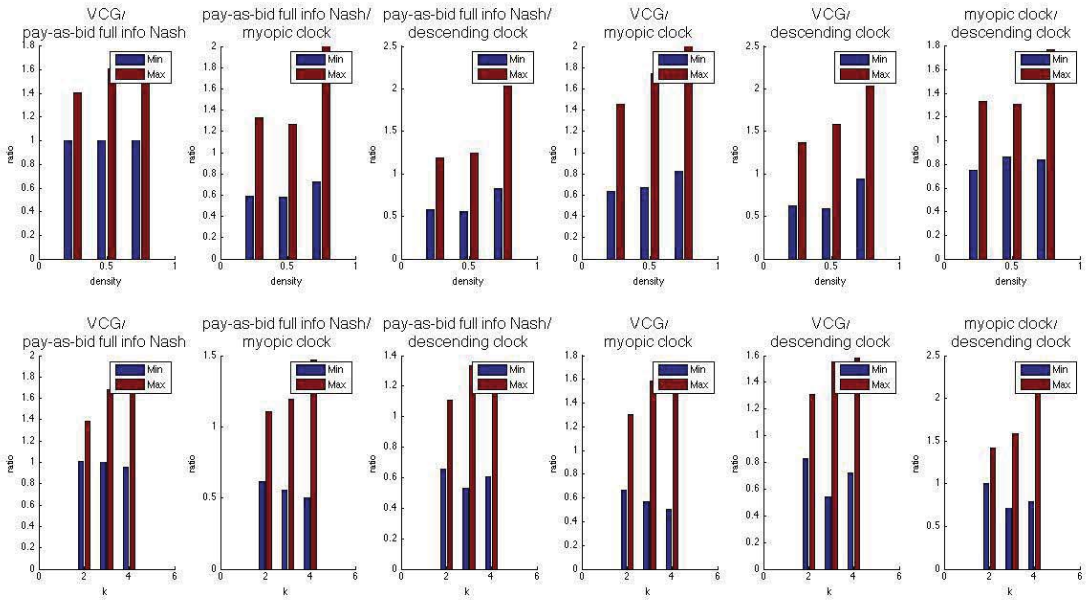


Figure 9: Maximum and minimum expenditure ratios for the mechanisms.

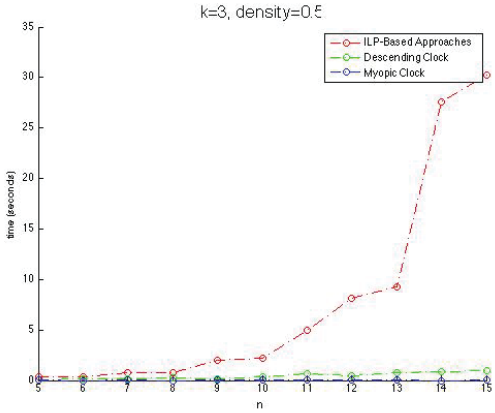


Figure 10: Computation time for the mechanisms as a function of problem size.

Finally, in addition to comparison of solution properties such as clearing expenditures, our simulation framework also permits computational comparisons and benchmarking. For example, in Figure 10, we show computation time (averaged over multiple trials) for each mechanism as a function of the number of broadcasters n. Since the computation time for both VCG and pay-as-bid sealed full-information Nash are dominated by calls to an ILP

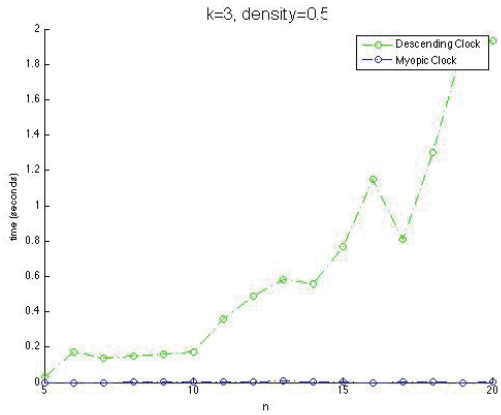


Figure 11: Computation time for the clock mechanisms as a function of problem size.

solver, we plot them together as "ILP-based approaches". We can see that the computation for these approaches grows rapidly as n increases, much more so than for the two clock auction variants. Since the scale is dominated by the ILP running time, in order to compare the clock auctions we show their computational needs on a separate plot in Figure 11. Here we see the standard clock auction running time growing much more rapidly than the guaranteed-efficient myopic clock auction.

References

Ausubel, L. M., and P. Cramton (2011): "Activity Rules for the Combinatorial Clock Auctions," Discussion paper, University of Maryland.

Ausubel, L. M., P. Cramton, and P. Milgrom (2006): "The Clock-Proxy Auction: A Practical Combinatorial Auction Design," in *Combinatorial Aucions*, ed. by P. Cramton, Y. Shoham, and R. Steinberg, pp. 115–138. MIT Press.

Ausubel, L. M., and P. Milgrom (2002): "Ascending Auctions with Package Bidding," *Frontiers of Theoretical Economics*, 1.

Ayres, I., and P. Cramton (1996): "Deficit Reduction Through Diversity: How Affirmative Action at the FCC Increased Auction Competition," *Stanford Law Review*, 48, 761–815.

Cramton, P. (2008): "A Review of the 10-40 GHz Auction," Discussion paper, Office of Communications, United Kingdom.

Cramton, P. (2012): "Spectrum Auction Design," Discussion paper, University of Maryland.

Cramton, P., Y. Shoham, and R. Steinberg (eds.) (2010): *Combinatorial Auctions*. MIT Press.

Federal Communications Commission (2012): "Notice of Proposed Rulemaking," FCC 12-118, September 28, 2012.

Levin, J. (2011): "New Development in Auction Theory and Practice," Lecture Slides, Cowles Foundation, Yale University.

Milgrom, P., L. Ausubel, J. Levin, and I. Segal (2012): "Incentive Auction Rules Options and Discussion," Auctionomics and Power Auctions.

Myerson, R. B., and M. A. Satterthwaite (1983): "Efficient Mechanisms for Bilateral Trading," *Journal of Economic Theory*, 29, 265–281.

Pagnozzi, M. (2010): "Are Speculators Unwelcome in Multi-Object Auctions?," *American Economic Journal: Microeconomics*, 2, 97–131.

ATTACHMENT

3

Reply Analysis of
Yeon-Koo Che and Phil Haile

March 12, 2013

Introduction

We have been asked by counsel for AT&T to respond to comments filed on the FCC's proposed incentive auctions. In Che, Haile and Kearns (2013) (henceforth "CHK") we provided extensive comments on the FCC's Notice of Proposed Rulemaking and accompanying proposal of Milgrom, Ausubel, Levin and Segal (2012) (henceforth "MALS"). Many of our responses to comments by others will refer to our discussion and proposals in CHK.

In general, most commenters agreed with our assessment that the MALS proposals regarding the forward and reverse auctions offered a strong baseline from which to build a final auction design.

For the forward auction, commenters generally agreed with us that the MALS design offers substantial improvements over the Simultaneous Multi-Round ("SMR") auction used in prior FCC spectrum auctions. There was general support for the use of clocks and generic licenses in particular. Many commenters also agreed with our concern about the exposure problem, which remains unaddressed by the MALS auction design and is likely to limit auction revenue, distort bidding behavior, and lead to inefficient allocations. On the other hand, some commenters expressed concern about the potential for introducing package bidding to the forward auction. In particular, some view package bidding as inherently too complex. Others object to package bidding based on a view that package bidding discriminates against small bidders.

A specific package bidding proposal was offered in CHK. As we explain below, our Clock Package Auction (CPA) proposal avoids the pitfalls underlying the commenters' concerns. The CPA alters the MALS design in only three ways:

1. It expands the set of objects offered to include a small number of packages, using a geographically driven hierarchical package design closely tied to the actual structure of bidder complementarities between spectrum licenses.
2. It specifies how excess demand can then be properly calculated.
3. It provides a rule governing price clocks that ensures that package prices are additive in the prices of the package components when possible.

The CPA proposal does not add significant complexity to the MALS auction design. Indeed it simplifies bidding for most bidders by providing a means of addressing the exposure problem, thereby avoiding the need for schemes by package bidders to reduce their exposure risk and

schemes by component bidders seeking to take advantage of others' exposure risk. Such strategies have been prevalent in past FCC spectrum auctions and create high demands on the sophistication of bidders seeking to bid optimally.

While this yields an important reduction in complexity relative to the MALS proposal, the MALS proposal's use of price clocks and generic licenses already simplifies bidding substantially relative to the SMR auction design. Thus, the CPA proposal design in fact offers substantial reductions in complexity relative to past FCC auctions.

We also explain below that the CPA does not discriminate against small bidders. Indeed the opposite is true. Contrary to common assertions that package bidding creates a threshold problem, we show that the threshold problem already arises in the MALS auction. Further we see no new potential for a threshold problem in the CPA that does not already exist in the MALS auction. In fact, there is at least one sense in which the CPA reduces the severity of the threshold problem relative to the MALS design and, *a fortiori*, the SMR auction design.

On the other hand, the CPA offers two specific corrections of biases against small bidders that exist in the MALS auction design. One is the exposure problem. Although exposure risk would affect almost all bidders in the MALS auction, it is important to recognize that small bidders seeking to enter the market are among those that need protection against this risk. The CPA offers such protection. The second bias against small bidders in the MALS auction design is the "overflow problem." As discussed in CHK, this flaw in the MALS design will tend to force small bidders out of the market by raising the prices they must pay even when their demands are not a source of scarcity. The CPA eliminates the overflow problem.

We also discuss general concerns that the CPA would be susceptible to incentives for manipulative bidding. We consider several specific types of manipulative strategies that might be attractive in other types of auctions and demonstrate that the specific rules of the CPA make these strategies unattractive to bidders. We see no new incentives for bid manipulation in the CPA relative to the MALS auction. Indeed, because elimination of the exposure problem eliminates the need for bidding schemes aimed at minimizing exposure risk (or exploiting that of other bidders), there may be fewer incentives for manipulative bidding in the CPA than in the MALS auction.

Finally, we address concerns about the reverse auction design raised by some commenters. We argue below that from a bidder's perspective there is no significant difference between a sequential and interleaved auction design. We also point out that, unlike other "sealed bid"

auction designs, the option to conduct the reverse auction by proxy bidding would not complicate bidding but would simplify it.

Complexity of Package Bidding

Several commenters suggest that package bidding is inherently complex.[1] This is true if one assumes that package bidding implies allowing bidding on all possible combinations of licenses. Even with generic licenses, with 172 EAs in the 50 states, this gives roughly 6 sexdecillion (6×10^{51}) different packages on which bids might be made!

However, package bidding is not synonymous with unrestricted packages. Further, the Clock Package Auction (CPA) proposed in CHK specifies a limited set of packages. Although in principle complementarities between objects in a multi-object auction could be arbitrary, in the case of spectrum licenses complementarities depend primarily on geographic contiguity and population distribution. This makes it possible to restrict the set of packages severely in terms of the number of packages considered while still allowing bidders to effectively express the relevant complementarities in their valuations.

Under the specific CHK proposal to offer EA licenses, MEA licenses, REAG licenses, and nationwide licenses, the number of objects for sale would increase from 172 to 229. Aside from the introduction of these objects, the CPA is essentially identical in complexity (indeed, in almost all dimensions) to the MALS ascending clock auction. The generic treatment of licenses keeps decision making as simple as possible and avoids the possibility that identical licenses sell at different prices. And bidders need not choose what to bid but only which objects they wish to demand at the current clock prices. Even with the proposed addition of package objects, the ascending clock auction design is in fact much simpler than the SMR auction that has been used in previous FCC spectrum auctions.

Further, the addition of packages will actually *reduce* complexity for most bidders, who will seek multiple complementary licenses. Unlike auctions that exclude packages, bidders in the CPA need not develop strategies for managing the severe exposure risk that would otherwise be involved in bidding for combinations of licenses needed by an entrant to build a viable network or by an existing provider seeking to make effective use of the newly offered spectrum band. Even bidders seeking single licenses face a simpler bidding problem in the CPA, as they

[1] *See, e.g.*, Comments of United States Cellular Corporation, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 51 (Jan. 25, 2013) ("USSC Comments"); Comments of Cellular South, Inc., *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 5 n.11 (Jan. 25, 2013) ("Cell South Comments").

have no incentives to manipulate their bids in attempts to exploit the exposure risk of package bidders.

Package Bidding and Treatment of Small Bidders

The Threshold Problem

Several commenters express concern about the effect that package bidding would have on small bidders, due to the "threshold problem" (Bykowsky, Cull and Ledyard (2000)).[2] The threshold problem can arise when a package bidder is competing against multiple bidders, each seeking a component of the package. In such situations, the "small bidders'' may have incentives to free ride by holding back their demand in the hope that others will contribute more toward pushing the sum of the component prices past the willingness to pay of the package bidder. Such free riding can result in allocation of licenses to the package bidder even when the small bidders together place greater value on them than the package bidder does.

The threshold problem is a potential concern in most types of auctions in which some bidders view licenses as complements. This includes the MALS auction, the SMR auction used in previous FCC auctions, and the CPA variation of MALS. However, we see no potential for a threshold problem in the CPA that does not also exist in the MALS auction (or in an SMR auction). And, as we show below, there is at least one sense in which the threshold problem can be more severe in the MALS auction than in the CPA**.**

The threshold problem has been discussed extensively since the first FCC spectrum auctions. Unfortunately, this discussion has often been imprecise. It is commonly asserted that the threshold problem is introduced by combinatorial auction designs. This is incorrect. The threshold problem exists in many auctions without combinatorial bidding, including the SMR auction used in previous FCC auctions and the MALS clock design proposed for the forward auction in the upcoming incentive auctions.

[2] *See, e.g.*, USSC Comments at 53; Comments of the MetroPCS, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 14 (Jan. 25, 2013) ("RTG Comments"); Comments of the Rural Telecommunications Group, Inc., *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, at 9 (Jan. 25, 2013) ("RTG Comments").

We will illustrate this with a simple example. Let there be two licenses, A and B. Suppose there are three bidders with valuations for the objects as follows:

	Object:	A	B	A+B
Bidder:				
1		3	0	3
2		0	3	3
3		0	0	4

The efficient allocation awards license A to bidder 1 and license B to bidder 2.

Consider the MALS auction and suppose that the current clock prices are $p_A = p_B = 1$. If all bidders follow straightforward bidding, bidder 1 will demand A as long as $p_A < 3$, bidder 2 will demand B as long as $p_B < 3$, and bidder 3 will demand a unit of each as long as $p_A + p_B < 4$.[3] The auction will end at prices $p_A = p_B = 2$ and the efficient allocation will be obtained.

However, consider a deviation by bidder 1. Instead of continuing to demand A at prices $p_A = p_B = 1$, he instead drops his demand for A, maintaining his eligibility by bidding on some other license whose price is rising in every round. If bidders 2 and 3 continue to follow straightforward bidding,[4] p_B will rise while p_A will not. Once p_B reaches $3-\varepsilon$, bidder 1 returns to demand A. The auction then ends at prices $p_A = 1+\varepsilon, p_B = 3$ where bidder 3 drops out. By withholding his true interest for A, bidder 1 is able to free ride on the straightforward bidding behavior of bidder 2 and obtain license A at a lower price. Of course, there is no reason for only bidder 1 to think this way. But if bidders 1 and 2 both attempt to free ride, bidder 3 may win. This is the threshold problem. Bidders 1 and 2 must both contribute to the effort to displace the package bidder, but each would prefer the other to contribute more.

This illustrates an important point. The threshold problem is not the result of package bidding (there is none in the MALS auction). Rather, it is the result of "package valuations,'' i.e., of complementarities that bidders act on to at least some degree. The same problem would arise in the SMR auction.

It is easy to see both that the threshold problem arises in the CPA as well and that there is no new threshold problem relative to the MALS auction. At prices

[3] Note that we are assuming here that bidder 3 is ignoring the exposure problem, but as we explain below, the conclusion does not hinge on this assumption.

[4] Under "straightforward bidding'' each bidder demands the set of objects that would maximize his profit if the current prices turned out to be final prices.

$$p_A = p_B = 1$$
$$p_{AB} = 2$$

bidder 1 is again tempted to withhold his demand for A, waiting until prices reach

$$p_A = 1$$
$$p_B = 3 - \varepsilon$$
$$p_{AB} = 4$$

to again demand A. When prices rise to

$$p_A = 1 + \varepsilon$$
$$p_B = 3$$
$$p_{AB} = 4 + \varepsilon$$

bidder 3 exits. However, once again, if bidders 1 and 2 both try to free ride this way, bidder 3 may win.

Although these examples suggest an identical threshold problem in the MALS auction and CPA, one might be concerned that we have been too pessimistic about the MALS auction. In particular, we have assumed above that bidder 3 ignores the exposure problem entirely when bidding. This may indeed be unrealistic. As discussed in CHK, the threshold problem is likely to suppress the bids of package bidders, likely leading to reduced revenue and inefficient allocations. However, less aggressive behavior by the package bidder does not necessarily soften the threshold problem. Above we assumed that bidder 3 continued to demand license j as long as

$$p_j \leq 4 - p_{-j}.$$

Suppose instead that he exposes himself to only half the risk, demanding j only as long as

$$p_j \leq \frac{4 - p_{-j}}{2}.$$

For example, if the price of A remains zero but that of B rises, this means that bidder 3 is willing to demand B only until its price reaches 2, thus putting on the line half of his package value.

Now the free riding incentive exists at the beginning of the auction. Suppose that the auction begins at reserve prices of ε. Hoping that bidder 2 bids straightforwardly, bidder 1 might, for example, plan to wait until p_B reaches $2 - \varepsilon$ to demand A for the first time with the auction then proceeding as follows

p_A	p_B	Demands
ε	ε	0,B,A+B
$\vdots$	$\vdots$	"
ε	$2-\varepsilon$	A,B,A+B
2ε	2	A,B,0

Thus, it is not generally true that the threshold problem softens when package bidders respond more conservatively to the threshold problem.[5] Here, the incentive to free ride begins immediately: each component bidder has an incentive to withhold its demand throughout the auction because, depending on how the other component bidder behaves, it may be possible to obtain the license at the reserve price. This contrasts with the CPA where the lowest price at which a component bidder could win is 1 (for example, bidder 3 is willing to pay 4 for AB while bidder 2 will pay no more than 3 for B; thus bidder 1 cannot win A at a price below 1).[6] Thus, there is at least one sense in which the threshold problem may be viewed as more severe in the MALS auction than in the CPA.

Note, however, that the use of price clocks in both the MALS auction and the CPA may reduce the need for bidders to “coordinate” in overcoming the threshold problem relative to an SMR auction. In the SMR auction, the same incentives arise. But the SMR auction provides no "suggested'' prices that might be used to coordinate. Ausubel, Cramton and Milgrom (2006, p. 134) have previously argued (in the context of the clock phase of the CCA) that "the price adjustment process is effectively resolving the threshold problem by specifying who should contribute what as the clock ticks higher." This may overstate the effectiveness of price clocks, but they may indeed reduce the need for bidders to "coordinate" to unseat a package bidder. One way to see this is to observe that a component bidder does not need to form a winning coalition with other component bidders to win his desired component license. All he needs is to demand the desired component in each round.

Another feature of the CPA is its use of additive package pricing (except in the case of excess demand for the package itself). Without this feature, large gaps could arise between the standing price for a package and the sum of the standing prices for the components of the package. This could be a serious concern when packages are added to the SMR auction, for example. When such gaps arise, bidders for the components must coordinate to overcome this gap in order to displace the package bidder. With additive package pricing, clock prices reveal to the component bidders a set of prices which, if accepted, would unseat the package bidder

[5] Of course, if the package bidder acts as if he has *no* complementarity, the threshold problem will not arise. However, given the substantial complementarities between spectrum licenses, the FCC should not hope for this outcome.

[6] Bidder 1 could still begin withholding demand at the beginning of the auction in the CPA. But unlike the MALS auction, he has no strict incentive to do so.

unless that bidder also agrees to a higher price. This may substantially mitigate the severity of the threshold problem.

This observation has been made previously by Goeree and Holt (2010, p. 148) in the context of their Hierarchical Package Bidding (HBP) extension of the SMR auction design, which uses additive package pricing to determine minimum acceptable bids: "bidders on individual licenses in that region would know how high they have to bid to unseat the provisional regional winner. In this sense, prices help these bidders solve a coordination or 'threshold problem'."[7]
Note that "package prices" are effectively additive in the MALS auction design as well: a bidder seeking the package AB must offer a total of $p_A + p_B$. Thus, we do not claim that the use of additive clock pricing in the CPA offers superior mitigation of the threshold problem relative to the MALS design. Rather, we point out that the CPA retains the substantial advantages of the MALS design without introducing any new threshold problem. Nonetheless, the previous example suggests that the CPA, by mitigating the exposure problem that exists in the MALS design, may in fact soften the severity of the free-riding incentives (threshold problem) that exist in the MALS auction design.

In practice, the threshold problem and its impact are less likely to be significant in clock auctions (e.g., MALS or CPA) than in the SMR auction. For strategic withholding of demand to be profitable, a component bidder must know that he is facing a package bidder and another component bidder to free-ride on. The presence of such opponents may be identifiable in an SMR auction, which reveals provisional winners in each round. But clock auctions do not reveal which opponents are demanding which objects. All a bidder can see are the prices quoted on different items; the sources of price movements are not revealed. A price increase on an individual license could just as likely be triggered by a component demand as by a package demand. This anonymity feature also makes ineffective any attempts by a bidder to strategically exploit a potential threshold problem, e.g., a component bidder pretending to be a package bidder or an individual bidder pretending to be a package bidder. The uncertainty about the free-riding potential does not of course mean that bidders will not attempt to free-ride. They may if they perceive a sufficient likelihood of an opportunity and expect a sufficient gain from it. But free-riding is not without risk. When a bidder holds back his demand at a price significantly below his value, he is risking a sizable profit since the auction could end in the next round. Uncertainty about even the existence of the free-riding incentive lowers the potential gain that could tempt a bidder to take on such risk.

[7] Goeree and Holt (2010) also provide evidence from the laboratory that, even in an SMR auction with package bidding, restricting packages to a hierarchical structure (as we proposed for the CPA) helps bidders overcome the threshold problem by eliminating ambiguity about which component prices must rise to displace the package bidder.

The Overflow Problem

In CHK we pointed out that the MALS auction design introduces a new type of bias against bidders seeking single licenses or small groups of licenses. Bidders seeking packages of licenses will be constrained by the fact that unequal quantities of spectrum will be cleared in different markets. Consequently there will be EAs in which the number of licenses available exceeds the maximum number of the encompassing regional packages that can be allocated. The auction design needs to account for this. Otherwise bidders for single EA licenses can face rising prices even when their demands are not a source of scarcity. This will push such bidders out of the market unnecessarily and lead to misallocation and/or undersell.

We discussed the overflow problem in greater detail in CHK, where we showed that the CPA eliminates the overflow problem. This is possible because the CPA provides a bidding language that allows the price clocks to ensure that EA license prices do not rise when the excess demand is for the package rather than for the EA license itself. This is possible only when bidders can express package bids and when the clock adjustment process properly accounts for feasibility constraints, making sure that demand for packages flows down to the EA licenses only when the demands for single EA licenses are themselves a source of scarcity at the current prices.

Entrants

Exposure risk has been neglected in most prior FCC auction designs.[8] In some cases this has likely led to withdrawal of potential entrants from the auction. In other cases, this has forced package bidders to bid strategically, deviating from straightforward bidding in hopes of resolving uncertainty about closing prices of some licenses before committing to other licenses in the package. Bidders competing against package bidders unprotected against exposure risk have incentives for strategic bidding designed to maximize their competitors' exposure risk, potentially softening competition. Such incentives for bid manipulation are undesirable in themselves, as they can lead to poor price discovery and inefficient allocations. Further, the

[8] An exception is the 700MHz Upper C Block auction of (regulatorily) impaired spectrum, where a SMR auction with limited hierarchical package bidding was used following the design of Goeree and Holt (2010). See also Rothkopf, Pekec and Harstad (1998) for an early proposal to use hierarchical packages in an ascending auction. Another exception is Auction 66 of spectrum for Advanced Wireless Services, where licenses for Regional Economic Areas were offered in addition to licenses for Economic Areas and Cellular Market Areas.

need to understand such bidding strategies places a heavy burden on entrants seeking to bid effectively in the auction.

Although the MALS forward auction design introduces a number of important improvements on the SMR auction, it does nothing to address the problems discussed above. The MALS design neglects the exposure problem entirely.

The CPA design substantially mitigates exposure risk by using a geography-based hierarchical package structure we understand to be closely tied to the actual structure of complementarities between licenses in the mobile wireless industry. By minimizing exposure risk, the CPA eliminates bias in the MALS design (and SMR) against bidders seeking packages by eliminating (or substantially reducing) the risk of exposure. This is likely to improve both the efficiency of the spectrum allocation and auction revenues. One can see evidence of the latter in the FCC's Auction 66, where bids for REAG licenses were on average 37 percent higher per MHz than those for EAs covering the same population.[9] The exposure problem is likely to affect all bidders, due to the economies of scale from horizontal spectrum contiguity (see CHK for additional discussion) and the fixed costs associated with introduction of a new frequency band to an existing wireless deployment. Smaller firms seeking to enter the wireless market certainly are not immune to this exposure risk. And they face, in addition, the need to establish a sufficient geographic footprint to enable service to consumers who now expect coverage to extend outside small areas like EAs. As argued by Cramton et al. (2007, p. 23), "Package bidding levels the playing field and removing it would seriously damage the prospects for new entry."

Manipulative Bidding

It has been suggested that the CPA design may introduce incentives for strategic bid manipulation. No specific manipulations have been articulated, and we speculate that the concerns may arise from a misunderstanding of the CPA.

The CPA changes no rules of the MALS auction design. The CPA design modifies the MALS design only by (1) adding new objects (packages), (2) explaining how excess demand can then be properly calculated, and (3) defining rules for how price clocks are to adjust to maintain additive package pricing when possible. All else is the same. This includes, for example, the rule regarding reductions in expressed demand: as in the MALS proposal, in the CPA a bidder may reduce his quantity demanded of an object only when its price increases.

[9] If one compares price per MHz-Pop, the premium paid for REA licenses was more than 100%.

We have already pointed out that, by eliminating (or substantially reducing) the exposure problem, incentives for strategic manipulation of bids that are present in the SMR and MALS design will be eliminated (or substantially reduced) by the CPA design. Thus, there is at least one way in which the CPA *reduces* incentives for manipulative bidding. Furthermore, we do not see any new opportunities for profitable bid manipulation that result from the modification of the MALS auction embodied in the CPA design proposal.

An example may help to illustrate the protection against profitable manipulation offered by the specific design of the CPA. Suppose there is one license available in each of two EAs, A and B. One bidder seeking the AB package competes against two component bidders demanding A and B, respectively. Call the first bidder the package bidder and the latter two bidders the A-bidder and B-bidder. There are several ways one might imagine a bidder manipulating his bids in hopes of improving his profit:

(i) *The package bidder may pretend to be a component bidder in order to divide and conquer the component bidders:* One possibility is for the package bidder to run up the price clock for A by repeatedly demanding it until the A-bidder drops out, then switch to demanding the AB package he actually desires. This strategy would not help the package bidder to lower the price for the package, since any increase in the price of A triggers a commensurate price increase in the package price. The package bidder can do no better than by demanding the desired package straightforwardly (i.e., until its price reaches his valuation for the package). Nor would either component bidder be preempted by such a manipulation by the package bidder. A component bidder can never lose by demanding its desired component straightforwardly (i.e., until price rises to his valuation for the component). This is in contrast to the SMR in which a package bidder could indeed lower the price of the package, or weaken the competition, by driving out a component bidder.[10] Thus, **due to the additive package pricing rule of the CPA, there is no gain from this type of manipulation**.

(ii) *A component bidder, say the A-bidder, may seek to shift the competitive burden to the B-bidder:* He may try to do this by either (i) withholding his demand on A (parking eligibility on some other licenses with rising prices), (ii) demanding B to push up its price, or (iii) demanding the package AB. We extensively discussed the first possibility earlier in considering the threshold problem, and the second possibility involves a risk of winning a license that the A-bidder does not desire. Importantly, these two options are also available in MALS with the same consequences. The only new option made available by package bidding in CPA is the last option. And this option is totally ineffective as a means of lowering the price for A, leading only to a risk of ending up with an unwanted item. Demanding the package AB creates excess demand for this

[10] This was the main motivation of the FCC 700 MHz auctions which limited the withdrawal of component bids even when they were no longer provisionally winning. Limiting bid withdrawal has a serious side effect, however, for it ties up the budget of the bidder and thus constrains his ability to move across different licenses as prices change.

package and leads to the same increase in the price of A that would have resulted if the A-bidder had just bid for A.[11] Thus, **the CPA's introduction of packages to the MALS auction introduces no new opportunity for manipulation of this type**.

(iii) *There are in fact no package bidders, but a component bidder may pretend to be a package bidder by demanding a package of licenses:* One can imagine a bidder engaging in such behavior in an attempt to cause his opponents to free-ride on each other (withhold their demands) and allow him to win. As mentioned earlier, such an attempt to "signal" package preferences might be effective in the SMR setting but will not work in a clock auction in which bidders see only prices rather than demands. The anonymity of demands in the CPA means that the opponents will not know the source of an observed price increase, so the bidder cannot communicate the message he wishes to send. At the same time, such an attempt will entail a risk of the A-bidder ending up with a package of licenses he does not want. Thus, **this strategy has cost but no benefit**.

We acknowledge (see also CHK) the possibility that some licenses may go unsold in the CPA. This can happen, for example, when a component bidder drops out but remaining component bidders manage to displace the package bidder. This kind of undersell potential should be familiar from the clock phase of the Combinatorial Clock Auction ("CCA"). However, the magnitude of undersell in the CPA will tend to be far less than that under the clock phase of the CCA. This is because in the clock phase of the CCA, a bidder may drop his demand for an object whose price has not risen, as long as the price has risen for some other object he also demanded. This is not permitted in the CPA.[12] Bidders may reduce demand only on objects whose prices have increased. This rule is natural in an auction and offers a compromise between the extremely lax bid withdrawal rule of the CCA clock phase and the severe MALS rule, which discriminates against package bidders by prohibiting such a bidder from reducing his demand for a package unless the price of *every* component has increased.

If some items are unsold at the end of the auction, we proposed in CHK that the FCC should retain the option of reoffering them via another clock auction. As discussed in CHK, the prospect of unsold items being available in such a supplementary resale auction, possibly at lower prices, could create incentives for "small" bidders to withhold demand in the primary auction. However, such a strategy would be highly risky, since such a bidder could not be

[11] The only case in which the A-bidder's added demand for AB would not "flow down" to object A under the CPA rules is when (due to unequal spectrum clearing in markets A and B) this additional unit of demand for AB does not conflict with any existing demand for one of the components. If that is component A, then the A-bidder does not need the price of B to rise for him to win A. If that is component B, then the A-bidder's manipulative demand for AB does not flow down to B. Thus, manipulative bidding for AB cannot help the A-bidder.

[12] In the CPA, only a bidder for a nationwide license has the same flexibility for demand reductions that exists in the CCA clock phase. If that is a significant concern, the national license could be excluded from the specific package structure proposed in CHK. The resulting structure would remain a multitree, as the CPA requires for unambiguous determination of excess demand. We understand (see for example the Comments of T-Mobile) that a substantial share of the geographic license complementarities that will exist in these auctions could be captured by having only MEA and REAG packages.

certain that his desired license would go unsold, or that the FCC would indeed choose to reoffer the license. Thus we do not expect such a strategy to be an attractive option for bidders.

Single Pass Reverse Auction

Several commenters expressed concern about separation between the forward and reverse auctions.[13] In CHK we proposed the option of conducting the reverse auction in a single pass. This option offers a number of advantages, including simplifying bidder participation in the reverse auction. Reverse auction bidders would not need to be reconvened to establish prices for each new closing target. And accepted bids in the reverse auction would be made on the same day with the same information. This contrasts with an interleaved design in which clock prices for the reverse auction resume from the closing prices obtained for the previous (unsuccessful) clearing target. In that case, bidders demanding high prices might effectively commit themselves to being repacked days or weeks ahead of the final offers that are made by other stations.

Further, the single-pass option would not introduce significant complexity for reverse auction bidders. From a bidder's perspective, the single-pass auction would be virtually identical to one of sequencing the reverse and forward auctions under an interleaved design. Just as with the interleaved design proposal, a bidder merely responds to a sequence of price offers by selecting its preferred option at each set of prices. The single pass option would traverse a wider range of prices than any single reverse auction stage under the interleaved design, but the bidder's options during the auction would be identical under both designs, as would the rules determining allocations and prices paid to bidders for each relinquishment option.

Proxy Bidding in the Reverse Auction

Several commenters expressed concerns about the demands on reverse auction bidders if a sealed bid mechanism or proxy bidding system is used. We share the concern that many types of sealed bid mechanisms would introduce unnecessary complexity in the reverse auction. For example, we discussed practical limitations of the Vickrey-Clarke-Groves (VCG) auction in CHK. We also discouraged the use of a discriminatory ("pay-as-bid") design in the reverse auction. A discriminatory auction requires substantial sophistication from bidders. To bid optimally, they must develop a clear understanding not only of their own valuations, but of the competition

[13] *See, e.g.*, MetroPCS Comments at 8.

they are likely to face. Such an auction design may be well suited to environments in which bidders have substantial bidding expertise, but not a one-off auction in which firms with little or no bidding experience are asked to bid to sell large assets.

Nevertheless, these limitations are not inherent to all sealed bid auctions, nor to clock auctions with proxy bidding. A clock auction with proxy bidding was one option we discussed in CHK, where we pointed out that proxy bidding may offer a substantial benefit to the well functioning of the reverse auction by allowing repacking problems to be solved offline rather than in real time. The single-pass reverse auction proposed in CHK adds no significant complexity to the reverse auction relative to the MALS clock auction proposal. Indeed, proxy bidding *simplifies* participation (this is why it is used by eBay, for example). Rather than standing by waiting to see whether prices reach a level where a bidder's preferred relinquishment option would switch, a bidder can simply report the "switch points" to the proxy system with assurance that his plan will be executed automatically.

References

Ausubel, L. M., P. Cramton, and P. Milgrom (2006). "The Clock-Proxy Auction: A Practical Combinatorial Auction Design," in *Combinatorial Auctions*, ed. by P. Cramton, Y. Shoham, and R. Steinberg, 115-138. MIT Press.

Bykowsky, M.M., R.J. Cull, R.J., and J.O. Ledyard (2000). "Mutually Destructive Bidding: The FCC Auction Design Problem," *Journal of Regulatory Economics*, 17 (3), 205–228.

Che, Y.K., P. Haile, and M. Kearns (2013). "Design of the FCC Incentive Auctions,'' comments on behalf of AT&T.

Cramton, P. , G. Rosston, A. Skrzypacz, and R. Wilson (2007). "Comments on the FCC Wireless Bureau's Proposed Competitive Bidding Procedures for Auction 73," (DA 07-3415, August 17, 2007; AU Docket No. 07-157).

Goeree, J.K. and C.A. Holt (2010). Hierarchical Package Bidding: A Paper & Pencil Combinatorial Auction," *Games and Economic Behavior*, 70, 146--69.

Milgrom, P., L. Ausubel, J. Levin, and I. Segal (2012). "Incentive Auction Rules Options and Discussion," Auctionomics and Power Auctions.

Rothkopf, M., A. Pekec, and R. Harstad (1998). "Computationally Manageable Combinational Auctions," *Management Science*, 44, 1131–1147.

ATTACHMENT 6

Comments of Verizon and Verizon Wireless
January 29, 2013

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January 29, 2013

Marlene H. Dortch
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Re: Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions (WT Docket No. 12-268)

Dear Ms. Dortch:

Verizon experienced technical issues converting the comments submitted on January 25, 2013 from Word to .pdf format. The result was that the figures on pages 7, 11 and 12 and the chart on page 13 were garbled in the document originally submitted. The attached corrects only those images and is otherwise unchanged.

Sincerely,

Christopher D. Oatway

Attachment

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

	)	
In the Matter of	)	
	)	
Expanding the Economic and Innovation	)	Docket No. 12-268
Opportunities of Spectrum Through	)	
Incentive Auctions	)	

COMMENTS OF VERIZON AND VERIZON WIRELESS

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TABLE OF CONTENTS

SUMMARY i

INTRODUCTION 1

I. THE COMMISSION SHOULD MODIFY THE PROPOSED 600 MHZ BAND PLAN TO SPEED DEPLOYMENT OF WIRELESS BROADBAND SERVICES AND MINIMIZE INTERFERENCE WITH BROADCASTERS. 5

A. The Band Plan Must Facilitate Efficient Deployment and Device Development. 6

B. The Optimal Band Plan Depends on the Amount of Spectrum that Clears in Different Markets. 7

1. Maximizing Paired Spectrum Under a High-Clearing Scenario. 7

2. The Optimal Band Plan Under a Lower-Clearing Scenario. 11

C. The Commission Should Maximize the Value of the Spectrum Auctioned and Use Spectrum Efficiently. 14

1. Locate Paired Spectrum Above Channel 37 with Paired Uplink Adjacent to the 700 MHz Band. 14

2. Auction Paired Generic 5 MHz Uplink and Downlink Blocks. 15

3. Dedicate Cleared Spectrum as Supplemental Downlink Where It Cannot Be Incorporated Efficiently as Paired Spectrum. 17

4. Create at Least a 10 MHz Duplex Gap Free from Broadcast Operations. 18

5. Ensure a Sufficient Guard Between Mobile and Broadcast Operations. 19

II. THE REVERSE AUCTION AND REPACKING RULES SHOULD MINIMIZE UNCERTAINTY FOR BROADCASTERS AND MAXIMIZE THEIR PARTICIPATION 20

A. Early Commission Decisions Should Address Important Reverse Auction Issues to Help Promote Broadcaster Participation. 21

B. The Commission Should Conduct the Reverse and Forward Auctions Simultaneously. 24

C. A Descending Clock Reverse Auction Will Encourage Broadcaster Participation. 27

D. The Commission Should Not Disclose Reverse Auction Bidder Identities. 29

E. Both Algorithms for Selecting Winning Bids Have Merit But the Commission Should Announce Its Choice Well In Advance of the Auction. 29

F. The Commission Should Provide Relief from Existing Broadcast Service and Ownership Rules to Promote Broadcaster Participation. 31

1. Relief from Media Ownership and Other Rules. 31

2. Accommodating VHF Relocation. 32

3. Additional Interference. 33

4. Pending Renewal/Enforcement Actions and Transactions. 35

G. The Commission Should Disclose the Repacking Methodology Well In Advance of the Reverse Auction and Ensure that it Maximizes the Spectrum Cleared for Mobile Broadband Use. 36

H. The Commission Should Act Now to Promote Clearing of Channel 51. 37

III. THE COMMISSION SHOULD DESIGN THE FORWARD AUCTION TO PROMOTE MAXIMUM PARTICIPATION BY WIRELESS PROVIDERS. 38

A. The Forward Auction and 600 MHz Service Rules Should Impose No Eligibility or Spectrum Aggregation Restrictions. 38

B. The Commission Should Adopt an Ascending Clock Format Using Generic 5 MHz Blocks 44

C. The License Assignment Stage Should Facilitate Contiguous Spectrum Blocks Within and Across Economic Areas. 45

D. Short Form Applications Will Reveal Where Mutual Exclusivity Could Occur Within EAs. 47

E. The Forward Auction Should Permit Limited Package Bidding for Generic 600 MHz Licenses. 49

F. The Commission Should Narrow the Scope of the Anti-Collusion Rule. 51

G. The Commission Should Not Impose Closing Conditions Beyond What the Spectrum Act Requires. 55

IV. THE RULES FOR 600 MHZ WIRELESS OPERATIONS SHOULD PROMOTE RAPID USE OF THE SPECTRUM TO SERVE CUSTOMERS. 56

A. The 700 MHz Band Technical Rules Mostly Provide the Right Model for 600 MHz Licensees. 56

B. Flexible Use Is the Best Model for 600 MHz Broadband Licenses. 58

C. The Commission Should Use Only Economic Areas for 600 MHz Licenses. 60

D. The Commission Should Provide Clear Pre-Auction Guidance on Coordinating with 600 MHz Operations in Canada and Mexico 63

E. The Commission Should Apply Partitioning, Disaggregation, and Spectrum Leasing Rules to 600 MHz Licenses. 64

F. 600 MHz Licensees Should Have 10-Year License Terms for Unencumbered Spectrum and Be Subject to Population-Based Performance Requirements. 64

G. The Commission Should Protect Mobile Licensees from Harmful Interference by Clearing Wireless Microphones and LPAS Devices Well in Advance of the Auction. 69

SUMMARY

Spectrum is the lifeblood of the wireless industry – an increasingly important sector of the U.S. economy. That industry comprises thousands of tower siting and other infrastructure vendors, equipment and device suppliers, and mobile content and app providers, as well as service providers, which are collectively investing tens of billions of dollars, generating jobs and strengthening the economy. But the growth of the wireless sector depends on a sufficient supply of spectrum. Consumers, businesses, public safety and governments at all levels are increasingly using and benefiting from the rapid technology advances in wireless, such as the construction of new 4G networks that will enable even more services that advance consumer welfare. These benefits depend on the Federal government's ability to deliver substantial amounts of additional spectrum to meet the public's growing needs. That is why the upcoming 600 MHz auction must deliver the maximum amount of spectrum to meet the growing needs of wireless consumers.

The Notice of Proposed Rulemaking makes major progress toward designing an incentive auction that will achieve Congress's Spectrum Act objectives and repurpose spectrum to benefit the American public. A well-designed auction that maximizes participation by broadcasters and wireless service providers alike and ensures that all potential bidders are eligible to participate will benefit the U.S. economy by increasing the amount of spectrum available to meet the growing need for wireless broadband, and will help achieve Congress's revenue goals. To succeed, this first-of-its-kind auction must be as transparent and predictable as possible, given the inherent complexity of conducting an incentive auction. The more certainty the rules provide, the more broadcasters and wireless providers will participate, the more spectrum will be repurposed to meet the needs of consumers and businesses for broadband, and the more Congress's revenue goals will be met. The Commission should promote certainty, and resolve

issues that will inform other aspects of the auction's design, by issuing early decisions regarding key issues including the spectrum clearing target, available reverse auction bids, the bid assignment and repacking methodology, and changes to broadcast technical and other rules.

Verizon's comments address four discrete topics related to the design of the auction and the rules for the new 600 MHz band, and offer recommendations for each. On many issues, Verizon fully supports the Commission's proposals. On some, Verizon suggests alternative approaches that are intended to achieve the most efficient and successful incentive auction and meet Congress's objectives.

1. Adopt a Band Plan that Maximizes the Value of the Spectrum for Wireless Industry Use.

Rules ensuring that the cleared spectrum is technically and economically attractive to the wireless industry are crucial to a successful forward auction that maximizes participation by existing and new service providers. Many of the Commission's proposals, such as locating paired uplink spectrum adjacent to the 700 MHz band, promote that goal. Modifications to the band plan, however, are needed to protect 600 MHz mobile broadband providers from interference from the remaining broadcast television operations, and to ensure that service providers and their vendors can efficiently incorporate the 600 MHz band into wireless devices and networks.

The band plan must have the flexibility to ensure that mobile operators can utilize the auctioned spectrum across the country for efficient deployments, while avoiding interference between wireless operations and broadcast operations. The configuration of spectrum blocks auctioned in any particular geographic market (which may be adjacent to a market where a different amount of spectrum clears) must both optimize the value of the spectrum auctioned in that specific market and account for the interrelatedness among markets. For example, in

geographic markets where less spectrum clears, the band plan must place broadcast operations to mitigate interference between the remaining broadcasters and mobile operations in adjacent markets where more spectrum clears. And the duplex gap (which can accommodate appropriate low-power devices but not broadcast stations) must line up across all geographic markets in order to facilitate the development of a single device filter.

The optimal band plan depends in large part on how much spectrum clears in different geographic markets, but under all scenarios the Commission should focus on repurposing as paired spectrum the spectrum currently allocated for TV Channels 38 through 51. The band plan should maximize the amount of paired spectrum made available for the forward auction by offering equal amounts of uplink and downlink in paired 5x5 MHz blocks, with the paired uplink constituting the upper channels adjacent to the lower 700 MHz band in order to minimize interference problems. Unpaired blocks of spectrum (i.e., supplemental downlink) should be auctioned on a market-by-market basis where more spectrum clears than can be efficiently dedicated to paired blocks, including in blocks below Channel 37. To maximize the attractiveness of the auctioned spectrum (and the success of the auction process), the Commission should auction all mobile spectrum in generic 5 MHz blocks suitable for FDD operations.

Verizon's proposed band plan will effectively accommodate LTE deployment in the 600 MHz band. It also has the advantage of avoiding the costs of relocating incumbent operations out of Channel 37, and efficiently using spectrum by employing Channel 37 as part of the guard band (which, like the duplex gap, can accommodate appropriate low-power uses) between mobile and broadcast operations.

2. Maximize Broadcaster Participation through the Reverse Auction Design.

To repurpose broadcast spectrum successfully, a substantial number of broadcasters need to participate in the reverse auction. Maximizing broadcaster participation will in turn maximize the amount of spectrum cleared, consistent with Congress's objectives. To achieve those goals the auction must be sufficiently predictable and transparent that broadcasters can reasonably analyze the business merits of participating in the auction. The Commission has appropriately reached out to the broadcaster community to explain the potential benefits of participation and solicit broadcasters' input, and those efforts should continue.

The Commission should also promote broadcaster participation by adopting early rules and guidance that will provide more certainty and predictability to broadcasters evaluating whether to participate. Rather than wait until the auction is imminent, the Commission should as soon as possible announce a spectrum clearing target of at least 120 MHz and the repacking procedures it will apply to non-participating broadcast stations. As to the design of the incentive auction, conducting the reverse and forward auctions simultaneously has clear advantages over a sequential auction. The descending clock approach holds promise for encouraging wide broadcaster participation, and the Commission will need to ensure that it can effectively integrate that approach with the other interdependent components of the incentive auction. The Commission should also grant extended confidentiality protection to reverse auction participants' identities and bids.

The Commission should also modify the current broadcast service rules to create incentives for additional broadcaster participation. Specifically, it should provide regulatory relief to participating broadcasters, accommodate relocation to both high-VHF and low-VHF channels, allow relocating stations to accept additional interference or a reduced service area,

and adopt clearing options for Channel 51 stations. The Commission should take this last step as soon as possible to facilitate early relocation of Channel 51 stations, enabling 700 MHz A Block licensees to provide wireless services to customers where they are today blocked due to Channel 51 licensees' protected broadcast contours.

3. Maximize Wireless Provider Participation in the Forward Auction.

The Commission should reject calls for spectrum aggregation limits or other restrictions on bidder participation. In addition to conflicting with Congress's direction in the Spectrum Act not to impose eligibility restrictions, they would undermine robust forward auction bidding, contrary to Congress's objectives. Limits would potentially suppress the value of bids and inefficiently distort the results of the auction by restricting companies that value the spectrum the most from obtaining it to serve their customers. They would also inject additional uncertainty into an auction that is already the most complex the Commission has ever administered.

The Commission should adopt procedures that encourage robust participation by new and existing wireless providers, by making the process as simple as possible and continuously informing bidders what spectrum is available and in what markets. It should thus conduct an ascending clock auction of generic 5 MHz blocks. Because of the clear technical benefits of deploying contiguous spectrum, the Commission should award winning bidders of more than one block in a market licenses for contiguous blocks. The Commission will also maximize the value of and bids for the spectrum in the forward auction by authorizing limited package bidding for groups of generic 600 MHz licenses.

To avoid suppressing demand, distorting bids, and deterring quick and efficient mobile broadband deployment, the Commission should not impose rules that could saddle 600 MHz licenses with regulatory burdens that make them unattractive to wireless operators looking to

expand or initiate service. Nor should it impose closing conditions beyond what the Spectrum Act requires because doing so would only complicate the auction and risk deterring participation and limiting the amount of spectrum cleared.

The Commission also should revise its application of the anti-collusion rule, which has put undue limits on routine business discussions, and imposed significant costs on auction participants. In addition to clarifying that the rule will not apply to communications between reverse and forward auction participants on non-auction matters, the Commission should revise the scope of the rule to eliminate counterproductive restrictions on routine business discussions. An anti-collusion rule of narrower scope would avoid deterring participation in the incentive auction while fully protecting against collusion.

4. Adopt 600 MHz Service Rules That Promote Rapid Deployment of the Spectrum.

The Commission correctly proposes to apply many of its Part 27 service rules for the 700 MHz band to the new 600 MHz band. Applying these proven rules and principles will provide much-needed certainty in an inherently complex auction and promote rapid build-out of 600 MHz spectrum to serve the public.

The Commission should, as the *NPRM* proposes, extend its successful flexible use policy to the 600 MHz band, use Economic Areas (EAs) as the geographic service area for all 600 MHz licenses, and apply the same 700 MHz power limits, out of band emissions limits, interference rules and other technical rules to the 600 MHz band, although a different protective field strength limit is appropriate to protect broadband LTE operations. The Commission should also extend existing rules for partitioning, disaggregation, and leasing to the 600 MHz band; those rules have promoted an active secondary market that puts spectrum in the hands of companies that can best put it to productive use. The Commission should also provide clear pre-auction guidance to

forward auction participants on coordinating 600 MHz band operations on Canada and Mexico border regions so that bidders can valuate that spectrum and plan networks accordingly. Population-based build-out requirements similar to those recently adopted for the new AWS-4 band are also in the public interest because they will promote rapid deployment of advanced wireless services, and the Commission should ensure that broadcasters are timely cleared from the repurposed 600 MHz band to facilitate such deployment. And, to avoid interference problems that would reduce the attractiveness of the spectrum to mobile operators, the Commission should promptly begin clearing wireless microphone and Low Power Auxiliary Services devices and operations from the spectrum to be repurposed.

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions	)	Docket No. 12-268

COMMENTS OF VERIZON AND VERIZON WIRELESS

The Commission's Notice of Proposed Rulemaking[1] is a groundbreaking step toward achieving Congress's mandate in the Middle Class Tax Relief and Job Creation Act to repurpose substantial amounts of spectrum for mobile broadband services and to speed deployment of additional wireless services to the public.[2] Verizon and Verizon Wireless ("Verizon")[3] thus strongly support the Commission's effort to design an auction that will maximize the amount of repurposed spectrum for inclusion in the new 600 MHz band, because an auction that achieves that objective will also provide substantial benefits to the U.S. economy and to consumer welfare.

INTRODUCTION

As the Commission has correctly found, wireless service providers require additional spectrum to meet their customers' demands. Data prove that customers are increasingly using

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[1] *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions,* Notice of Proposed Rulemaking, Docket No. 12-268, 27 FCC Rcd 12357 (2012) ("*NPRM*").

[2] *See* Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, §§ 6402, 6403, 126 Stat. 156 (2012) (the "Spectrum Act").

[3] In addition to Verizon Wireless, the Verizon companies participating in this filing are the regulated, wholly owned subsidiaries of Verizon Communications Inc.

wireless for their broadband needs, buying more devices and services that access the Internet, increasing their minutes of use of those devices and services, and downloading more bandwidth-intensive applications for purposes as diverse and important as monitoring health and conserving energy. The Obama Administration's objectives for wireless broadband and the Commission's National Broadband Plan recognize that new licensed spectrum is necessary for service providers to meet these demands, and to preserve the economic growth and innovation that mobile broadband services have engendered.[4] Conversely, the Commission also recognized that "[t]he growth of wireless broadband will be constrained if government does not make spectrum available to enable network expansion and technology upgrades . . . [resulting in] higher prices, poor service quality, an inability for the U.S. to compete internationally, depressed demand and, ultimately, a drag on innovation."[5] To promote and preserve the enormous economic potential of mobile broadband services, the *National Broadband Plan* established a goal of making 300 MHz of spectrum newly available for mobile broadband services by 2015, and 500 MHz by 2020.

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[4] *See* Presidential Memorandum, *Unleashing the Wireless Broadband Revolution*, 75 Fed. Reg. 38387, 38387 (2010) ("America's future competitiveness and global technology leadership depend, in part, upon the availability of additional spectrum. . . . Expanded wireless broadband access will trigger the creation of innovative new businesses, provide cost-effective connections in rural areas, increase productivity, improve public safety, and allow for the development of mobile telemedicine, telework, distance learning, and other new applications that will transform Americans' lives."); *Connecting America: The National Broadband Plan*, at 76-78 (FCC 2010), http://download.broadband.gov/plan/national-broadband-plan.pdf ("*National Broadband Plan*"); *see also* FCC Staff Technical Paper, "Mobile Broadband: The Benefits of Additional Spectrum," at 5, http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-302324A1.pdf (Oct. 2010) ("Mobile Broadband Technical Paper") ("[a]s smartphones, laptops, and other devices become increasingly integral to consumers' mobile experiences, mobile data demand is expected to grow between 25 and 50 times current levels within 5 years").

[5] *National Broadband Plan* at 77.

In the nearly two years since the *National Broadband Plan*'s release, consumer demand for mobile broadband services and smartphone devices has continued to surge[6] – to such an extent that Chairman Genachowski warned just last fall that the National Broadband Plan targets of 300 MHz and 500 MHz in five and ten years may be insufficient given data usage trends for LTE devices and the emergence of tablet devices and machine to machine technologies that use substantially more data and spectrum capacity than smartphones.[7] According to public estimates, "the average smartphone will generate 2.6 GB of traffic per month in 2016 [(]a 17-fold increase over the 2011 average of 150 MB per month[), a]ggregate smartphone traffic in 2016 will be 50 times greater than it is today," and mobile-connected tablets alone "will generate almost as much traffic in 2016 as the entire global mobile network in 2012."[8]

Maximizing the amount of newly licensed mobile broadband spectrum through the incentive auction of broadcast spectrum is an essential component of the Federal government's policy of achieving the economic benefits and the transformative capabilities of wireless

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[6] *See, e.g.,* Cisco, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2011–2016," at 5 (Feb. 14, 2012), http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf ("Cisco 2011-2016 Forecast"); Ericsson Mobility Report: On the Pulse of the Networked Society, at 5-13 (Nov. 2012), http://www.ericsson.com/res/docs/2012/ericsson-mobility-report-november-2012.pdf; Reply Comments of CTIA – The Wireless Association, WT Docket No. 11-186, at 5 (filed Apr. 30, 2012) (reporting that data usage on wireless networks grew 123 percent during 2011 (more than 100 percent for the third year in a row) and now amounts to more than 866 billion megabytes a year, and the number of smartphones on wireless providers' networks increased by 43 percent in 2011 to 111.5 million).

[7] *See* Julius Genachowski, Chairman, Federal Communications Commission, Prepared Remarks, University of Pennsylvania – Wharton, at 6-7 (Oct. 4, 2012), http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-316661A1.pdf ("Genachowski Wharton Speech").

[8] *See* Cisco 2011-2016 Forecast at 3.

technologies and services.[9] Put simply, further gains in consumer welfare from the wireless sector depend in part on ensuring that the sector has sufficient spectrum, and the 600 MHz auction is essential to freeing that spectrum for wireless use. Moreover, achieving the Spectrum Act's revenue objectives depends on maximizing the incentives of both wireless providers and broadcasters to enter the auction and to vigorously participate, and on ensuring that all potential bidders are eligible to bid. The *NPRM* correctly recognizes the complexity and interrelatedness of the different components of the incentive auction: wireless providers are more likely to participate if there is certainty about what they are bidding for and there is a sufficient amount of spectrum available, while broadcasters are likely to participate only to the extent they perceive that demand for cleared spectrum will be sufficiently robust to make their participation worthwhile. The incentive auction and rules for the new 600 MHz band must:

- Adopt reverse auction procedures that will maximize broadcaster participation in the reverse auction and maximize the number of channels cleared in a given market, while ensuring that that remaining broadcasters are repacked promptly, efficiently and fairly.
- Maximize wireless provider bidding and participation in the forward auction and get the spectrum in the hands of entities that place the highest value on the spectrum by ensuring all interested entities can freely bid without restrictions.
- Maximize the value of the 600 MHz spectrum and speed its deployment to serve the public post-auction, by adopting a band plan that will put the most spectrum to its best use, as well as flexible use and secondary market rules that enable providers to expand services efficiently while enabling market forces to move the spectrum to where it can best be used and produce the greatest consumer welfare.

The *NPRM* appropriately focuses on these interrelated objectives and Verizon supports many of its proposals for achieving them. Below, Verizon also suggests alternatives for some parts of the incentive auction design that are more likely to promote a successful auction. The

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[9] *See National Broadband Plan* at 88, Recommendation 5.8.5 (positing that an incentive auction could repurpose around 120 MHz of broadcast spectrum for mobile broadband).

Commission should: (1) adopt a band plan for paired 5 MHz uplink and downlink blocks above Channel 37 with additional cleared spectrum designated as supplemental downlink; (2) adopt reverse auction design and repacking procedures and modify current broadcast rules to minimize broadcasters' uncertainty and maximize their participation; (3) adopt forward auction rules that are free of restrictions on license eligibility and maximize wireless providers' participation; and (4) adopt 600 MHz technical and service rules that encourage rapid deployment of more wireless broadband capacity and services. Verizon's comments below detail specific recommendations for Commission actions as to each of these four aspects of its incentive auction program.

DISCUSSION

I. THE COMMISSION SHOULD MODIFY THE PROPOSED 600 MHZ BAND PLAN TO SPEED DEPLOYMENT OF WIRELESS BROADBAND SERVICES AND MINIMIZE INTERFERENCE WITH BROADCASTERS.

Like the 700 MHz band repurposed through the Digital Television (DTV) transition, the 600 MHz band can offer wireless providers additional spectrum to meet the growing demands of the public for mobile services, particularly broadband. Many of the Commission's proposals for the 600 MHz band plan will support deployment of broadband services by 600 MHz licensees and will also facilitate an efficient and successful forward auction. Modifications to the band plan, however, are needed to protect 600 MHz mobile broadband providers and television broadcasters from mutual interference, and to ensure that service providers and vendors can efficiently incorporate the 600 MHz band into wireless devices and networks.

For multiple reasons, the Commission should make clearing DTV broadcast operations from Channels 38 through 51, and reallocating those channels to paired spectrum blocks for mobile uses, its primary goal, with supplemental downlink below Channel 37. The *NPRM*'s proposed band plan – including its proposal to locate mobile paired downlink spectrum below

Channel 37 and to place broadcasters in the duplex gap – would create network engineering and handset design issues that would constrain the deployment of advanced mobile broadband services. This section outlines the path toward an optimal band plan configuration that will enable such deployments and therefore promote robust forward auction bidding.

A. The Band Plan Must Facilitate Efficient Deployment and Device Development.

Like the *NPRM*'s band plan proposal, the right band plan framework must have the flexibility to ensure that mobile operators can utilize the auctioned spectrum across the country for efficient nationwide deployments. That means that the configuration of spectrum blocks auctioned in any particular geographic market (which may be adjacent to a market where a different amount of spectrum clears) must both optimize the value of the spectrum auctioned in that specific market and also account for the interrelatedness among markets. First, the auctioned channels in all markets must be lined up in ways that avoid or minimize co-channel interference between broadcast operations remaining in low-clearing markets and mobile operations in high-clearing markets. Second, coordination across geographic markets is necessary to ensure band plan configurations that facilitate efficient national deployment and device development.

The following key principles should drive the development of the national framework:

- Maximize the attractiveness of the spectrum (and the success of the auction process) by creating and auctioning generic 5 MHz blocks suitable for FDD operations.
- Maximize the amount of paired spectrum auctioned on a nationwide basis while avoiding inefficient spectrum use. If even more spectrum is cleared, designate it as supplemental downlink spectrum which can be auctioned on a market-by-market basis.
- Enable successful device and infrastructure deployment by aligning the duplex gap across all geographic markets and by placing all paired spectrum above Channel 37 – with all paired uplink spectrum adjacent to the 700 MHz Band.

- Coordinate the spectrum auctioned in different markets to minimize potential co-channel cross-market interference problems. For example, to the extent broadcast operations in low-clearing markets will unavoidably compromise mobile spectrum in higher-clearing adjacent markets, the broadcasters should be located so they affect only supplemental downlink as opposed to paired spectrum.

A band plan based on these principles will promote robust participation in the forward auction, maximize revenue, and help ensure that the 600 MHz mobile licenses are put to their highest and best use.

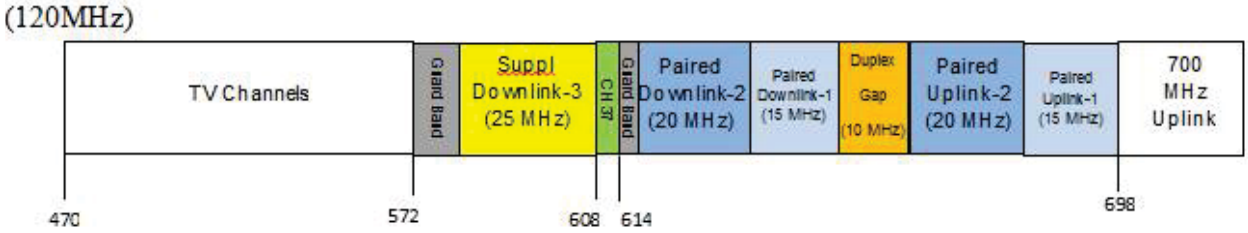
B. The Optimal Band Plan Depends on the Amount of Spectrum that Clears in Different Markets.

The band plan that will best promote the principles set forth above will depend on the amount of spectrum that clears in various markets across the country. This section first discusses the optimal band plan if substantial amounts of spectrum clear in most or all markets, and then discusses the optimal band plan under a scenario where smaller amounts clear. In each clearing scenario, the optimal band plan discussed here can be adjusted on a market-by-market basis to create a family of plans that can co-exist and that collectively facilitate nationwide deployment and single device development that can work across the family of plans.

1. Maximizing Paired Spectrum Under a High-Clearing Scenario.

Based on currently available information and analyses, under a clearing scenario of 120 MHz, the optimal band plan for promoting the principles set forth in the previous section is:

Figure 1



This band plan takes full advantage of a high-clearing scenario in order to auction a total of 14 blocks of 5 MHz paired spectrum (for a total of 70 MHz) by creating two sets of paired spectrum in the space above Channel 37. The band plan shown in Figure 1 is optimal for a pass band[10] of this size because a single tunable antenna with two duplexers can cover both pairs of uplink/downlink spectrum. Verizon's current information and analysis indicates that the supported antenna bandwidth (uplink 1 + uplink 2 + duplex gap + downlink 1, or uplink 2 + duplex gap + downlink 1 + downlink 2) needs to be 65 MHz or less or the device antenna size will become impractical (more than 30% larger than 700 MHz device antennas). Practical RF component technology also limits the pass band of the duplexer filters to 25 MHz in order to minimize loss in sensitivity. In addition, any uplink band in Channels 31 to 45 may create harmful uplink harmonics in the mobile device.

While it is theoretically possible to configure a band plan with even more paired spectrum by placing some paired spectrum in Channels 33 through 36, such a structure may not be feasible because of the uplink harmonics and because of form factor limitations. Such a band plan may require an additional antenna or tuner for LTE, and given that 600 MHz antennas are 20-30% larger than 700 MHz antennas, substantial challenges can be expected for device vendors to include up to four 600 MHz antennas in small form factor devices.

The Figure 1 band plan involves certain compromises that are unavoidable if the amount of paired spectrum is to be increased and that are inherent in any band plan featuring more than 50 MHz of paired spectrum. First, although it enables the use of a single antenna (two antennas for 2x2 MIMO), the device needs two duplexers – which would be avoidable with a smaller pass

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[10] *See NPRM* ¶¶ 166-167. A pass band is the range of frequencies that can be covered by a single device filter. *See NPRM* ¶ 140 n.217.

band with 50 MHz or less of paired spectrum that needs only one duplexer. Second, the pass band limitation may compromise the generic nature of certain blocks of auctioned spectrum given that it will be difficult to combine 5x5 licenses from band 1 and band 2 to create larger contiguous blocks of spectrum. Given that a generic block objective can only be fully achieved with 50 MHz (i.e. 25 x 25 MHz paired) or less of paired spectrum due to the filter pass band constraint, it is somewhat compromised to allow for more than 50 MHz of paired spectrum. To make this band plan more generic in terms of ability to generate additional paired blocks, two overlapping duplexers may be used.

The Figure 1 configuration is a base plan that can easily be adjusted and implemented in markets where between 84 MHz and 120 MHz clears: the supplemental downlink below Channel 37 would be reduced (starting with the lower channels) and replaced with broadcast operations. Having a common base plan of paired spectrum above Channel 37 in all markets avoids co-channel interference risk in the paired spectrum. Appropriate geographic buffer zones would need to be implemented to avoid co-channel interference between broadcast operations and mobile services in the supplemental downlink spectrum. These buffer zones may extend into adjacent markets, potentially somewhat compromising the "generic" nature of some of the supplemental downlink in higher-clearing markets.

Where more than 120 MHz is cleared, additional supplemental downlink channels should be assigned below Channel 37, also with appropriate buffer zones to protect from co-channel interference. This approach has the benefit that if more broadcast channels are cleared in the future, it may be possible to add another band of paired spectrum (with the uplink on the lower end of 600 MHz frequency) to effectively create an "upper 600 MHz" above Channel 37 and a "lower 600 MHz" below Channel 37. Verizon's analysis indicates that the uplink band for the

"lower 600 MHz" pair should be located between Channels 26 to 30 to avoid harmful uplink harmonics interference into other bands. However, it should be noted that this third paired band may significantly increase device cost and complexity because few components could be shared across the entire band.

In markets with less than 84 MHz clearing, it is important to align the duplex gaps[11] with the base plan's duplex gap to facilitate the development of a single device that can be used for nationwide deployment. In this case, it may be possible to locate broadcast stations in channels lining up with the uplink or downlink pass bands in Figure 1 – but not in the duplex gap given that broadcasters in the duplex gap can create intermodulation interference issues into device downlink reception. Ideally this configuration should be avoided because it necessitates additional guard bands and buffer zones that may extend into adjacent markets, and because it creates intermodulation interference concerns. In general, the presence of TV broadcast operations in such low-clearing markets could preclude the Commission from auctioning the 600 MHz spectrum in generic blocks because the value of individual blocks would vary depending on the frequency band and geographic proximity of DTV broadcast stations to the 5 MHz blocks in each licensing area. Given the importance of generic blocks to the success of the forward auction,[12] the case-by-case impairments associated with allowing broadcast operations in the duplex gap, uplink pass band, or downlink pass band would create substantial hurdles to conducting a successful forward auction.

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[11] In the configuration of Figure 1, the effective duplex gap for a two-duplexer device is greater than 10 MHz. Further analysis is being undertaken to determine if this gap can be narrowed without undermining performance of future single-duplexer solutions.

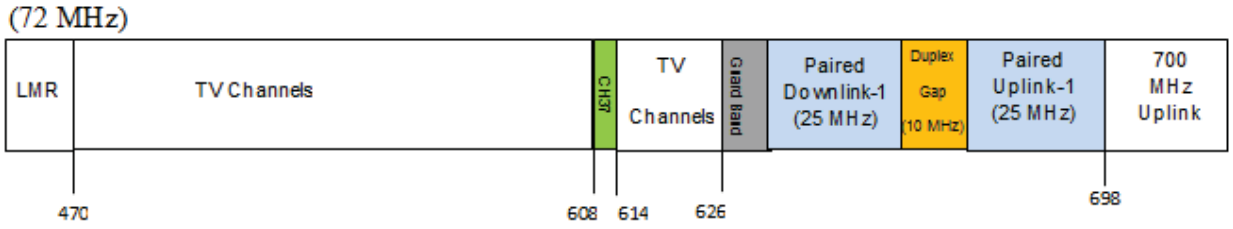
[12] *See infra* Section III.C.

Because of those hurdles and because of the substantial reduction in the amount of paired spectrum that would be auctioned, the Figure 1 band plan would not be optimal if less than 84 MHz clears in a substantial number of markets. While it may be possible to accommodate – as part of a framework that maximizes auctionable paired spectrum across the country – a few outlier markets where less than 84 MHz clears, the Figure 1 band plan should be replaced with a different one under such a lower-clearing scenario.

2. The Optimal Band Plan Under a Lower-Clearing Scenario.

To the extent less than 84 MHz clears in a substantial number of markets, the base band plan must be adjustable to accommodate more TV channels with minimal guard bands. Under this scenario, the following base band plan is optimal:

Figure 2



This configuration is very similar to the alternative band plan discussed in paragraph 178 of the *NPRM*. It maximizes the amount of paired spectrum using a *single* set of paired downlink and uplink blocks and allows up to two broadcast channels above Channel 37 or possibly three broadcast channels above Channel 37 by placing a lower power television station adjacent to the downlink spectrum and reducing the guard band.

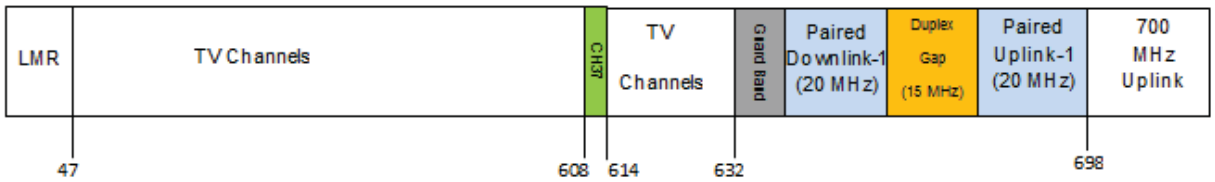
The Figure 2 band plan can be adjusted on a market-by-market basis to accommodate different amounts of spectrum in different geographic markets while retaining the key features needed to facilitate nationwide deployment and to reduce or minimize cross-market co-channel

interference problems. In markets where more than 72 MHz clears, there would be no change in the structure of the paired spectrum or the duplex gap; instead, supplemental downlink blocks would be added to the left of the guard band in those high-clearing markets where extra spectrum is available.[13]

Markets in which only 66 MHz clears can also be configured to include paired spectrum, while successfully co-existing with the Figure 2 configuration, by employing the same structure except that the size of the paired blocks is reduced to 20x20 MHz. Figure 3 below illustrates that configuration:

Figure 3

(66 MHz)



In this 66 MHz configuration, three broadcast channels are located above channel 37. The duplex gap is 15 MHz because device constraints (e.g., the ability to use a single duplexer) require that it line up with the duplex gap in Figure 2. This configuration minimizes co-channel interference problems with markets where more spectrum clears by lining up the broadcast operations in channels 38-40 with either the guard bands or the supplemental downlink in adjacent markets, and not with the paired spectrum.[14]

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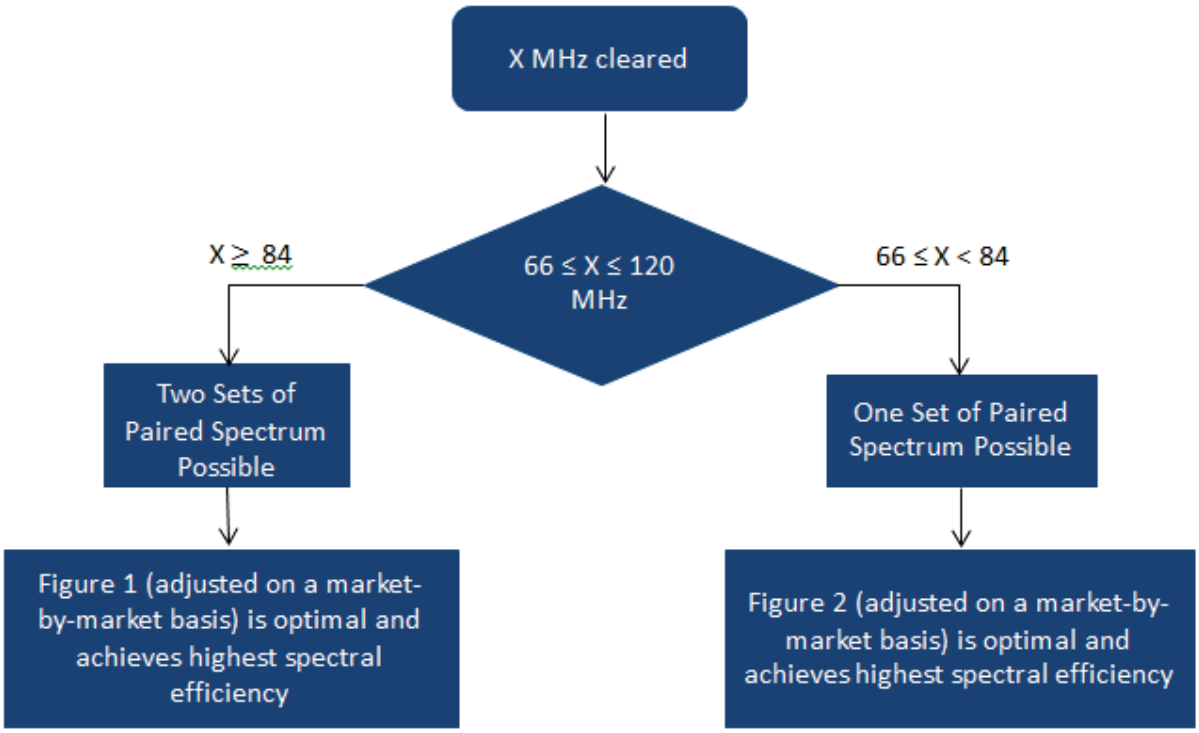
[13] Employing the Figure 1 configuration (for high-clearing markets) is not an option because it cannot co-exist with the Figure 2 configuration. For example, the duplex gaps would not align.

[14] Of course, a buffer zone would be required to the extent this market is adjacent with one where supplemental downlink is located above Channel 37.

The path to determining the optimal band plan is illustrated by the following decision tree:



The viability of a framework that optimizes the amount of generic paired spectrum made available in the forward auction on a nationwide basis is substantially increased if at least 66 MHz clears in all markets. To the extent less spectrum may clear in some markets, strategies would need to be implemented to mitigate the risk that broadcast operations in such low-clearing markets would jeopardize the viability of a national framework that auctions substantial amounts of paired spectrum. For example, in markets where less than 66 MHz clears, it would not be possible to avoid locating broadcast operations in channels that line up with – and therefore potentially create co-channel interference with – mobile operations in adjacent markets where the Figure 2 or Figure 3 band plan is viable. Strategies to facilitate the co-existence of higher-clearing and lower-clearing markets may include configuring band plans in low-clearing markets

so that broadcast stations primarily line up with supplemental downlink (as opposed to paired spectrum) in adjacent high-clearing markets; establishing geographic buffers between markets; and, if it is impossible to avoid compromising some paired spectrum, locating low-power broadcasters in channels that line up with paired spectrum in adjacent markets. The use of such strategies, however, would potentially reduce both the value and the generic-ness of the spectrum to be auctioned in higher-clearing markets.

C. The Commission Should Maximize the Value of the Spectrum Auctioned and Use Spectrum Efficiently.

1. Locate Paired Spectrum Above Channel 37 with Paired Uplink Adjacent to the 700 MHz Band.

The *NPRM* correctly proposes to locate paired uplink spectrum adjacent to the 700 MHz band. That location avoids wasting spectrum because there is no need for a guard band between the Lower 700 MHz band and the 600 MHz band. Moreover, the uplink band should be limited to 35 MHz wide and confined to Channels 46 to 51 to avoid the uplink harmonics problems discussed above.

The band plan, however, should not locate paired downlink spectrum below Channel 37 as the *NPRM* contemplates. The existence of any paired spectrum below Channel 37 would also increase the antenna bandwidth that needs to be supported, thus increasing the size/volume of components due to the low frequencies, creating device feasibility issues. Verizon's band plan proposal avoids those problems by locating paired downlink spectrum in part of the remaining spectrum above Channel 37.

Another advantage of Verizon's band plan is that it, like the NPRM's principal plan, avoids the need to relocate the numerous operations that currently use the spectrum designated as

Channel 37.[15] Under some configurations, Channel 37's placement at the boundary between mobile and broadcast operations would be useful as part of the guard band between mobile and broadcast operations. In other markets, where enough spectrum clears such that mobile broadband can be located below Channel 37, the channels below Channel 37 will be allocated for supplemental downlink. While additional analysis of potential interference issues is needed, under those configurations it would likely be possible to permit existing Channel 37 users to continue to operate on a non-interfering basis.

2. Auction Paired Generic 5 MHz Uplink and Downlink Blocks.

The Commission should use 5 MHz "building blocks" for the 600 MHz band plan, as proposed in the *NPRM*.[16] As the *NPRM* notes, 5 MHz blocks can support a variety of Frequency Division Duplex (FDD) wireless technologies, including LTE, which is the likely technology of choice for 600 MHz broadband licensees.[17]

The Commission should not simply convert the 6 MHz broadcast channels into 6 MHz licenses for 600 MHz mobile services because doing so would strand spectrum.[18] Most 600 MHz licensees using FDD technology will use service channels of 5 MHz or multiples of 5 MHz, consistent with current LTE technology. Therefore, using 6 MHz blocks from the outset would not provide as many license blocks and would leave some portion of the reclaimed broadcast spectrum both unused by the licensed provider and also unavailable for guard bands

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[15] *See NPRM* ¶¶ 179-180.

[16] *Id.* ¶ 128.

[17] LTE has proven successful because it "provides high spectral efficiency, supports high data rates and implements a flexible access architecture." Magdalena Nohrborg for 3GPP, "LTE Overview," http://www.3gpp.org/lte.

[18] *See NPRM* ¶ 129.

since it would be included in the licensed block. 5 MHz blocks are therefore preferable because they would be far more efficient in maximizing productive use of the repurposed spectrum.

Offering licenses based only on 5 MHz blocks also simplifies the forward auction. With 5 MHz building blocks, the Commission has the opportunity to offer generic licenses for each geographic license area. If bidders want to obtain larger spectrum blocks, they can do so by bidding on multiple generic 5 MHz blocks in the same geographic license area. For this reason, 5 MHz blocks best enable licensees to combine blocks. Mobile broadband providers that want to offer service on a 10x10 MHz or wider service channel can aggregate the 5 MHz building blocks to support such plans. The use of 5 MHz building blocks thus supports the business plans of carriers who want to pursue multiple adjacent blocks in the forward auction or in secondary market transactions after that auction.[19]

Given that generic paired blocks are particularly valuable and important to the auction's success, the Commission should avoid or minimize measures that may affect the substitutability among spectrum blocks. To the extent it is necessary to take measures that might impair some auctionable spectrum in some markets, the Commission should protect paired spectrum from any such impairments. For example, if it proves necessary to create geographic buffer zones or other measures to protect mobile operations in high-clearing markets from co-channel interference from broadcast operations in low-clearing markets, the broadcast channels in low-clearing markets should be lined up with the *supplemental downlink* (not with the paired spectrum) in adjacent higher-clearing markets. By potentially impairing (at most) only supplemental downlink blocks, the Commission would maximize the amount of generic paired spectrum.

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[19] As discussed in Section III.C, the ability to aggregate spectrum during the auction requires a reasonable and transparent procedure for distribution of blocks to winning bidders in the assignment phase.

3. Dedicate Cleared Spectrum as Supplemental Downlink Where It Cannot Be Incorporated Efficiently as Paired Spectrum.

The Commission should license any cleared spectrum that cannot be efficiently licensed in paired spectrum blocks for supplemental downlink.[20] Wireless providers' need for supplemental downlink capacity is growing rapidly because of customers' increasing use of video streaming and other spectrum-intensive uses that place asymmetrical demands on mobile networks. Because supplemental downlink blocks can be used with other spectrum bands (e.g., Cellular, PCS, 700 MHz), they offer more flexibility to industry participants than asymmetrical 600 MHz band licenses.[21] That is why the optimal band plan configurations discussed above feature supplemental downlink in high-clearing markets where the extra cleared spectrum cannot be efficiently licensed as paired blocks. For example, in markets where clearing facilitates mobile broadband operations below Channel 37, the optimal band plan fills that space with supplemental downlink.[22]

The *NPRM* also seeks comment on whether to authorize Time Division Duplex (TDD) operations in the auctioned spectrum.[23] TDD operation on this (and any band) would require guard bands between the bands, reducing the amount of spectrum that could be auctioned to licensees for mobile broadband use. Authorizing TDD would also create substantial technical

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[20] *NPRM* ¶¶ 132-134.

[21] While maximizing paired spectrum is a higher priority than making supplemental downlink available, supplemental downlink spectrum is better than paired spectrum from a device implantation, feasibility, and inter-operability point of view.

[22] Also, as discussed above, the supplemental downlink approach provides the possibility of creating paired bands (in the "lower 600") if additional TV stations below the supplemental downlink are cleared in the future. In order to minimize uplink harmonic interference into other device bands, the uplink block must be located between Channel 26 and 30.

[23] *See NPRM* ¶¶ 183-184.

issues including co-existence of TDD and FDD mobile devices.[24] In addition, as discussed earlier, the generated harmonics from uplink transmissions in a TDD mobile device transmitting on frequencies below Channel 46 would potentially create interference problems within mobile devices.

Moreover, auction bidders will value the reclaimed spectrum the most if employed for FDD use. As the Commission previously explained for 3G technologies, "CDMA2000 and W-CDMA technologies employ a frequency division duplex (FDD) transmission mode that requires a paired-channel architecture and operates in symmetric paired blocks of spectrum. FDD is the most commonly used transmission procedure for PCS, cellular, and other mobile telephony applications and the record indicates it is the technology most likely to be employed in this spectrum."[25] The same is true of the 4G technology LTE. The Commission therefore should not authorize TDD operations in the 600 MHz band.

4. Create at Least a 10 MHz Duplex Gap Free from Broadcast Operations.

A duplex gap between the paired uplink and downlink spectrum blocks spectrum is necessary for FDD operation used for LTE and other technologies.[26] The gap must be at least 10 MHz (and possibly larger, depending on the overall band design). A larger duplex gap results in less insertion loss and also facilitates a larger pass band of 25 MHz or possibly more without impacting sensitivity in the mobile device. Because dedicating sufficient spectrum to the duplex

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[24] Uplink transmissions from one or more TDD-LTE devices can potentially create intermodulation into downlink of one or more nearby FDD-LTE devices due to mixing of FDD uplink transmissions and TDD uplink transmissions.

[25] *Service Rules for Advanced Wireless Services in the 1.7 GHz and 2.1 GHz Bands*, Report and Order, 18 FCC Rcd 25162, 25179, ¶ 45 (2003).

[26] The "duplex gap" is the amount of frequency separation between the transmit and receive bands. *See NPRM* ¶¶ 166-167.

gap is critical to device design, the Commission should adopt a band plan with at least a 10 MHz duplex gap for the 600 MHz paired spectrum bands.

The Commission proposes to leave broadcast operations in the duplex gap. Verizon does not support that proposal because the duplexer would not be able to provide sufficient attenuation and intermodulation interference would be generated by interactions between 600 MHz uplink transmission and DTV transmissions within the duplex gap. Therefore, leaving broadcast operations in the duplex gap will increase the risk of harmful interference against which current mobile device and base station filter technology cannot protect. In markets with very low clearing, it may be possible to allow TV stations in the uplink or downlink pass bands; however, ideally this should be avoided because it creates additional guard bands and buffer zones that may extend into adjacent markets.

Moreover, the presence of TV broadcast operations within the duplex gap, uplink pass band, or downlink pass band could preclude the Commission from auctioning the 600 MHz spectrum in generic blocks because the value of individual blocks would vary depending on the frequency band and geographic proximity of DTV broadcast stations to the 5 MHz blocks in each licensing area. As discussed above, the case-by-case impairments associated with allowing broadcast operations in the duplex gap, uplink pass band, or downlink pass band would create substantial hurdles to conducting a successful forward auction.

5. Ensure a Sufficient Guard Between Mobile and Broadcast Operations.

Section 6407(b) of the Spectrum Act requires that the guard band size be "no larger than is technically reasonable to prevent harmful interference between licensed services outside the guard bands." Verizon is continuing to analyze the technical issues, but preliminary analysis indicates that the minimal guard band will probably need to be greater than the 6 MHz proposed

in the *NPRM*,[27] at least where mobile operations are adjacent to high-power broadcast operations. Therefore, Verizon's proposed band plan configurations (Figures 1, 2 and 3) assume a minimal guard band of 10 MHz to protect downlink from adjacent high-power broadcast channels.[28] However, it is important to note that in the high-clearing scenario (Figure 1 above), the 6 MHz comprising Channel 37 can be employed as part of the guard band, requiring adding only 4 MHz more to make the minimum 10 MHz total guard band between mobile and broadcast operations on opposite sides of that channel. Appropriate low-power Part-15 type devices could operate in the guard band and the duplexer gap on a non-interfering basis provided they meet certain specifications.

II. THE REVERSE AUCTION AND REPACKING RULES SHOULD MINIMIZE UNCERTAINTY FOR BROADCASTERS AND MAXIMIZE THEIR PARTICIPATION

In order to achieve Congress's objective of promoting wireless broadband deployment by maximizing the amount of spectrum that will be made available for flexible use, the Commission must encourage broad participation by broadcasters. The design of the reverse auction and repacking requirements should be as simple and transparent as possible so that broadcasters know what spectrum rights they will have after the incentive auction and repacking are complete. Those requirements also must work in tandem with the forward auction in a manner that achieves an efficient outcome for all participants and achieves Congress's spectrum repurposing

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[27] *Id.* ¶ 156.

[28] Under the framework discussed above, in some markets the optimal configuration may involve a guard bands larger than 10 MHz. That is a function of the fact that after clearing broadcast spectrum in blocks of 6 MHz and then dividing the total amount into 5-MHz blocks, in some markets the only reasonable place to locate the remainder spectrum is in the guard band. Tacking on an extra MHz or two to an otherwise-generic block of auctionable spectrum would not make sense. And from a device design point of view, dedicating remainder spectrum to guard band use is technically preferable to increasing the size of the duplex gap.

and revenue requirements. And the Commission must address these matters well in advance of the incentive auction so that the broadcasters for whom the reverse auction may be a viable business option have time to appraise their business models, coordinate with investors, and formulate plans to participate.

A. Early Commission Decisions Should Address Important Reverse Auction Issues to Help Promote Broadcaster Participation.

Chairman Genachowski appropriately has "committed to getting [broadcasters] the information [they] need to make sound business decisions and to help [them] recognize the full value of the opportunity" presented by the reverse auction.[29] The Commission can help achieve this objective by providing broadcasters with an understandable and transparent reverse auction process, and adequate certainty regarding the channel re-assignment method and post-repacking RF interference criteria that will apply to broadcasters remaining after the reverse auction is complete. Verizon discusses specific actions the Commission could take to help ensure a successful reverse auction below.

Verizon encourages the Commission to address and resolve many of these issues now rather than later, through an initial Order or Public Notice that leaves other issues to subsequent decisions. Not only will prompt decisions on some key issues provide broadcasters with more certainty and thus enable them to begin planning for the auction; it could enable the Commission to narrow the scope of the remaining issues, and thus expedite its resolution of those issues before the auction. The Commission should determine, based on the record of the *NPRM* and its

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[29] *See* Julius Genachowski, Chairman, Federal Communications Commission, Prepared Remarks, NAB Show 2012, at 5 (Apr. 16, 2012), http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-313605A1.pdf.

outreach to broadcasters through the "Learn Everything About Reverse-Auctions Now Program" (LEARN)[30] and other venues, which actions it can take quickly, and complete those actions.

The Commission has discretion to address the issues in this rulemaking in stages.[31] The Spectrum Act does not require otherwise and, indeed, the Commission's implementation of the broadband PCS auctions as well as the 700 MHz auction illustrates its success in addressing issues such as auction processes and service-specific technical and service rules in staged but parallel tracks.[32] The importance of providing certainty for broadcasters, and the threshold nature of many of these issues to the incentive auction design, merits a similar approach here.

The Commission should immediately address the spectrum clearing target.[33] It should promptly announce a spectrum clearing target of at least 120 MHz, an amount consistent with the

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[30] *See* http://www.fcc.gov/learnprogram.

[31] *See ITT World Communications, Inc. v. FCC*, 725 F.2d 732, 754 (D.C. Cir. 1984) (Commission may "resolve some issues and to defer the resolution of other issues when the issues decided were not inextricably related to the issues deferred ….").

[32] The Commission adopted broadband PCS technical/service rules and auction procedures in a series of Orders in different rulemaking dockets. *See Amendment of the Commission's Rules to Establish New Personal Communications Services*, Second Report and Order, 8 FCC Rcd. 7700 (1993), *recon.* Memorandum Opinion and Order, 9 FCC Rcd. 4957 (1994), and Third Memorandum Opinion and Order, 9 FCC Rcd. 6908 (1994) (technical/service rules); *Implementation of Section 309(j) of the Communications Act – Competitive Bidding*, Second Report and Order, 9 FCC Rcd. 2348 (1993), Fifth Report and Order, 9 FCC Rcd. 5532 (1994), and Fifth Memorandum Opinion and Order, 10 FCC Rcd. 403 (1994) (auction rules). It did the same for the 700 MHz spectrum. *See Service Rules for the 698-746, 747-762 and 777-792 MHz Bands*, et al., Second Report and Order, 22 FCC Rcd 15289 (2007) ("*700 MHz Service Rules Order*") (adopting 700 MHz band plan); Report and Order and Further Notice of Proposed Rulemaking, 22 FCC Rcd 8064 (2007) ("*700 MHz First Report and Order*") (adopting 700 MHz band auction and service rules).

[33] *See NPRM* App. C at 9 (describing a "provisional clearing target" for purposes of initiating the reverse auction).

National Broadband Plan and the enormous potential of the incentive auction.[34] By the nature of the two-sided incentive auction, participants' bids and the effectiveness of the Commission's bid assignment and repacking methods will determine the amount ultimately cleared. But a known target can help instruct the Commission's and stakeholders' deliberations about the band plan and, in conjunction with that band plan, provide mobile broadband providers and non-exiting broadcasters an idea of where broadcast and mobile broadband operations could occur in the 600 MHz band post-auction. Moreover, in markets where the repacking formula reveals that Commission can achieve this target entirely through repacking, broadcasters will know that their stations in those markets will not be part of the reverse auction. Broadcasters will also know where repacking alone cannot clear 120 MHz, and this information could be valuable in planning an auction strategy.

Decisions on the bid options that will be available to broadcasters, the bid assignment and repacking methodologies, and live demonstrations of those methodologies for potential bidders well in advance of the auction, are necessary to determine the viability of the various auction designs the Commission has proposed. In addition, the potential impact of repacking on a broadcaster's geographic and population coverage will be relevant to its decision to participate in the auction at all and, if it does, whether it submits an exit bid or chooses another option that enables it to remain on air. Prompt decisions about specific changes to broadcast technical and other rules, and about preserving the confidentiality of broadcasters that decide to participate, will provide more time and certainty for broadcast station owners to assess whether and how to participate in the reverse auction.

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[34] *See* Genachowski Wharton Speech at 5 (stating that the opportunity for "clearing new bands for flexible broadband use" from the incentive auction "is large, particularly given the highly desirable nature of this 600 MHz spectrum for mobile broadband").

Rather than expedite resolution of these and other important issues, however, the *NPRM* proposes to defer doing so. Deferral would push critical issues such as the basic reverse auction design, the sequence of the reverse and forward auction, and the reserve price, to a date *after* other rules are adopted and even closer to the auction.[35] While the Commission (on delegated authority to the Wireless Telecommunications Bureau) typically details the auction-specific procedures for forward auctions in a Public Notice closer to the auction date, the complexities of the incentive auction and novel issues facing potential auction participants compel a different approach here. Moreover, the unique and groundbreaking nature of the incentive auction has statutory implications for how the Commission proceeds with these important issues. The Commission must ensure that broadcasters and other interested parties have adequate time to evaluate new rules and plan their businesses accordingly.[36] Most broadcasters have never before participated in a spectrum auction, so the usual timing of auction-related notices is not sufficient. The Commission and the relevant Bureau(s) should instead work to resolve as many issues as possible sooner rather than later, and should announce all auction procedures well in advance of the auction.

B. The Commission Should Conduct the Reverse and Forward Auctions Simultaneously.

The Commission seeks comment on how best to integrate the reverse and forward auctions and, in particular, whether the auctions should be run simultaneously or sequentially.[37]

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[35] *See NPRM* ¶ 273; *id.* at App. A, proposed rules §§ 1.22002(b), 1.22003(b)-(c).

[36] *See* 47 U.S.C. § 309(j)(3)(E) (Commission must ensure "an adequate period is allowed— … after issuance of bidding rules, to ensure that interested parties have a sufficient time to develop business plans, assess market conditions, and evaluate the availability of equipment for the relevant services ….").

[37] *NPRM* ¶¶ 66-68.

A simultaneous auction would better serve all participants' common interests in limiting the duration of the auction process and encouraging broadcaster participation, ultimately clearing more spectrum.

Under a "sequential" approach, the Commission presumably would first conduct the reverse auction for a range of target channels, thus determining the clearing prices for each target and generating a form of supply curve of incrementally lower amounts of spectrum that would be available at each subsequent round of the forward auction. The Commission then would conduct the forward auction, and the entire auction would "close" when the Commission determines the maximum number of channels that can be cleared based on the submitted bids, ensuring that the revenues from the forward auction are sufficient to meet whatever closing conditions are adopted.

Under a "simultaneous" approach – which also can be described as a "staged" or "interleaved" approach – both the reverse and forward auctions would proceed in stages:[38]

- *Reverse Auction.* The initial stage starts with a target of broadcast spectrum to clear, and a reverse auction is conducted to determine what prices stations would accept to exit (or channel share), move to VHF, or for other bids as the Commission might allow, in order to meet the target. The prices from the winning bids are used to calculate the total cost.

- *Forward Auction.* The Commission next (or concurrently) conducts a forward auction to determine the bidders that would receive licenses created via the repurposed spectrum, using the band plan associated with this clearing target. The auction then reveals the total amount those forward auction bidders are willing to pay.

- *Closing Conditions Met? End.* If, at the end of this stage, the forward auction winning bids cover the closing conditions, then the incentive auction ends.

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[38] *See id.* App. C at 9, 14-15; Broadcaster LEARN Program Workshop, *Overview of the Incentive Auction NPRM*, Oct. 26, 2012, at 17-22, http://wireless.fcc.gov/learn/LEARN-Deck-12-5-12.pdf.

- *Closing Conditions Not Met? Continue.* If forward auction revenues do not meet the closing conditions, the initial spectrum clearing target is reduced, the band plan is modified, and the process continues via a second stage of reverse and forward auctions is conducted for remaining bidders (i.e. broadcasters that have not exited the reverse auction and forward bidders that retain eligibility to bid). Closing conditions are reassessed, with reductions in the clearing target based on the outcomes in the previous stage(s). The supply of spectrum is thus reduced, resulting in lower total payments to existing broadcasters and higher bids for the remaining, now scarcer spectrum. This process continues until the closing conditions are met.

The simultaneous approach offers important advantages over the sequential approach, provided that the Commission's auction processes can handle the complexities and quickly assess the optimal bid assignment, repacking, total revenue objectives and band plan changes between or during stages. First, it can result in lower participation costs for reverse and forward auction bidders. The value a broadcaster derives for remaining on air may depend in part on the number of channels cleared (and thus the potential competition for advertising revenues) in its broadcast area. A staged process requires broadcasters to determine this value only incrementally, and not for scenarios that never arise because the auction will already have closed. Similarly, bidders in each stage of the forward auction will know the nationwide band plan applicable during that stage and can more easily determine their willingness to pay for licenses. A sequential approach, in contrast, requires that broadcasters make the necessary valuations for many hypothetical band plan scenarios and thus places an unnecessary burden on potential incentive auction participants. Broadcasters also must reveal more sensitive information under a sequential approach, including the offer price for their channel(s) under those multiple hypothetical band plan scenarios. A broadcaster's concern that such information might be used against its interests could dampen its interest in participating in the auction.

Timing also is an important factor weighing in favor of a simultaneous approach. As noted above, under a sequential approach, participating broadcasters would have to commit to a variety of bids for multiple band plan and post-repacking scenarios. They then would be left

waiting until the operation of the forward auction closes the entire process. Broadcasters may be reluctant to participate in the reverse auction if they are to remain bound to their contingent offers for the duration of the incentive auction. In contrast, a simultaneous approach enables a broadcaster to exit the auction at various incremental stages, thereby limiting the duration of the auction for that broadcaster. Thus, the consequences of bidding behavior would be resolved more quickly, which could also reduce the uncertainty of the reverse auction and make it more attractive for broadcasters.

For these reasons, a simultaneous auction is the best approach, but resolving other components of the Commission's incentive auction regime will be critical to a successful simultaneous auction. Specifically, the Commission must be able to run its bid assignment and repacking algorithms at multiple points throughout the auction stages so that participants will have insight into the available spectrum supply during the bidding stage. Bidders will require confidence that the repacking mechanism can be run quickly and that the results of the algorithm are reliable and repeatable. A dependable repacking mechanism also can provide auction participants with certainty that their bids accurately reflect the applicable band plan for each stage.[39] And the Commission will need to decide how it intends to apply the closing conditions in the context of simultaneous reverse and forward auctions, and which closing conditions to apply.[40]

C. A Descending Clock Reverse Auction Will Encourage Broadcaster Participation.

Because widespread broadcaster participation will be necessary for the Commission to clear the maximum amount of spectrum, the reverse auction mechanism must encourage, not

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[39] *See infra* Section II.G.

[40] *See NPRM* ¶ 69.

deter, broadcaster participation. The Commission can achieve this by ensuring that reverse auction bidders have strong incentives to offer bids that reflect their actual opportunity costs. The *NPRM* describes two general auction designs: a single round sealed bid auction; and a multiple round descending clock auction, described in more detail in the Auctionomics paper.[41] Each option has advantages and disadvantages. A descending clock auction simplifies broadcasters' bidding strategies into a sequence of "In" or "Out" decisions, potentially encouraging bidder participation. Yet, a sealed bid approach is simpler for the Commission to administer, and is less dependent on the speed of the repacking and bid assignment mechanisms.[42]

On balance, a descending clock approach likely has the most potential for encouraging broadcaster participation in the reverse auction. The Commission needs to couple this approach with important auction design components to ensure that the Commission achieves the dual objectives of promoting broadcaster participation and achieving an efficient outcome. The initial reverse auction reserve price for each of the exit, channel sharing and VHF relocation options must be high enough to ensure that broadcasters will have incentive to participate in the first instance.[43] In addition, the Commission's repacking and bid assignment mechanisms will need to run accurately in real time to avoid disrupting and delaying the auction for reverse and forward bidders alike. Thus, the Commission will need to effectively integrate the descending clock approach with the other interdependent components of the incentive auction.

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[41] *Id.* ¶¶ 38-40, App. C.

[42] *See id.* ¶ 40.

[43] *See id.* ¶ 53.

D. The Commission Should Not Disclose Reverse Auction Bidder Identities.

Verizon agrees that the Commission should incorporate into its auction rules the Spectrum Act's requirement to "take all reasonable steps necessary to protect" a licensee's identity and data in its competitive bidding rules.[44] The Spectrum Act establishes the *minimum* period during which the Commission must protect such information (through the reassignment and reallocation process)[45] and does not preclude the Commission from continuing to protect such information from public disclosure after the auction concludes pursuant to Exemption 4 of the Freedom of Information Act.[46] Such longer protection may be a prerequisite for certain broadcasters to participate in the auction, as the mere fact that a company is participating in the reverse auction, not to mention information such as bid selection and bid valuation, is highly competitively sensitive, particularly (but not exclusively) for participants whose bids are not accepted. The Commission therefore should order that the identity of reverse auction bidders, any of the bids they submit, and data that would enable the public to determine a bidder's identity will be exempt from public disclosure both during and after the incentive auction.

E. Both Algorithms for Selecting Winning Bids Have Merit But the Commission Should Announce Its Choice Well In Advance of the Auction

The Commission seeks comment on two principal reverse auction bid assignment procedures – the "integer programming" and "sequential algorithm."[47] The Commission's choices present clear trade-offs. An integer method for choosing the winning bids is, in design at least, probably more effective at finding the winning bids that will maximize the amount of

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[44] *See id.* ¶ 257, 259.

[45] *See* Spectrum Act § 6403(a)(3).

[46] *See* 5 U.S.C. § 552(b)(4); *NPRM* ¶ 261.

[47] *See NPRM* ¶¶ 45-46.

spectrum reallocated for flexible use because it could determine more expeditiously which of the various bids and feasible repacking solutions would minimize the amount of the total bids while clearing the maximum amount of spectrum. On the other hand, the sequential algorithm would be easier for the Commission to implement and probably would more effectively ensure that the reverse auction proceeds smoothly and concludes quickly – benefits that will be important for broadcasters as well as forward auction participants.

If an integer programming method could operate as quickly as the sequential algorithm method, it would be preferable because it would clear the maximum amount of spectrum most efficiently. The Commission may find, however, that given the complexities and variables involved with integer programming, its software may not be able to find an optimum solution within a reasonable amount of time. Timeliness is particularly critical for the proposed descending clock auction because the algorithm must be run and the band plan regenerated throughout the auction on a nearly real time basis.

If the Commission is unable to resolve these complexities and variables, then on balance the more transparent sequential algorithm would appear to provide more certainty to broadcasters and thus have greater potential to encourage their participation in the reverse auction – which is also critical to maximizing the spectrum reallocated for flexible use. Developing the software program that can reach a good result quickly should be less of a burden for the Commission and can have countervailing benefits – namely encouraging broadcaster participation – that can help offset the loss of an optimal outcome, particularly if the difference between the two options can be minimized. Alternatively, if the Commission is able to develop a reliable integer method that reaches an optimal result quickly, it could run both methods in parallel during the auction, and use the sequential algorithm in those cases when the integer program does not generate the result

quickly enough, or limit use the integer method to the later auction rounds when the final allocations and assignments are in sight, while using the sequential method to help expedite the auction during the earlier stages.

Whichever method the Commission plans to use, it should disclose its selected method(s) as soon as possible. This process should include publication of a full description, with the relevant source code and a test case that could be used to verify the operation of the software, and should include the location/power database and the interference model used. This will allow broadcasters to verify that the constraints used in the repacking algorithm properly reflect the Commission's RF interference rules and enable forward auction participants to evaluate the effectiveness of the software in helping derive the band plan.

F. The Commission Should Provide Relief from Existing Broadcast Service and Ownership Rules to Promote Broadcaster Participation.

The Commission seeks comment on additional measures to encourage broadcaster participation in the reverse auction. Several of these measures could enhance broadcasters' interest in the auction, thus improving the likelihood of a successful auction.

1. Relief from Media Ownership and Other Rules.

The Commission should, as it proposes, "grandfather any station combinations that would no longer comply with [its] multiple ownership rules as a result of the" incentive auction, to avoid discouraging reverse auction participation.[48] In creating a one-time market-based mechanism for broadcast licensees to exit the market entirely through the reverse auction, Congress necessarily understood that there would be fewer broadcasters in many markets, which could place the remaining stations in violation of ownership rules. In addition, to the extent that

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[48] *Id.* ¶ 356.

the results of the auction may have longer term implications for the Commission's multiple ownership and other ownership rules and policies, the Commission can consider further changes to the ownership rules in its quadrennial regulatory reviews under Section 202 of the Telecommunications Act,[49] and should not restrict reverse auction participants' bid opportunities on that basis.[50]

2. Accommodating VHF Relocation.

Many broadcast stations may be willing to accept compensation to relocate to the upper *or* lower VHF bands, particularly smaller or middle-sized stations for which must carry rights may be more valuable than retaining all of their existing POPs or coverage area through the repacking process. The 30 MHz of spectrum in the lower VHF band (Channels 2-6) is largely unutilized, and high VHF spectrum has far fewer stations than UHF, including in areas where UHF is highly utilized and where demand for flexible use spectrum will be most acute. Moreover, while the noise floor in the VHF band is problematic for broadcast operations (particularly at lower VHF), the incentive auction presents an opportunity to promote more efficient use of that spectrum by encouraging voluntary relocation to the upper *and* lower VHF band.

The Commission should consider allowing broadcasters the opportunity to submit a variety of VHF relocation bids in the reverse auction. It could also take steps to accommodate existing and future VHF operations after repacking in both the upper and lower VHF bands. These options could include allowing a broadcaster in the UHF spectrum to limit its relocation

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[49] *See* Telecommunications Act of 1996, Pub.L. No. 104-104, § 202(h), 110 Stat. 92 (1996).

[50] *See NPRM* ¶ 48 (seeking comment on whether to "consider in the repacking and assignment procedures whether a given broadcaster going off the air would create areas without any commercial or noncommercial broadcast television service.").

bid to the high VHF channels where the noise floor problems are less acute, accommodating broadcasters' reasonable requests for waiver of the height and power limits to improve VHF coverage, ensuring that must carry rights are preserved, and allowing (and encouraging) broadcasters in the high VHF or UHF band to relocate to the lower VHF band in exchange for a winning bid in the reverse auction.[51] These actions could achieve more efficient use of the lower VHF band, particularly if coupled with a renewed Commission effort, begun in its 2010 Notice of Proposed Rulemaking, to take additional measures to improve the viability of lower VHF through modified power limits and improving indoor and outdoor rooftop antenna performance.[52] In addition, some stations may be able to utilize low power repeaters on a secondary basis, or even distributed transmitter systems on a primary basis, to provide enhanced coverage to the outer portions of their new service areas in the upper or lower VHF bands to overcome noise floor issues.

3. Additional Interference.

Verizon supports allowing broadcasters to accept additional interference or a reduced service area as a method of encouraging additional broadcaster participation in the reverse auction.[53] This option could appeal to broadcasters that view a percentage loss in over-the-air covered POPs as a calculable percentage loss in their business, and even to larger stations that do not rely on their must carry rights for cable TV carriage and view their over the air viewers separately. Allowing broadcasters to submit an alternative bid based on coverage would likely add a degree of complexity to the Commission's administration of the auction, including the bid

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[51] *See NPRM* ¶¶ 85-86.

[52] *See Innovation in the Broadcast Television Bands: Allocations, Channel Sharing and Improvements to VHF*, Notice of Proposed Rulemaking, 25 FCC Rcd 16498, ¶¶ 42-57 (2010).

[53] *See NPRM* ¶¶ 87-88.

assignment and repacking methodology. But given the potential benefits, including the possibility that such a bid to accept additional interference (thus reducing a station's covered POPs while maintaining must carry rights) could free up more spectrum at a possibly lower price than an exit bid, the Commission should consider the feasibility of this approach.

For example, allowing a broadcaster to offer two bids – one to exit the spectrum, and the other to accept interference to, say, ten percent of its covered population – could create more flexibility in the repacking process and lower the cost of clearing significant spectrum amounts. In this scenario, where a broadcaster obtains approximately ninety percent or more of its viewing through carriage on cable or satellite systems, a ten percent loss of over-the-air covered POPs may translate to a one percent loss of viewership. Indeed, the impact may be even less because viewers on the fringes of coverage (where the relevant co-channel or adjacent channel interference would occur) may be more likely to watch the programming via cable or satellite to begin with. In addition, as noted above, broadcast stations may be able to regain some covered POPs via low power repeaters or distributed transmitter systems to enhance coverage to these portions of their service areas and mitigate interference from other stations.

The Commission should thus consider the feasibility of allowing broadcasters to accept up to ten percent interference to their covered POPs at a given price. Ten percent was the highest range of acceptable interference permitted during the DTV transition, so this calculation should be feasible for broadcasters.[54] One potential method for implementing this approach would be to provide reverse auction bidders with a sliding scale option for which the final payment would depend on the percentage of POPs interfered with that the broadcaster would

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[54] *See Advanced Television Systems and Their Impact upon the Existing Television Broadcast Service*, Memorandum Opinion and Order on Reconsideration of the Sixth Report and Order, 13 FCC Rcd 7418, ¶¶ 78-87 (1998).

accept. Thus, for example, a broadcaster that bids $2 million per percentage lost up to ten percent but, after repacking, loses only five percent of covered POPs, would receive no more than $10 million for its winning reverse auction bid. In rural markets, where there are more available channels and fewer stations, there may be no need to invoke this option under the bid assignment and repacking algorithms (and OET Bulletin 69), but in urban areas (and markets adjacent to urban areas), where potential interference issues associated with repacking will likely be more of a problem, this option could encourage more stations to participate.

4. Pending Renewal/Enforcement Actions and Transactions.

The Commission correctly proposes that the pendency of a license renewal application or enforcement action against a broadcaster should not render it ineligible to participate in the reverse auction.[55] There could be particular benefit in providing broadcasters in pending enforcement proceedings with the option of a standard settlement amount in order to provide them with additional certainty for bid valuation purposes.[56] The Commission might also provide broadcasters with additional regulatory certainty by facilitating the processing of transfer of control or assignment applications that may be necessary for a particular station to participate in the reverse auction. For example, the Commission could issue a Public Notice advising interested parties that want transfer of control or assignment applications granted before the reverse auction to file them by a given date sufficiently in advance of the reverse auction.[57]

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[55] *See id.* ¶¶ 81-83.

[56] *See id.* ¶ 83.

[57] *Cf. Wireless Telecommunications Bureau, Public Safety and Homeland Security Bureau, and Office of Engineering and Technology Provide Reminder of January 1, 2013 Deadline for Transition to Narrowband Operations in the 150-174 MHz and 421-512 MHz Bands and Guidance for Submission of Requests for Waiver and Other Matters*, Public Notice, DA 11-1189, 26 FCC Rcd. 9647 (2011) (urging parties to file waiver requests before the end of 2011); *Commercial Mobile Radio Service Year-End Transfer and Assignment Applications*, Public

G. The Commission Should Disclose the Repacking Methodology Well In Advance of the Reverse Auction and Ensure that it Maximizes the Spectrum Cleared for Mobile Broadband Use.

The repacking formula and methodology is important for reasons beyond preserving broadcasters' post-auction Spectrum Act rights. The repacking methodology the Commission uses will be closely tied to its bid assignment processes, so it is critical that the Commission be able to "run" the repacking formula quickly and predictably to ensure that the reverse *and* forward auctions run smoothly and that broadcasters have certainty. The Commission also should conduct simulations well in advance of the auction. Moreover, the Commission should test the methodology in advance of the reverse auction in those markets where repacking alone is sufficient to meet the clearing target. These actions would demonstrate to forward auction participants that the band plan on which they will bid during an auction round accurately reflects the spectrum that would be available.

The Spectrum Act also requires that the Commission take "reasonable efforts" to preserve the broadcasters' coverage areas and population served. Although individual channel assignments are subject to the parameters of OET Bulletin 69, the Commission should apply its repacking methodology in a manner that maximizes the Commission's flexibility so as to maximize the amount of spectrum reallocated for flexible use. For example, population served should be based on *total* over-the-air population, not "the same specific viewers."[58] Otherwise, the Commission would be locked into preserving existing geographic markets irrespective of the different RF environment in which the repacked station would operate. For that reason as well, changes in coverage area contemplated within OET Bulletin 69 clearly should be considered the

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Notice, 12 FCC Rcd. 15228 (1997) (recommending that CMRS transfer and assignment applicants seeking year-end approval file their applications by particular dates).

[58] *See NPRM* ¶¶ 105-06.

minimum that is "reasonable" under the Spectrum Act. Finally, the Commission should apply the Bulletin in a manner that preserves a broadcaster's Designated Market Area (DMA)-based community of license in a manner that enables broadcasters to retain carriage rights to help ensure the viability of VHF relocation and channel sharing bids.[59]

H. The Commission Should Act Now to Promote Clearing of Channel 51.

Existing broadcast operations at Channel 51 already pose deployment challenges for mobile broadband providers in the adjacent Lower 700 MHz A Block. Many A Block licensees cannot provide coverage throughout their licensed service areas due to significant adjacent-channel interference challenges. Under the Commission's rules, A Block licensees may not deploy service in exclusion zones designed to protect DTV receivers, and must accept harmful interference into their mobile broadband networks.

The Commission already sought comment on how to address those issues in a separate proceeding and has a full record on which it can act.[60] Rules addressing repacking, reverse auction eligibility and reimbursement eligibility should enable and encourage Channel 51 licensees to cease or relocate their operations in the near term. The Commission's rules should, for example: allow Channel 51 broadcasters to channel share with other broadcasters, without losing either their ability to participate independently in the incentive auction or their must-carry rights; adopt expedited procedures under which Channel 51 broadcasters may relocate to other

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[59] *See* 47 U.S.C. § 534(h).

[60] *See Promoting Interoperability in the 700 MHz Commercial Spectrum, Interoperability of Mobile User Equipment Across Paired Commercial Spectrum Blocks in the 700 MHz Band*, Notice of Proposed Rulemaking, WT Docket No. 12-69, 27 FCC Rcd 3521, ¶ 44 (2012); AT&T Comments in WT Docket No. 12-69 at 45-46; CTIA Comments in WT Docket No. 12-69 at 3-6; Blooston Rural Carriers Comments in WT Docket No. 12-69 at 5; Rural Telecommunications Group Comments in WT Docket No. 12-69 at 13-14, National Telecommunications Cooperative Association (NTCA) Comments in WT Docket No. 12-69 at 8-9; MetroPCS Comments in WT Docket No. 12-69 at 12.

available channels,[61] and determine whether it is feasible to ensure that Channel 51 licensees that voluntarily relocate to below Channel 31 (i.e. beyond a 120 MHz clearing target) are not relocated a second time as a result of the repacking algorithm; permit the sale of Channel 51 licenses to entities (including wireless providers) that will not operate on the spectrum pending the upcoming incentive auctions, thus allowing the broadcaster to "auction" its license now and the purchaser of that license to participate in a future incentive auction; allow Channel 51 broadcasters to maintain non-operational licenses beyond one year if necessary,[62] or waive the minimum operating requirements for Channel 51 broadcasters and any other rules that may prohibit a licensee from ceasing operations[63] – either of which would allow Channel 51 broadcasters to cease operations without losing their licenses and thus their ability to participate in a future incentive auction.[64] The Commission should act on these proposals now through a separate Order, which will provide certainty to existing Channel 51 broadcasters that the incentive auction will remain a viable option for them.

III. THE COMMISSION SHOULD DESIGN THE FORWARD AUCTION TO PROMOTE MAXIMUM PARTICIPATION BY WIRELESS PROVIDERS.

A. The Forward Auction and 600 MHz Service Rules Should Impose No Eligibility or Spectrum Aggregation Restrictions.

Section 6404 of the Spectrum Act provides that the Commission cannot "prevent a person from participating in a system of competitive bidding" if that person complies with the

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[61] *See* CTIA Comments in WT Docket No. 12-69 at 6.

[62] *See* 47 U.S.C. § 312(g) ("If a broadcasting station fails to transmit broadcast signals for any consecutive 12-month period, then the station license granted for the operation of that broadcast station expires at the end of that period . . . except that the Commission may extend or reinstate such station license . . . to promote equity and fairness.").

[63] *See, e.g.*, 47 C.F.R. § 73.1740(a)(2) (requiring TV stations to operate no less than 2 hours each day and no less than 28 hours each week during their first 36 months of operation).

[64] *See* AT&T Comments in WT Docket No. 12-69 at 47-48.

Commission's auction rules and meets the technical, financial, character and citizenship qualifications.[65] That requirement is consistent with the Commission's repeated finding that open eligibility for wireless spectrum allocations serves the public interest and is clearly the most efficient means for licensing spectrum by auction.[66] Allowing all interested parties to participate fully in the forward auction without limits on that participation is not only statutorily mandated, but it will ensure that the 600 MHz spectrum is put to its highest and best use, as required by Section 309(j).[67]

The Commission states that it intends to apply the statutorily-required open eligibility standard for this incentive auction,[68] but it also requests comment on whether to adopt a rule of "general applicability" to promote the goals of 47 U.S.C. § 309(j)(3)(B).[69] Those goals are to promote "economic opportunity and competition" and to ensure that "new and innovative technologies are readily accessible to the American people by avoiding excessive concentration of licenses and by disseminating licenses among a wide variety of applicants…."[70] Given the highly competitive nature of the wireless industry and the robust bidding to be expected in the forward auction, any rule that restricts bidding is likely to *undercut* – rather than promote – those goals, because it would suppress demand and fail to ensure that spectrum is put to its best and most productive use. These risks posed by eligibility limits are particularly acute given

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[65] Spectrum Act § 6404, *codified at* 47 U.S.C. § 309(j)(17)(A).

[66] *See, e.g.*, *700 MHz Service Rules Order*, 22 FCC Rcd at 15383-84, ¶ 256.

[67] *See 700 MHz Service Rules Order*, 22 FCC Rcd at 15385, ¶ 259 (*citing Implementation of Section 309(j) of the Communications Act – Competitive Bidding,* Second Report and Order, 9 FCC Rcd 2348, 2349-50, ¶¶ 3-7 (1994) ("*Competitive Bidding Second R&O"*)).

[68] *NPRM* ¶ 381.

[69] *Id.* ¶¶ 383-84.

[70] 47 U.S.C. § 309(j)(3)(B).

Congress's authorization of only one incentive auction of the broadcast spectrum in the 600 MHz band.[71]

First, any restriction could not be justified. The Commission has recognized that restrictions on spectrum ownership could only be appropriate if there is a finding of a "significant likelihood of substantial competitive harm in a specific market."[72] Given the strong and increasing competition in the market for mobile broadband, there is no indication that competitive harm would develop for services provided using 600 MHz spectrum. According to the Commission's Fifteenth Wireless Competition Report, 97 percent of the U.S. population already lives in census tracts with access to three or more different operators offering mobile telephone service.[73] The vast majority of these operators also offer some form of data service. Indeed, most wireless providers are in the process of deploying 4G networks that will offer wireless consumers broadband services at speeds faster than DSL. Over 80 percent of the U.S. population lives in census tracts with access to three or more mobile broadband providers, and over 90 percent lives in census tracts with access to two or more mobile broadband providers.[74]

The Commission recently confirmed the expansion of the mobile broadband market, noting that the "[b]est available estimates of mobile broadband coverage by 3G or better technologies (including CDMA EV-DO, EV-DO Rev. A, WCDMA/HSPA, HSPA+, mobile WiMAX, and LTE) indicate growth from 98.1% of the U.S. population in November 2009 to 99.4% in January 2012. . . . In addition, the percentage of the population covered by at least four

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[71] *See* Spectrum Act § 6403(e).

[72] *700 MHz Service Rules Order*, 22 FCC Rcd at 15383, ¶ 256.

[73] *Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993*, Fifteenth Report, 26 FCC Rcd 9664, 9669 (2011) ("*Fifteenth CMRS Report*").

[74] *Id.* at 9670.

mobile broadband providers increased from 58 percent to 79 percent during that period."[75] In this competitive market, any interested mobile provider should have the option of fully participating in the bidding for all 600 MHz spectrum available in the forward auction.

Second, restricting bidders from acquiring the spectrum they need to serve their customers would harm competition and consumers because at least some portion of the available spectrum would likely go to providers other than those that value it most and are most likely to deploy it productively. Restricting auction participation would "risk reducing the likelihood that the party valuing the license the most will win the license and put it to use for the benefit of the public."[76] Instead, it could result in the spectrum being held by an entity that is not capable of utilizing it and deploying service in the most efficient manner. As the Commission has noted, it is preferable for "the marketplace forces operating through the auction process, rather than regulatory fiat, [to] determine which of the multitude of service proposals will actually be implemented."[77] Thus, any rule restricting open bidding would likely *undercut* the Commission's statutory mandate to facilitate "the development and rapid deployment of new technologies, products, and services" and to promote "economic opportunity and competition."[78]

Third, rules restricting bidding would artificially suppress demand for the 600 MHz spectrum and risk not meeting the closing conditions and Congress's other fiscal goals for the

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[75] *Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps To Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act,* Ninth Broadband Progress Notice of Inquiry, 27 FCC Rcd 10523, 10525, n.12 (2012).

[76] *700 MHz Services Rules Order,* 22 FCC Rcd at 15385, ¶ 259.

[77] *Service Rules for the 746-764 and 776-798 MHz Bands, and Revisions to Part 27 of the Commission's Rules*, First Report and Order, 15 FCC Rcd 476, 489, ¶ 31 (2000) ("*Upper700 MHz Service Rules Order"*).

[78] 47 U.S.C. § 309(j)(3)(A), (B).

auction. By "reducing the likelihood that the party valuing the license the most will win,"[79] the robustness of overall bidding is reduced – and with it the prospect that substantial competition among bidders will drive bid amounts. Empirical evidence from past auctions supports the conclusion that "the effects of limiting particularly strong bidders from participating are detrimental to auction revenues."[80] Indeed, losses to the U.S. Treasury "could amount to billions of dollars."[81]

Fourth, restrictions such as a per-service area cap would reduce revenues by suppressing demand. Indeed, it could facilitate arbitrage by bidders taking advantage of below market prices at auction and then reselling the licenses on the secondary market to entities that value the spectrum more highly. Such an outcome would have the perverse effect of funneling dollars that should go to the U.S. Treasury into the hands of private parties.[82] It would also inject uncertainty into the forward auction and undermine vigorous bidding.[83] Because it is not possible for a bidder to know whether a particular bid will win and potentially place it over a cap, imposing a cap could cause bidders to forego bidding for certain licenses to avoid the possibility that the total amount of spectrum won might exceed the cap. Forward auction bidders will not know how much spectrum will ultimately clear, so they will not know ahead of time the amount spectrum on which they can bid in a market without violating the cap. And the problem is further complicated insofar as different amounts of spectrum may be available in different

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[79] *700 MHz Service Rules Order*, 22 FCC Rcd at 15385, ¶ 259.

[80] *See, e.g.*, Michael L. Katz, "An Economic Analysis of Auction Set Asides" at 9, ¶ 14 (May 2012), *available at* www.gcbpp.org/files/Academic_Papers/AP_Katz_AuctionSet.pdf.

[81] *Id.* at 10, ¶ 15. Dr. Katz's analysis specifically refers to set-aside rules, but the same economic principles apply to other types of bidding restrictions.

[82] *See* Comments of Verizon Wireless, WT Dkt. No. 12-269, at 33-34 (filed Nov. 28, 2012).

[83] *See NPRM* ¶ 384.

geographic markets and at different stages throughout the auction, making it potentially impossible for a bidder to coordinate bids across multiple markets while complying with the cap everywhere. For example, if only a small amount of spectrum clears in Market A but a large amount of spectrum clears in Market B, a bidder whose business plan involves obtaining the same quantity of spectrum in both markets may forego bidding for at least some of the spectrum in Market B because of the cap imposed in Market A that restricts the bidder to an extremely small amount of spectrum there. Given the substantial uncertainty already inherent in the forward auction, injecting such an additional complication would distort the bidding process and depress participation and revenues.

Accordingly, to the extent the Commission chooses to modify its existing spectrum screen policy, it should avoid imposing constraints on auction participants' ability to participate fully in this or any other specific auction.[84] Section 6404's express prohibition on preventing any person from participating in the auction underscores that conclusion. Under the statute, any rule could affect, at most, a company's overall spectrum holdings after the auction and not its bidding during the auction. If divestitures are required as a result of spectrum acquired in the auction, the only appropriate mechanism would be for affected companies to bring themselves into compliance with any generally applicable rule on a post-auction basis. Relying on post-auction procedures would comply with Section 6404 and avoid artificially distorting or suppressing participation in the important 600 MHz auction.

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[84] The Commission notes that it has an open rulemaking proceeding on whether it should modify its existing spectrum screen and/or adopt any limits on mobile spectrum holdings. *See NPRM* ¶ 384 (citing *Policies Regarding Mobile Spectrum Holdings,* Notice of Proposed Rulemaking, 27 FCC Rcd 11710 (2012)). That proceeding is the appropriate forum to consider any generally-applicable policies governing spectrum holdings, and/or what might constitute an "excessive concentration of licenses."

B. The Commission Should Adopt an Ascending Clock Format Using Generic 5 MHz Blocks

Verizon supports an ascending clock auction using generic 5 MHz blocks.[85] With generic licenses, wireless providers can bid on licenses at a given price during the appropriate stage of the bidding process, without the need to account for disparities in service area and band placement. As a result, the forward auction – and, thus, the overall incentive auction – can proceed and conclude much more quickly. Given that multiple stages of the forward auction would be necessary as part of a simultaneous forward and reverse auction approach, expediting the incentive auction process in this manner can provide some assurance to reverse and forward auction participants alike that the overall auction process will not drag on interminably. This added certainty can help encourage broadcasters to participate that otherwise may be wary about the impact of reverse auction participation on their business plans.

For a generic bidding approach to succeed, however, the Commission must design the auction and the 600 MHz band plan service rules in a manner that ensures that licenses are sufficiently similar. Uniform block sizes and service areas – Economic Areas ("EAs"), as the Commission has proposed – are particularly important in this regard.[86] Designating various block sizes and service areas for the 600 MHz spectrum, as the Commission has done for broadband PCS, AWS and 700 MHz, would preclude the use of generic blocks in the forward auction – which, in turn, would extend the duration of the auction to the detriment of all participants and make the incentive auction irreparably complicated for bidders and the

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[85] *See NPRM* ¶¶ 57-61.

[86] *See infra* Section IV.C (discussing merits of EAs as the applicable service area for 600 MHz licenses).

Commission alike.[87] In addition, service rules that result in bidder- or license-specific burdens, such as an open access obligation imposed on a particular license or performance requirements that are not imposed on all licenses, would preclude an effective generic bid approach. Auctioning such dissimilar spectrum blocks as "generic" would lead to bidder uncertainty, depressed bid amounts and inefficient allocations. Moreover, the Commission's experience in the 700 MHz auction illustrates that imposing disparate service rules and license conditions would limit the substitutability of the licenses and thus the efficiency of the auction, and also would require participants to develop complicated bidding strategies that result in an inefficient bid prices and assignment of licenses.

C. The License Assignment Stage Should Facilitate Contiguous Spectrum Blocks Within and Across Economic Areas.

An effective final assignment phase, in which specific licenses are assigned to specific winning bidders, also will be important for the auction of generic blocks. Even when licenses are intrinsically similar, auction outcomes across different geographic areas may result in winning bidders having different preferences among potential license assignments. In this regard, contiguous blocks within an EA are essential for winning bidders in the forward auction to ensure that they are able to economically deploy networks and provide a viable broadband service in the 600 MHz band. Secondarily – but still very important – the Commission correctly notes that wireless service providers with spectrum blocks across multiple EAs prefer harmonized blocks that encompass the same frequencies.[88]

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[87] *See NPRM* ¶ 147 (noting that smaller CMA license areas "may raise implementation risks for the auction designs" and "complicate potential bidders' efforts to plan for, and participate in, the auction for such licenses").

[88] *See id.* ¶ 64.

The successful implementation of generic bidding thus will be highly dependent on the effective operation of a final assignment phase that distributes specific blocks within the generic group to the winning bidders.[89] The outcome of this phase must be transparent, predictable, and reflect bidder preferences to the extent possible. While Verizon is not categorically opposed to competitive bidding for this purpose,[90] for generic licenses this assignment phase (at least with respect to contiguous blocks within an EA) should instead be accomplished through rules and policies that enable the Commission to coordinate assignments among the winning bidders in a sensible manner. The Commission should then rely on the secondary market to sort out discrepancies between EAs, rather than on competitive bidding via a Commission auction.

The Commission's auction rules should thus provide that winners of more than one 5 MHz generic block within an EA will always be assigned contiguous spectrum within that EA, and that winners of multiple and "solo" blocks will be assigned to particular portions of the 600 MHz band (e.g. placing winners of contiguous blocks in the lower part of the applicable bands and solo blocks in the higher part, or vice-versa). This approach will help ensure that the value created by contiguous spectrum blocks as reflected in network and handset design efficiencies will be reflected in the bids for the generic licenses in the preceding auction rounds, thus capturing the potential benefits of using competitive bidding in the assignment round.

The licensing of consistent spectrum blocks *across* broad geographic areas also has value for network and handset design purposes. The Commission should address this issue principally through requirements other than the assignment process by designating license service areas no smaller than EAs and permitting package bidding as described below. In the license assignment

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[89] *See id.* ¶ 64.

[90] *See id.* (positing that "[t]here could also be an additional auction phase to assign specific frequencies for generic licenses, which could be based on accepting additional bids.").

process, the Commission nevertheless could, as an administrative matter and to the extent possible, provide winning bidders with the option of consistent frequency assignments across EAs, up to a single REAG. Providing winning bidders with contiguous blocks within an EA would make this task easier for the Commission, as would a policy of presumptively placing winners of multiple versus solo 5 MHz blocks in certain parts of the licensed 600 MHz band.

This process cannot be perfect, however, and beyond an initial "rough cut" the Commission should not seek to resolve inconsistent frequency assignments across EAs through competitive bidding. Wireless service providers have considerable experience in working together to exchange spectrum blocks to optimize their respective spectrum holdings, according to their network configurations and customer needs. Thus, to the extent that individual bidders determine that particular spectrum blocks within the licensed bands are preferable to the blocks the Commission assigned to them, they should have freedom to work with other winning bidders in the secondary market to achieve a mutually beneficial outcome. The Commission should apply flexible assignment application rules and policies to such transactions, including a policy of treating the exchange(s) of 600 MHz blocks among winning bidders within an EA as tantamount to a *pro forma* transaction and presumptively in the public interest.

D. Short Form Applications Will Reveal Where Mutual Exclusivity Could Occur Within EAs.

The Commission "seek[s] comment on how to apply the requirement of mutual exclusivity in the context of the broadcast television spectrum forward auction," particularly in regard to "generic (non-frequency-specific) blocks" and specifically "whether applications to participate in the reverse and forward auctions are 'mutually exclusive applications' for 'initial license[s]' since the reverse and forward auction applicants will submit bids relating to mutually exclusive spectrum usage rights (*i.e.,* the spectrum currently used by broadcast television

licensees)."[91] Section 309(j)'s competitive bidding requirement applies when "mutually exclusive applications are accepted for any initial license."[92] The question of whether applications for licenses are "mutually exclusive" under Section 309 of the Act is generally left to the Commission's service-specific rules, which vary from service to service.[93] The Commission generally has determined whether mutual exclusivity in an auction exists based on the short form application process and can apply that approach here as well.[94]

The Commission's assessment of mutual exclusivity also must account for the unique context of an incentive auction and not undermine Congress's Spectrum Act objectives. Unlike a traditional spectrum auction, the range of specific licenses for which a forward auction participant can submit bids in the incentive auction is unknown at the outset and will change throughout the course of the forward auction up to the assignment round. (This will be the case regardless of whether generic bids are used.) In addition, Congress expressly authorized the Commission to conduct the reverse and forward auctions contemporaneously.[95] Given this statutory context, the Commission could, for example, require that short form applications designate the EA(s) for which the bidder seeks eligibility to participate and find mutual

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[91] *See NPRM* ¶ 292.

[92] 47 U.S.C. § 309(j)(1).

[93] *See, e.g.*, 47 C.F.R. § 22.131 (defining mutual exclusivity in general for Public Mobile Services); *id.* §§ 22.949(a)(2) and (b)(2) (for cellular applications); *id.* § 24.431(a) (for narrowband PCS); and *id.* § 24.831 (for broadband PCS licenses).

[94] *See Implementation of Sections 309(j) and 337 of the Communications Act of 1934 as Amended; Promotion of Spectrum Efficient Technologies on Certain Part 90 Frequencies; Establishment of Public Service Radio Pool in the Private Mobile Frequencies Below 800 MHz*, Notice of Proposed Rulemaking, 14 FCC Rcd. 5206, 5243, ¶ 73 (1999) ("The Commission has found the short-form application process used in conjunction with our auctions to be the most efficient means of determining if mutual exclusivity exists.").

[95] *See* Spectrum Act § 6403(f)(1).

exclusivity if there is more than one short form applicant for a service area containing generic blocks.

E. The Forward Auction Should Permit Limited Package Bidding for Generic 600 MHz Licenses.

In addition to creating a band plan that includes generic 5 MHz paired or unpaired spectrum licenses, the Commission should allow a limited form of package bidding in the forward auction. For example, the Commission could allow bidders to submit package bids for a generic 600 MHz license (specified as a bid on either all paired or all unpaired frequencies if both are available) across each EA within a single REAG. In the assignment stage, such a winning package bid would be assigned a 600 MHz license on the same frequency band in each EA in the REAG. The Commission could also make available a nationwide package bid for a generic license (again, either paired or unpaired, as available) in each of the 176 EAs. Again, in the assignment round, the winning bidder would be assigned the same frequency band license in each EA on a nationwide basis.

Providers may offer mobile broadband services on a nationwide or regional basis. Accordingly, some operators will participate in the 600 MHz forward auction either to complement or expand existing spectrum holdings, or to develop new mobile broadband services that will compete with existing regional or nationwide services. A risk of failing to acquire all licenses in a business plan (the "exposure problem") may inhibit participation in the auction because, for some bidders, the potential for acquisition of all desired licenses is needed to support the amount of a bid for multiple licenses.[96]

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[96] *700 MHz Service Rules Order*, 22 FCC Rcd at 15395-96, ¶ 287.

Allowing forward auction participants the opportunity more readily to acquire regional or nationwide spectrum licenses will benefit their broadband deployment plans. And by allowing the winning bidders to take advantage of the economies of scale in larger licensed areas, package bidding will facilitate more rapid build-out of licensed 600 MHz services, which in turn will benefit consumers. The Commission recognized these public interest benefits for package bidding in Auction 73:

> Minimizing the exposure problem with package bidding should facilitate the entry of applicants whose business plans require the economies of scale that only can be obtained with nationwide operation. We anticipate that package bidding can be implemented so as to shield such bidders from a potential significant exposure problem. Importantly, we also anticipate that it can be implemented without imposing disadvantages on parties that wish to bid on individual licenses comprising the nationwide footprint.[97]

Package bidding also offers an opportunity to increase participation in the forward auction such that the incentive auction would more efficiently meet the closing conditions and other Spectrum Act objectives. Package bidding allows auction participants to bid not just on the value of the individual EA licenses, but also on the value of obtaining all EAs in a REAG over a consistent set of frequencies.[98] Thus, forward auction participants can commit more of their resources toward acquiring licenses in the auction, rather than trying to meet their goals in the subsequent secondary market. If the Commission does not allow package bidding, then at minimum it should accept bids on every license in the auction until bidding has stopped on all

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[97] *Id.* at 15397, ¶ 290.

[98] In past auctions, winning bids on larger licenses have raised more per MHz/POP than have bids on smaller licenses. In Auction 66 for AWS spectrum licenses, the REAG licenses sold for an average of $0.705 per MHz/POP, while CMA licenses sold for $0.417 per MHz/POP. The EA licenses for Block B sold at $0.451 and for Block C at $0.548. Jeremy Bulow, et al., "Winning Play in Spectrum Auctions," NBER Working Paper Series, No. 14765 at 25 (Mar. 2009).

licenses. The Commission has previously noted that "[t]his approach . . . allows bidders to take advantage of synergies that exist among licenses and is administratively efficient."[99]

F. The Commission Should Narrow the Scope of the Anti-Collusion Rule.

The goals the Commission identified when it adopted the auction anti-collusion rule in 1994 remain sound today – to prevent parties from "agreeing in advance to bidding strategies that divide the market according to their strategic interests and disadvantage other bidders," to "strengthen confidence" in the bidding process, and to "help ensure that the government receives a fair market price for the use of the spectrum."[100] But since then, the Commission has extended its restrictions to routine business discussions,[101] causing uncertainty as to whether discussions not related to bids or bidding strategies or post-auction market structure could violate the rule. The Commission has acknowledged that this approach goes well beyond the nation's antitrust laws, but there is no evidence that it enhances "the competitiveness of the auction process and of the post-auction market structure."[102] Companies are now forced to weigh the significant costs of putting unrelated, conventional business negotiations on hold for months at a time against the potential advantages of auction participation. Some firms have likely foregone participation in

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[99] *Auction of Advanced Wireless Service Licenses Scheduled for June 29, 2006*, Public Notice, 21 FCC Rcd 4562, ¶ 138 (2006) ("*AWS Auction Procedures PN*").

[100] *Competitive Bidding Second R&O*, 9 FCC Rcd at 2386 ¶ 221.

[101] *Wireless Telecommunications Bureau Provides Guidance on the Anti-Collusion Rule for D, E, and F Block Bidders*, Public Notice, DA 96-1460, 11 FCC Rcd. 10134 at 10135 (WTB 1996) (instructing potential auction participants that the anti-collusion rule "may affect the way in which they conduct their routine business during the auction" and that "management, resale, roaming, interconnection, partitioning and disaggregation agreement negotiations may all raise impermissible subject matter for discussion by applicants").

[102] *Competitive Bidding Second R&O*, 9 FCC Rcd at 2387, ¶ 225 (1994). *See also* Public Notice, *Auction of 700 MHz Band Licenses Scheduled for January 24, 2008; Notice and Filing Requirements, Minimum Opening Bids, Reserve Prices, Upfront Payments, and Other Procedures for Auctions 73 and 76*, DA 07-4171, 22 FCC Rcd 18141, 18153 (Auctions Div., 2007) ("*700 MHz Auction Procedures PN*").

auctions because the substantial burdens on routine business outweigh the potential benefits of auction participation. These uncertainties place undue limits on routine business discussions, impose significant costs, and the Commission should take this opportunity to narrow the scope of the rule to ensure that it does not deter auction participation.

First, the anti-collusion rule should apply only to discussions that directly convey information regarding bids or bidding strategies or directly relate to post-auction market structure, but not to other unrelated routine business discussions – an approach consistent with the Commission's enforcement actions today.[103] Business negotiations that do not directly involve any such communications or agreements do not violate the rule, so the Commission should clarify that business discussions including those regarding management, resale, roaming, interconnection, and partitioning and disaggregation agreements are not prohibited, unless the participants expressly convey information regarding their bids or bidding strategy or post-auction market structure. The Commission should also confirm that discussions regarding generic technical handset and network issues, such as discussions in industry standards-setting bodies and discussions with manufacturers regarding specifications for network equipment or handsets, are not prohibited. At a minimum, the Commission should allow applicants to segregate their representatives negotiating such arrangements from those company employees involved in, and knowledgeable about, the company's auction and bidding strategy. To the extent that such

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[103] *See, e.g., Northeast Communications of Wisconsin, Inc*., Forfeiture Order, 19 FCC Rcd 18635 (EB 2004); *Star Wireless, LLC*, Forfeiture Order, 19 FCC Rcd 18626 (EB 2004); *Star Wireless, LLC and Northeast Communications of Wisconsin, Inc*., Order on Review, 22 FCC Rcd 8943 (2007), *rev. denied*, *Star Wireless, LLC v. FCC*, 522 F.3d 469 (D. C. Cir. 2008)); Mercury PCS II, LLC, *Notice of Apparent Liability for Forfeiture*, 12 FCC Rcd 17970 (1997), *aff'd Memorandum Opinion and Order*, 13 FCC Rcd 23755 (1998), *aff'd High Plains Wireless, L.P. v. FCC*, 276 F.3d 599 (D.C. Cir. 2002)); *Cascade Access, L.L.C*., Notice of Apparent Liability for Forfeiture, 24 FCC Rcd 1350 (EB 2009), *aff'd* Forfeiture Order, DA 13-32 (EB rel. Jan. 11, 2013).

separation is established and there is no prohibited communication to or from individuals outside of the applicants' auction teams, there is no risk of harm to the auction. Second, the Commission should narrow the definition of "applicants" for purposes of the rule to include the filing entity and its controlling equity interest holders, but otherwise exclude persons/entities holding a ten percent or greater interest in the filing entity.[104] A commercial agreement between a holder of a non-controlling interest in a filer and another auction applicant does not bind the filer or otherwise influence its behavior in the auction in a way that would disadvantage other bidders. Further, a minority non-controlling interest holder is highly unlikely to have knowledge regarding the filer's bids or bidding strategy at auction. Yet application of the rule in this instance could bar non-controlling entities from a variety of commercial transactions that otherwise would advance the economy and benefit consumers. In any event, the Commission's policies barring prohibited communications via a third party conduit would apply to non-applicants.[105]

Third, the Commission should shorten the period during which the rule is in effect to the period between the short-form application deadline prior to the auction and when the bidding closes, rather than extend it to the date when long-form applications are due, as in the past. (For example, in Auction 73 the anti-collusion rule was in effect for four months, from December 3, 2007 to April 3, 2008.) Once the bidding closes, communications between auction applications

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[104] *See* 47 C.F.R. § 1.2105(c)(7)(i).

[105] *See Amendment of Part 1 of the Commission's Rules – Competitive Bidding Procedures*, Seventh Report and Order, 16 FCC Rcd 17546, 17550 (2001) (cautioning applicants "against indirectly communicating their bids or bidding strategies to each other through third-party discussions or disclosures to other auction applicants"); *AWS Auction Procedures PN,* 21 FCC Rcd, ¶ 17 (cautioning against "dealings with other parties, such as members of the press, financial analysts, or others who might become a conduit for the communication of prohibited bidding information.").

cannot, by definition, affect participants' bids or bidding strategies, and cannot disadvantage other bidders. To the extent such communications could result in winning bidders defaulting on their final payments, the Commission can assess an appropriate default penalty.[106] Given the complexities of the incentive auction, moreover, extending the period during which the rule is in effect until the long-form application deadline could result in an extensive, unnecessarily long period under the anti-collusion rule.

Finally, the Commission should not prohibit or restrict communications between reverse auction applicants and forward auction applicants. There is no basis in the *NPRM* or otherwise to conclude that such communications or agreements could disadvantage other bidders in either the reverse or forward auction.[107] In the reverse auction, broadcasters will engage directly with the Commission as to bidding options and bid amounts, and will not entertain offers from individual applicants in the forward auction. There is thus no reason why discussions between reverse and forward auction applicants could make either auction less competitive – particularly as forward auction applicants will likely bid on generic blocks of spectrum rather than broadcasters' current licensed frequencies.

In no event should the Commission prohibit business discussions between broadcaster and mobile broadband providers unrelated to an auction applicant's bids or bidding strategies, or the post-auction market structure. The *NPRM* recognizes that discussions between a broadcast affiliate and a network programming supplier "on issues unrelated to the reverse auction" would not fall within the rule's communications prohibition,[108] and this type of guidance should

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[106] *See* 47 C.F.R. § 1.2104(g)(1); *700 MHz Auction Procedures PN*, 22 FCC Rcd at 18211 ¶¶ 267-68.

[107] *See NPRM* ¶ 269.

[108] *See id.* ¶ 264 n.405.

similarly apply to discussions between a broadcast licensee and a wireless provider regarding content deals and other types of arrangements "unrelated to the reverse auction" such as distribution of the broadcaster's programming over the carrier's network, or discussions of broadcaster/wireless collocation at tower sites, or wireless service resale arrangements.

G. The Commission Should Not Impose Closing Conditions Beyond What the Spectrum Act Requires.

The Commission seeks comment on how best to implement the three statutory "closing conditions" (payment of reverse auction winning bids, the Commission's administrative costs, and repacking reimbursements)[109] and "whether there are additional statutory, policy or other considerations that should be addressed in establishing the closing conditions."[110] The Commission can most effectively achieve Congress's multiple Spectrum Act objectives – freeing up substantial amounts of new spectrum for mobile broadband services while providing additional revenues for other programs, such as the nationwide public safety broadband network – through a well-designed incentive auction that does not restrict bidder participation and a band plan and service rules with wide appeal to mobile service providers. Such measures will help ensure that spectrum is licensed to those entities that value it most and, thus, will incidentally result in substantial revenue to the Treasury.

Importantly, such an approach is most consistent with Section 309(j) of the Communications Act and the Spectrum Act itself, which prohibit the Commission from adopting a competitive bidding methodology based "solely or predominantly on the expectation of Federal revenues" and do *not* require incentive closing conditions other than those enumerated at Section

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[109] *See* Spectrum Act § 6403(c)(2).

[110] *NPRM* ¶ 69.

6403(c)(2).[111] Congress could have modified Section 309(j)(7) and made revenues for the nationwide public safety broadband network and other programs a condition of closing, but it chose not to do so. Finally, should the forward auction fail to meet any additional conditions, the Commission risks a *complete* failure of the incentive auction – which would be a far worse outcome for the nationwide public safety broadband network than an auction that raises some but not all the $7 billion statutory maximum. For these reasons as well, he Commission should not impose additional closing conditions beyond those the Spectrum Act requires.

IV. THE RULES FOR 600 MHZ WIRELESS OPERATIONS SHOULD PROMOTE RAPID USE OF THE SPECTRUM TO SERVE CUSTOMERS.

A. The 700 MHz Band Technical Rules Mostly Provide the Right Model for 600 MHz Licensees.

Verizon supports the Commission's proposals to apply the 700 MHz out-of-band emissions limits, power limits, and antenna height restrictions at Part 27 to 600 MHz band licenses, but recommends a modified field strength limit. Verizon thus generally agrees with the Commission's assessment that the similarity between the 700 MHz and 600 MHz bands supports adoption of the same or similar rules, with one notable exception.

Out-of-Band Emissions. The out-of-band emissions limit and the measurement procedure set forth in Section 27.53(g) of the Commission's Rules will provide adequate protection from harmful interference within the 600 MHz band.[112] Applying this rule also will ensure adequate protection for 700 MHz uplinks at the boundary between the proposed 600 MHz uplink and

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[111] *See* 47 U.S.C. § 309(j)(7)(B); Spectrum Act § 6403(c)(2).

[112] *NPRM* ¶ 188. 47 C.F.R. § 27.53(g) provides in principal part: "[T]he power of any emission outside a licensee's frequency band(s) of operation shall be attenuated below the transmitter power (P) within the licensed band(s) of operation, measured in watts, by at least 43 + 10 log (P) dB. Compliance with this provision is based on the use of measurement instrumentation employing a resolution bandwidth of 100 kilohertz or greater."

Lower 700 MHz uplink bands.[113] Verizon agrees that the proposed out-of-band emissions limit for 600 MHz will protect any Channel 37 services that require protection from flexible use operations.[114] As was discussed above regarding the band plan, any remaining DTV channels should be separated by at least 10 MHz from mobile services, and thus no additional protection to or from adjacent DTV channels is needed for 600 MHz flexible use licenses.

Power Limits. The Commission's power limit proposals in the *NPRM* are appropriate for 600 MHz licenses. For downlink operations, fixed and base station power limits in non-rural areas would be 1000 watts per MHz ERP for emission bandwidths greater than 1 MHz and 2000 watts ERP in rural areas.[115] While the 700 MHz power limits generally make sense in this context, Verizon agrees that the Commission should not apply here the power flux density requirements adopted for 700 MHz because those requirements protect base station receivers from other high powered base stations, a consideration not presented here because high powered base stations are not allowed in the 600 MHz band.[116] For uplink operations, the Commission should adopt a power limit of 3 watts ERP for both portables and mobiles,[117] and apply the same prohibition on fixed and base station operations in the uplink bands that applies to the 700 MHz band. There should be no provision for high power control stations for public safety operations in the 600 MHz uplink band.

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[113] *NPRM* ¶ 189.

[114] *Id.* ¶ 191.

[115] *Id.* ¶ 193; *see* 47 C.F.R. §§ 27.50(c)(3), (4).

[116] *Id.* ¶ 193.

[117] *See* 47 C.F.R. § 27.50(c)(10).

Antenna Height Restrictions. Verizon supports application of the 700 MHz band flexible antenna height rules to the 600 MHz band.[118]

Co-Channel Interference Among 600 MHz Systems. Unlike the field strength limit of 40 dBμV/m that the Commission adopted for 700 MHz licensees, the Commission should adopt a 50 dBμV/m per MHz field strength limit for 600 MHz licensees. This limit is more appropriate for broadband LTE technologies and will better ensure that 600 MHz licensees do not cause interference to co-channel systems operating in adjacent geographic areas.[119] Accordingly, the Commission should apply a different limit to 600 MHz licenses.

B. Flexible Use Is the Best Model for 600 MHz Broadband Licenses.

Verizon supports the Commission's proposal "to provide 600 MHz licensees with the flexibility to provide any service that is consistent with the allocations that are adopted for this spectrum."[120] To fully implement this policy and to lay the groundwork for longer-term flexible use of this spectrum, the Commission also should add a fixed and mobile designation to the UHF and VHF bands in the Part 2 Table of Allocations, as proposed in the *NPRM*.[121] The Commission's flexible use policy, as adopted also for 700 MHz,[122] benefits the public interest: "As a matter of practice, licensees continually devise and update the types of advanced devices they deploy, and improve the management of the dynamic spectrum use between and among

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[118] *NPRM* ¶ 195; *see* 47 C.F.R. § 27.50(c) (Tables 1-4).

[119] *See* 47 C.F.R. § 27.55(a)(2).

[120] *NPRM* ¶ 374.

[121] *See id.* ¶ 121.

[122] *700 MHz Service Rules Order,* 22 FCC Rcd at 15378-79 ¶ 242 (goal of adopting flexible use policy for 700 MHz spectrum is "to remove regulatory impediments in order to enable more efficient use of licensed spectrum"); *see Reallocation and Service Rules for the 698-746 MHz Spectrum Band (Television Channels 52-59),* 17 FCC Rcd 1022, 1023 ¶ 1, 1051-52 ¶¶ 70-71 (2002) (adopting flexible use policy for 700 MHz spectrum).

their subscribers, consistent with the applicable service rules and their respective business models."[123] Allowing licensees to decide how best to meet consumer demand by offering one or more different services is one of the bedrock principles that has fostered a competitive, innovative wireless industry.[124] The Commission's flexible use policy has allowed the wireless industry to flourish and respond in a variety of ways to consumer demand, and should apply to 600 MHz licensees as well.

In this regard, the Commission should not interfere with licensees' ability to choose which bands to include in wireless devices. As discussed above, if a significant amount of spectrum clears, the auction may result in assignment to wireless licensees of more spectrum than one mobile device or base station duplexer can cover.[125] It is possible to build a device that supports multiple filters or duplexers, but each additional duplexer imposes additional cost and complexity that must be weighed against other factors, such as the bands that must be included in the device to operate on the provider's existing networks.[126] In making decisions on wireless device design, wireless providers and vendors must take into account a number of considerations because of current limitations on how many and what type of duplexers can be included in the same device, as well as the need for commercially-desirable device form factors. The spectrum assigned to each 600 MHz filter would count as a separate "band" for this purpose. Given these technical and cost considerations for mobile providers and ultimately consumers, 600 MHz

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[123] *700 MHz Service Rules Order*, 22 FCC Rcd at 15378-79 ¶ 242.

[124] *See Fifteenth CMRS Report*, 26 FCC Rcd at 9826, ¶ 279.

[125] *NPRM* ¶¶ 160-164.

[126] *See* Comments of Verizon Wireless, WT Dkt. No. 12-69 (filed June 1, 2012); Reply Comments of Verizon Wireless, WT Dkt. No. 12-69 (filed July 16, 2012); Comments of Verizon Wireless, RM-11592 (filed Mar. 31, 2010); Reply Comments Verizon Wireless, RM-11592 (filed Apr. 30, 2010).

licensees and their vendors should have the flexibility to decide which 600 MHz bands to include in the devices they market.

C. The Commission Should Use Only Economic Areas for 600 MHz Licenses.

As noted above, to facilitate rapid deployment of mobile broadband services at 600 MHz and to ensure an efficient forward auction of generic spectrum blocks, Verizon supports the Commission's proposal to license all reclaimed 600 MHz broadcast spectrum in Economic Areas (EAs). Verizon agrees that "EA licensing strikes an appropriate balance between geographic granularity from a spectrum reclamation standpoint and having a manageable number of licenses from an auction design standpoint."[127] The Commission's proposal is also consistent with its obligations under Section 309(j)(4) of the Communications Act to allocate spectrum in a manner that will promote investment in, and rapid deployment of, new technologies and services.[128]

While larger areas such as EAGs and REAGs ordinarily would be preferable from a facilities deployment and auction design perspective, EAs draw an appropriate balance between enabling the efficient deployment of nationwide and regional services, and the policy objectives set forth in Section 309(j) and the Spectrum Act.[129] The Commission should not adopt service areas smaller than EAs, such as CMAs. Larger geographic licenses offer mobile providers

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[127] *NPRM* ¶ 148.

[128] *See* 47 U.S.C. § 309(j)(4) ("In prescribing regulations pursuant to paragraph (3), the Commission shall—…(C) consistent with the public interest, convenience, and necessity, the purposes of this chapter, and the characteristics of the proposed service, prescribe area designations and bandwidth assignments that promote…investment in and rapid deployment of new technologies and services").

[129] *See* 47 U.S.C. § 309(j)(4)(C); Spectrum Act § 6403(c)(3); Comments of Verizon Wireless, WT Dkt. No. 06-150, at 9-15 (filed May 23, 2007).

flexibility in deployment and the ability to take advantage of economies of scale.[130] For example, in selecting license areas for the Upper 700 MHz band plan, the Commission noted that "large geographic areas would readily allow aggregation into a nationwide service area and would enable multiple parties to bid on this spectrum for the provision of high-speed wireless data services."[131]

License areas of EAs also facilitate a more efficient auction. When attempting to build a national or regional footprint, in the auction or on the secondary market, licenses larger than a CMA will require fewer transactions and make it less likely that an operator would come out of an auction with "holes" in its footprint. And uniform service areas also are necessary for the Commission's proposal to conduct forward auction bidding on generic spectrum blocks.

While Verizon ordinarily would prefer a larger area such as an EAG or REAG, as the Commission notes, there is a countervailing issue in the upcoming incentive auction that has not previously been present: the Commission does not know ahead of the auction how much broadcast spectrum will be reclaimed or whether the same amount of spectrum will be available in every geographic area. Using REAGs, the largest geographic sized licenses, could limit the Commission's flexibility to provide the most amount of spectrum in as many geographic areas as the repacking methodology will allow. That uncertainty militates in favor of smaller EAs, which strike an "appropriate balance."[132] EAs facilitate aggregating spectrum in regions or nationwide, either during the auction or on the secondary market, which will be useful for services that

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[130] *See Upper 700 MHz Service Rules Order*, 15 FCC Rcd at 501 n. 145 ("These [larger] geographic areas should permit industry to internalize the costs of developing its own standards.").

[131] *Id.* at 501 ¶ 60.

[132] *NPRM* ¶ 148.

require nationwide footprints. EAs are large enough to allow winning licensees to deploy regional services, but small enough to allow bidders to acquire a very limited amount of area – often only a few counties. And uniform use of EAs for all spectrum blocks will facilitate an efficient incentive auction and more clearing of broadcast spectrum for mobile broadband. And as discussed above, package bidding could also enable bidders interested in acquiring broader coverage to achieve that goal while still maintaining the flexibility offered by EA licenses.

Section 6403(c)(3) of the Spectrum Act obligates the Commission to "consider assigning licenses that cover geographic areas of a variety of different sizes."[133] That provision, however, does not obligate the Commission to offer different-sized licenses in the forward auction. The Commission's explicit statutory obligations in selecting a license size are to promote rapid deployment of advanced wireless broadband services and to ensure an efficient incentive auction. EAs most effectively fulfill those goals. The Commission has already recognized that auctioning licenses that are too small will undermine these goals, noting that "[w]hen [license] areas are inefficiently small, the costs of aggregation during or after the auction in terms of delay and transaction costs may harm both service providers and customers alike."[134]

Finally, the administrative challenges associated with managing a forward auction and subsequent assignment process for 734 individual CMA-based generic licenses, and interjecting even more geographical complexity into the repacking formula, would be very high and could extend the duration and complexity of the auction – contrary to the interests of reverse auction bidders as well. Where market forces create economic incentives to deploy service in smaller

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[133] Spectrum Act § 6403(c)(3).

[134] *Upper 700 MHz Service Rules Order*, 15 FCC Rcd at 501.

geographic areas, existing providers and new entrants can employ the Commission's partitioning rules to accommodate those incentives.

D. The Commission Should Provide Clear Pre-Auction Guidance on Coordinating with 600 MHz Operations in Canada and Mexico

The Commission correctly notes that it may be necessary to modify existing 700 MHz band international arrangements or create new international arrangements for the 600 MHz band licensees to implement 600 MHz mobile operations in areas along the U.S. borders with Canada and Mexico.[135] Verizon has had substantial experience coordinating its Upper 700 MHz C Block license in border areas. Those arrangements for 700 MHz were difficult in part because there were no clear rules or guidance to govern disputes that arose in the coordination process. For this reason, it is very important for the Commission to begin discussions with Canada and Mexico now.

Clear guidance on coordinating with 600 MHz operations in Canada and Mexico is important not just to ensure successful deployment of 600 MHz broadband services in border areas but also to facilitate an efficient forward auction. The forward auction will be more efficient if bidders know beforehand whether licensed facilities in border areas will generally be free from harmful cross-border interference through coordination agreements with Canada and Mexico, and/or if they would need to configure their facilities to protect foreign operations. If post-auction coordination arrangements are needed for operations along the Canadian and Mexican borders, the Commission should publish such information well before the auction, even if the precise frequencies available in the forward auction are not known. Only through early

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[135] *NPRM* ¶ 197.

guidance on coordinating with 600 MHz operations in Canada and Mexico can bidders in the forward auction assign the appropriate value to licenses in those geographic areas.

E. The Commission Should Apply Partitioning, Disaggregation, and Spectrum Leasing Rules to 600 MHz Licenses.

The Commission should apply its Part 27 geographic partitioning, disaggregation, and spectrum leasing rules to 600 MHz band licenses, as proposed in the *NPRM*.[136] Allowing licensees the ability to partition and/or disaggregate portions of their spectrum holdings, and/or to lease such holdings, promotes a robust secondary market in spectrum. And it particularly facilitates acquisition of spectrum rights by smaller carriers, who may serve small, targeted markets.[137] These rules have been effective and should be applied to the 600 MHz band.

For example, Verizon has successfully used partitioning to lease its Upper 700 MHz C Block spectrum to nearly two dozen participants in its "LTE in Rural America" (LRA) program. Through this program, rural wireless carriers provide 4G LTE services within their coverage area on the C Block spectrum, bringing advanced mobile broadband services to rural communities.[138] The Commission should ensure such beneficial secondary market activity can continue in the 600 MHz band by applying its partitioning, disaggregation and leasing rules to that band.

F. 600 MHz Licensees Should Have 10-Year License Terms for Unencumbered Spectrum and Be Subject to Population-Based Performance Requirements.

Verizon supports the Commission's proposal to grant licenses for 10-year terms, which is consistent with the terms it has used for 700 MHz and other wireless licenses.[139] Verizon also supports performance requirements on 600 MHz licenses to drive licensees to put the spectrum

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[136] *Id.* ¶¶ 387, 391.

[137] *See Fifteenth CMRS Report*, 26 FCC Rcd at 9828, ¶ 282.

[138] *See* http://news.verizonwireless.com/news/2012/09/4G-LTE-rural-america-conference.html.

[139] *NPRM* ¶ 392.

to use to serve the public.[140] The Commission should adopt population-based performance requirements similar to those the Commission recently ordered for AWS-4 spectrum licensees.[141]

Specifically, the Commission should adopt following build-out requirements:

- *600 MHz Interim Build-out Requirement*. Within four (4) years, a 600 MHz licensee shall provide signal coverage and offer service to at least forty (40) percent of its total 600 MHz population. A licensee's total 600 MHz population shall be calculated by summing the population of all of its license authorizations in the 600 MHz band.
- *600 MHz Final Build-out Requirement*. Within seven (7) years, a 600 MHz licensee shall provide signal coverage and offer service to at least seventy (70) percent of the population in each of its license authorization areas.

These requirements will accomplish the Commission's primary goal for performance requirements: "to foster timely deployment" in the 600 MHz band for the provision of wireless, terrestrial broadband service "and to enable the Commission to take appropriate corrective action should the required deployment fail to occur."[142]

With respect to penalties for failure to meet these requirements, the Commission should adopt the approach used for the WCS REAG and EA licenses:[143]

- In the event a 600 MHz licensee fails to meet the 600 MHz Interim Build-out Requirement, the term of *all* of the licensee's 600 MHz license authorizations shall be reduced by two years.
- In the event a 600 MHz licensee fails to meet the 600 MHz Final Build-out Requirement in any of its license areas, its 600 MHz license for each license authorization area in which it fails to meet the build-out requirement shall terminate automatically without Commission action for those geographic portions of its license where it is not providing service, and such licensee may be subject to an appropriate enforcement action, including forfeitures. The Commission would then re-auction the unserved area as a new license.

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[140] *NPRM* ¶¶ 392, 394.

[141] *See Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands*, Report and Order and Order of Proposed Modification, FCC 12-151 (rel. Dec. 11, 2012) ("*AWS-4 Service Rules Order*"), ¶¶ 187-88.

[142] *AWS-4 Service Rules Order*, ¶ 193.

[143] *See* 47 C.F.R. § 27.13(*h*)-(*i*).

These penalties meet the Commission's goal of imposing "meaningful and enforceable consequences" for failure to meet the 600 MHz build-out requirements, without discouraging investment by denying the licensee the benefits of the build-out accomplished during the initial license term.[144]

These population-based, "keep-what-you use" performance requirements will ensure 600 MHz licensees deploy wireless broadband services effectively and efficiently throughout the nation. This approach accords with the Commission's long-standing policy of utilizing population-based construction benchmarks. Wireless providers offer services for the benefit of consumers, making alternative build-out requirements, such as coverage of land mass, a poor measure of the public benefit. A population-based build-out requirement will ensure that licensees provide wireless broadband services where consumers actually will use them and need them.

This proposal also promotes rapid deployment and service to the public. Licensees who fail to meet the interim four-year build-out requirement face sanctions shortening their licenses. In addition, licensees who fail to meet the seven-year coverage requirement risk losing unused spectrum. The "new applicant" process provides an opportunity for third parties to bid for the unserved area, but it does not foreclose service by the licensee if no competing bidder materializes. In that case, the incumbent licensee should be allowed to reclaim the unserved area.

Verizon does not support "use-it-or-lease-it" or "use-it-or-share-it" requirements.[145] First, such obligations do not carry the same incentive as "use-it-or-lose-it." Second, they are

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[144] *NPRM* ¶ 398.

[145] *Id.* ¶¶ 404-405.

difficult to administer. The Commission has substantial experience with reclaiming unused spectrum for re-auction, but little experience judging whether a licensee has entered into "good faith negotiations with third parties expressing an interest" in either leasing or using unused spectrum. Third, unless "use-it-or-lease-it" and "use-it-or-share-it" rules come with incentive for the lessee or sharer actually to build-out the spectrum, the rules do not address the heart of the problem: the spectrum has not been put to use. In contrast, the Commission is familiar with imposing such requirements on a newly-auctioned license for the unserved area. In addition, it is not at all clear that any party would be interested in such arrangements given the potential for license termination caused by the licensee's failure to meet its performance requirements, which presumably would also terminate any lease or sharing arrangement with the licensee.

The Commission should not experiment with untried performance requirements with this spectrum, the value of which is critical to Congress's statutory scheme for the incentive auction. Rather, it should continue to use established performance-based requirements and penalties such as those proposed above. For similar reasons, the Commission should apply the established substantial service license renewal criteria used for the 700 MHz band, including the provisions for a renewal expectancy and the exclusion of comparative renewal proceedings.[146]

Finally, as a corollary to these performance and renewal requirements, the Commission should afford 600 MHz licensees access to this spectrum as expeditiously as possible after the incentive auction closes and individual licenses are assigned to the winning forward auction bidders. Therefore, it is critical that winning reverse auction bidders and stations that will remain on the air after repacking be subject to a date certain by which they must cease broadcasting in the 600 MHz band. The Commission thus should adopt reasonable deadlines for

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[146] *See id.* ¶ 409 (citing *700 MHz First Report and Order* ¶¶ 75-77).

remaining broadcasters to cease broadcasting in the 600 MHz band and construct new facilities, and for broadcasters with winning exit bids to transition their businesses as appropriate.[147] In no event should this period extend beyond the three-year statutory deadline for reimbursement of relocation costs (which, in any case, applies only to repacked stations),[148] and Verizon expects that the record will support a deadline of substantially shorter duration.[149] For the same reasons, Verizon supports the Commission's proposals "that a winning reverse auction bidder that relinquishes all of its spectrum usage rights with respect to its pre-incentive auction television channel will retain no further rights with regard to that channel" and that all reverse auction bids be deemed "irrevocable, binding offers" that must "be relinquished by a Commission-imposed deadline."[150]

To the extent there are delays in implementing the administrative measures that may be necessary to effect broadcasters' new channel assignments, the Commission should be prepared to toll the performance requirements by a corresponding period. Such assurances will provide mobile broadband providers with added certainty that they will have prompt access to unencumbered frequencies, thereby enhancing the value of the spectrum to forward auction participants.

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[147] *See NPRM* ¶¶ 321-29.

[148] *See* Spectrum Act § 6403(b)(4)(D).

[149] *See NPRM* ¶ 322 (noting that "of the more than 100 licensees whose requests to substitute channels were granted towards the end of the digital transition, most completed construction within 12 months of receiving a construction permit); *id.* ¶ 325 (noting that winning license termination bidders will not need to modify technical facilities).

[150] *See id.* ¶¶ 90, 282.

G. The Commission Should Protect Mobile Licensees from Harmful Interference by Clearing Wireless Microphones and LPAS Devices Well in Advance of the Auction.

The Commission has appropriately recognized that, as with the 700 MHz band, it will be necessary to protect the repurposed 600 MHz spectrum from harmful interference by clearing wireless microphones and Low Power Auxiliary Service (LPAS) devices from the auctioned band.[151] In the 700 MHz band, the Commission concluded that wireless microphones and LPAS devices operated on a co-channel basis could interfere with commercial base stations and mobile receivers even if operated at power levels lower than those authorized by the Commission.[152] The same concerns apply here given the similarities between the 600 MHz and 700 MHz bands. Therefore, to establish the certainty and predictability needed to promote robust participation in the forward auction, the Commission should promptly set in motion a process for clearing such devices from the band, including an immediate prohibition on the manufacture, importation, and

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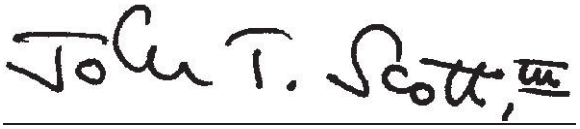
[151] *See id.* ¶¶ 225-26, 238.

[152] *See Revisions to Rules Authorizing the Operation of Low Power Auxiliary Stations in the 698-806 MHz Band; Public Interest Spectrum Coalition, Petition for Rulemaking Regarding Low Power Auxiliary Stations, Including Wireless Microphones, and the Digital Television Transition; Amendment of Parts 15, 74 and 90 of the Commission's Rules Regarding Low Power Auxiliary Stations, Including Wireless Microphones,* Report and Order and Further Notice of Proposed Rulemaking, 25 FCC Rcd 643, 663 ¶ 37 (2010).

marketing of devices capable of operating in the repurposed 600 MHz band, and a reasonable but short transition period for existing users to cease operations in the band.

Respectfully submitted,



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January 25, 2013

ATTACHMENT 7

Reply Comments of Verizon and
Verizon Wireless
March 12, 2013

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions	)	Docket No. 12-268
	)	
	)	

REPLY COMMENTS OF VERIZON AND VERIZON WIRELESS

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March 12, 2013

TABLE OF CONTENTS

I. THERE IS CONSENSUS ON KEY BAND PLAN FEATURES AND PRINCIPLES.....1

A. Agreement Is Emerging Among Operators and Device Manufacturers on the Sizes of the Duplex Gap and Other Guard Bands 2

B. Most Parties Agree that Technical Considerations Preclude TDD Operations in the 600 MHz Band. 5

II. VERIZON SUPPORTS AUTHORIZING UNLICENSED OPERATIONS IN THE GUARD BANDS AND DUPLEX GAP 8

A. Authorizing Low-Powered Unlicensed Operations Will Meet the Statutory Requirement that they Not Cause Interference.....8

B. Authorizing Unlicensed Operations in Guard Bands While Maximizing Licensed Spectrum Would Achieve Congress's Objectives 10

1. The Spectrum Act Mandates that All Auctionable Spectrum Be Repurposed via the Forward Auction 10

2. Proponents of Reducing Licensed Spectrum Fail to Defend the Legality of their Proposals.....12

3. Compromising the Optimal Band Plan Would Jeopardize the Fiscal Targets of the Incentive Auction and Harm Consumers.....14

III. THE COMMISSION SHOULD REJECT CALLS FOR RULES THAT WOULD FAVOR SOME BIDDERS OR SUPPRESS BIDDING. 17

A. The Commission Should Not Imperil the Auction's Success by Imposing Eligibility or Bidding Restrictions.....17

1. This Is the Wrong Proceeding for Addressing Spectrum Holdings Issues.....17

2. All Interested Bidders Have a Statutory Right to Participate Fully.....18

3. No Party Identifies Any Competition Analysis for Which a Bidding Restriction Is an Appropriate Remedy.....20

4. Restrictions Would Artificially Depress Auction Bid Amounts by Protecting Some Bidders Against Competition in the Auction.....23

5. Restrictions Could Cause Auction Failure.....26

B. The Commission Should Reject Requests to Provide Some Large Wireless Operators with Bidding Credits. 27

C. The Commission Should Adjust its Anti-Collusion Rules to Avoid Deterring Auction Participation 28

IV. THE REPACKING METHODOLOGYAND REVERSE AUCTION DESIGN SHOULD MAXIMIZE THE AMOUNT OF REPURPOSED SPECTRUM AND ENCOURAGE BROADCASTER PARTICIPATION. 30

A. The Record Affirms the Potential Benefits of Early Action on Several Key Issues. 30

B. The Spectrum Act Authorizes the Commission to Conduct the International Coordination Process and Implement the Incentive Auction Concurrently. 31

C. A Flexible Repacking Formula Will Best Serve Congress's Spectrum Clearing Objectives. 33

D. Simultaneous Reverse and Forward Auctions Are Preferable to Sequential Auctions. 35

E. Offering Added Bid Options to Broadcasters Has merit. 36

V. THE FORWARD AUCTION AND SERVICE RULES SHOULD BE DESIGNED TO ENSURE MAXIMUM PARTICIPATION. 37

A. Service Providers and Manufacturers Should Retain Flexibility to Design Their Devices. 37

B. The Auction Should Use a Forward Ascending Clock Process, Generic 5 MHz Blocks, and Anonymous Bidding 40

C. Economic Areas Are the Proper License Area for this Auction. 43

D. Package Bidding Will Help Ensure that 600 MHz Licenses Are Assigned to Providers that Value Them Most Highly. 45

E. Population-Based Performance Requirements and Prompt Timetables for Repacked and Exiting Broadcasters to Cease 600 MHz Operations Will Promote Rapid Service Deployment. 46

F. The Commission Should Adopt Verizon's Proposal for an Administrative Rather than Competitive Bidding Assignment Phase. 49

G. The 700 MHz Technical and Service Rules Are Appropriate for the 600 MHz Band. 50

SUMMARY

The incentive auction Congress authorized in the Spectrum Act gives the Commission a critical opportunity to enable substantial additional spectrum to be put to use to meet the rapidly growing needs of the American public for wireless broadband services. Verizon and numerous other parties support many of the Commission's concepts for the auction, and there is agreement on how the Commission should address many of the issues it raised. With the closing of the comment period today, the Commission can begin putting in place some of the building blocks for the 600 MHz band plan, the design of the reverse and forward auction, and the rules to govern new 600 MHz services.

In building the framework for the incentive auction, the Commission should have as its lodestar repurposing the maximum amount of spectrum through a plan that will incent purchase of and investment in that spectrum for new broadband service to the public, while providing the safeguards to broadcast stations that Congress enacted. Taking the actions Verizon and other commenters here recommend will maximize the likelihood of a successful auction for wireless providers and broadcasters alike, which will in turn maximize auction revenues to support the goals Congress envisioned. These actions fit three overall objectives:

1. The 600 MHz band plan and forward auction rules should maximize the amount and attractiveness of the spectrum made available for licensed services, and should avoid restrictions that will impede bidding or delay service to the public. There is substantial support for important aspects of the Commission's proposed band plan, including auctioning 5 MHz blocks of paired spectrum for Frequency Division Duplexing (FDD) use and locating uplink spectrum adjacent to the 700 MHz band. There is also widespread agreement on certain modifications to the plan to better address interference and device issues. Verizon's proposed band plan mitigates interference problems and promotes the development of cost-efficient,

interoperable devices, while maximizing the amount of paired spectrum available to be auctioned.

- ***Guard bands***. Based on Verizon's engineering analysis, a guard band of 10 MHz is technically reasonable to avoid harmful interference between mobile operations and high-powered broadcast operations, and a duplex gap (which is itself a guard band) of 10-11 MHz is reasonable to avoid harmful interference between the uplink and downlink of licensed mobile services.
- ***Unlicensed Operations in Guard Bands.*** Consistent with the balance between licensed and unlicensed services that Congress has struck, Verizon supports authorizing appropriate unlicensed operations in guard bands (including the duplex gap) of the 600 MHz band plan. Verizon's proposed band plan has a uniform duplex gap enabling the development and deployment of unlicensed devices operating on the same frequency anywhere in the country, and additional unlicensed devices can operate in the frequencies dedicated to other guard bands subject to geographic constraints. The Commission should not, however, further increase the size of the duplex gap or other guard bands in order to increase the amount of spectrum available for unlicensed use. The Commission is statutorily required first to establish a band plan with guard bands that maximizes the amount and attractiveness of the spectrum to be auctioned, and then determine what unlicensed uses should be permitted within those guard bands. Increasing unlicensed spectrum by creating a band plan that reduces auctioned spectrum would also jeopardize the Spectrum Act's goals by decreasing the revenue received in the forward auction.
- ***No Bidding or Eligibility Restrictions.*** The Commission should not restrict the ability of forward auction participants to participate in the forward auction, because such

restrictions would violate Section 6404 of the Spectrum Act, distort bidding, reduce auction revenues, and potentially lead to outright auction failure. The spectrum that is licensed in this auction should be included in the spectrum screen already in place, and the Commission should consider requests for modifications to the existing spectrum aggregation policies in the *Spectrum Holdings* rulemaking, not here. Some commenters' proposals for restricting other bidders are not only unlawful but are also transparent efforts to protect themselves from fully competitive bidding. Moreover, no party presents evidence that there is a competitive problem for which a bidding or eligibility restriction might be an appropriate remedy.

- ***Anti-Collusion Rules.*** The record supports Verizon's recommendation that the Commission scale back the scope of its auction anti-collusion rules rather than reflexively apply those rules to this auction. The Commission should also reject proposals to expand the rules to restrict communications among reverse and forward auction participants, and to keep them in force until after licenses are issued to forward auction participants. These proposals could deter participation in the auction and depress bidding.

2. <u>The broadcast station repacking process and reverse auction design should encourage broadcaster participation</u>. Commenters support repacking procedures and reverse auction design rules that encourage wide broadcaster participation. Specifically, commenters broadly agree that the repacking methodology and reverse auction design should maximize the amount of repurposed spectrum and encourage broadcaster participation. Announcing a 120 MHz clearing target, and adopting a repacking methodology, broad confidentiality protections for reverse auction bidders, and incentives for early relocation of Channel 51 broadcast operations, all have wide support and warrant prompt action in order to provide more certainty to

interested parties, which will in turn promote a successful auction. The record also supports Commission action on other issues related to the broadcast spectrum as follows:

- ***International Coordination.*** If the Commission determines that particular international coordination measures could significantly increase the potential amount of available spectrum for mobile broadband service, it should pursue those efforts as a matter of good spectrum planning. The Spectrum Act does not, as some commenters claim, require the Commission to defer repacking, repurposing and incentive auction preparation until coordination is completed. The Commission should nonetheless quickly determine what coordination measures are appropriate for the auction to proceed consistent with Congress's Spectrum Act objectives.
- ***Flexibility to Determine Station Population/Coverage.*** The Spectrum Act grants the Commission flexibility in how it applies its "reasonable efforts" standard for preserving broadcasters' coverage areas and populations served. Arguments that existing population and coverage area must be preserved except in extraordinary circumstances are contrary to the plain meaning of the term "reasonable" and would unnecessarily hamstring the Commission's ability to meet its spectrum repurposing objectives.
- ***Reverse Auction Design.*** If the Commission adopts a descending clock approach, which many commenters support, it should set initial bid amounts at prices that will incent widespread broadcaster participation. Because participation in the reverse auction is voluntary, it is important that the Commission set prices at levels that attract broadcasters in order to maximize the amount of spectrum repurposed for mobile broadband use. Many commenters also recognize the merits of conducting the reverse and forward auctions simultaneously or in multiple stages, rather than sequentially. Many

commenters also share Verizon's position that the Commission should consider additional VHF band bid options and allow stations to accept more interference in order to provide the Commission more flexibility in the repacking process and potentially repurpose more 600 MHz spectrum. A proposal to allow channel sharing bids requiring changes in a station's community of license has merit and should be considered as well.

3. The forward auction design and service rules for the 600 MHz spectrum should promote maximum participation and efficient deployment of new services. Finally, the record provides considerable support for specific actions that will encourage robust bidding for the 600 MHz spectrum. Those actions should include not only auction rules but also rules for the spectrum once it is auctioned that will promote rapid and efficient deployment of service to the public to meet the growing demand for wireless broadband.

- ***No Device Mandate.*** The Commission should continue to afford service providers and manufacturers flexibility to address handset interoperability issues through standards processes, which have yielded rapid development of devices to meet consumers' needs. The issue of Lower 700 MHz device interoperability results from that particular band's uniquely fragmented and impaired nature, so the analogies some parties make to that band are inapposite. Given that interoperability mandates can adversely affect the value of the auctioned spectrum and harm consumers by increasing device costs, the Commission should instead promote interoperability by establishing a sound band plan that avoids the problems of the Lower 700 MHz band.
- ***Forward Auction Methodology***. There is strong support for an ascending clock forward auction methodology. One commenter's proposal for non-generic licenses using different service areas and sequential reverse and forward auctions would result in an

inefficient and complex auction and further complicate the repacking formula. Generic blocks do not have adverse impact on smaller bidders, as an efficient assignment process will ensure that license values are realized in the generic auction bid prices. Verizon supports anonymous bidding because safeguarding the identity of bidders properly ensures that participants' bids are based on license values rather than on other bidders' bidding strategies.

- ***EA Service Areas.*** There is broad support by large and small carriers for licensing the 600 MHz spectrum on an Economic Area (EA) basis. The small Cellular Market Areas (CMAs) are not necessary to encourage buildout to rural areas, as evidenced by Verizon's own 700 MHz deployment. Nor is it apparent how the use of CMAs will help clear more spectrum through repacking; CMAs would make the forward auction and repacking more complex and undermine participation in the reverse and forward auctions.
- ***Package Bidding.*** Several commenters agree with Verizon that accommodating package bidding will serve Congress's Spectrum Act objectives. Package bidding can also help mitigate the complexities of the assignment phase of the forward auction, promote efficient network buildout and device development, and ensure that bidding reflects the value that results from bidders' ability to aggregate different licenses to meet their business objectives.
- ***Prompt Issuance of Licenses.*** Delay in the issuance of 600 MHz licenses to winning forward auction bidders would not only risk suppressing the value of forward auction bids but would also delay deployment of new wireless services to the public. The Commission should thus reject one commenter's assertion that the agency should not issue 600 MHz licenses to forward auction winners until new broadcast allotments are

assigned. Requiring winning bidders to pay billions of dollars, while also holding their license grants or prohibiting them from deploying service for potentially years afterward, would suppress forward auction bids and could cause the auction to fail.

- ***Contiguous License Assignment.*** No commenters took issue with the merits of assigning to winning bidders contiguous and consistent blocks across EAs. The Commission should adopt Verizon's proposed administrative process utilizing default assignment rules can meet that objective while ensuring that licenses are assigned expeditiously.
- ***Technical Rules.*** Commenters overwhelmingly support use of the 700 MHz technical, service and flexible use rules as a model for 600 MHz facilities and services. There is also broad agreement on the benefits of population-based buildout requirements, which Verizon supports. While a few parties propose a handful of different technical rules, they do not supply a valid basis for the Commission to depart from the 700 MHz rules, which promoted the rapid and nationwide deployment of that spectrum to meet consumers' growing wireless broadband needs.

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions	)))	Docket No. 12-268

REPLY COMMENTS OF VERIZON AND VERIZON WIRELESS

I. THERE IS CONSENSUS ON KEY BAND PLAN FEATURES AND PRINCIPLES.

There is widespread support for the Commission's proposal to develop a 600 MHz band plan that makes paired spectrum available in the forward auction, creates 5 MHz blocks, locates uplink spectrum adjacent to the 700 MHz band, licenses spectrum on an Economic Area (EA) basis, and leaves in place existing operations in Channel 37.[1] There is also broad agreement that modifications to the proposed plan would better protect 600 MHz mobile service providers from interference from the remaining broadcast television operations, and also ensure that service providers and their vendors can efficiently incorporate the 600 MHz into wireless devices and networks. Specifically, numerous wireless operators and device manufacturers are concerned about the Commission's proposal to create a large duplex gap[2] containing broadcast operations.[3]

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[1] *See Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions,* Notice of Proposed Rulemaking, Docket No. 12-268, 27 FCC Rcd 12357, ¶¶ 126, 128, 132-33 (2012) ("*NPRM*"); *see also*, *e.g.*, Joint Letter of AT&T, Inc., Intel Corp., Nat'l. Ass'n of Broadcasters, Qualcomm, T-Mobile, & Verizon Wireless, GN Docket No. 12-268 (filed Jan. 24, 2013) (Joint January 24 Letter); CTIA Comments at 18-22.

[2] As discussed in Section II.B.2, a "duplex gap" is a guard band that prevents harmful interference between licensed paired uplink spectrum and licensed paired downlink spectrum. Another type of guard band is one that prevents interference between two distinct types of technologies (such as broadcast

In addition to concerns about harmful interference from broadcasters in the duplex gap,[4] locating paired downlink spectrum below Channel 37 would increase device costs and sizes, thereby reducing the attractiveness of the auctioned spectrum and increasing the challenges of developing interoperable devices.[5] As Qualcomm explained, the Commission's approach would create "extremely wide operating bandwidth that cannot possibly be supported via a single antenna in a smartphone form factor."[6]

Verizon's approach to the band plan builds on the benefits of the Commission's proposal, including the flexibility to address different clearing scenarios in different markets, while also addressing the interference and device issues discussed above. Both Verizon band plan configurations (the high-clearing scenario plan and the one for the lower-clearing scenario) avoid impairment of licensed spectrum by broadcast stations by removing them from the duplex gap. They also enable the development of devices with a single antenna – and, in the context of a lower-clearing scenario, a single duplexer.[7] Verizon's band plan therefore promotes the development of cost-effective, interoperable devices that consumers demand while maximizing the amount of paired generic spectrum available for the auction on a nationwide basis.

A. Agreement Is Emerging Among Operators and Device Manufacturers on the Sizes of the Duplex Gap and Other Guard Bands.

There is a consensus among many wireless operators and device manufacturers that the 6 MHz guard bands proposed in the *NPRM* provide inadequate separation between high-power

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operations and mobile operations). For ease of reference, throughout this reply the term "duplex gap" (rather than the term "guard band") is used to describe guard bands between licensed paired uplink spectrum and licensed paired downlink spectrum.

[3] *See, e.g.*, Joint January 24 Letter; Motorola Mobility Comments at 9-12; CTIA Comments at 25.

[4] Verizon Comments at 18-19.

[5] Verizon Comments at 14.

[6] Qualcomm Comments at iv; *see also id.* at 13-15.

[7] *See* Verizon Comments at 8-9.

broadcast operations and mobile operations to avoid harmful interference.[8] Verizon's engineers have done additional analysis and have worked with other companies to develop further the details of the optimal band plan. A guard band of 10 MHz is reasonable to avoid harmful interference between licensed wireless and licensed broadcast operations. If the guard bands between mobile and broadcast spectrum are too small, they would inadequately protect against interference and would compromise the generic nature (and the value) of the adjacent block of mobile spectrum. The result would be similar to what happened in the Lower 700 MHz band, where harmful interference to and from broadcast operations impaired adjacent licensed mobile blocks and led the development of a band class that did not include the Lower 700 MHz A block.

Verizon has also undertaken additional duplex gap analysis. Verizon's initial comments presented two band plan configurations – one optimal for a high-clearing scenario and another optimal for a lower-clearing scenario.[9] Both plans, like the Commission's proposal, seek to maximize the total amount of cleared spectrum by "flexing" to address different clearing scenarios in different markets, and both have duplex gaps of 10 MHz to protect against interference between licensed mobile uplink and downlink operations.[10] Based on additional analysis, Verizon has determined that in some contexts, increasing the duplex gap to 11 MHz would be reasonable because it would reduce self-interference (desense) within devices (from the transmitter to its receiver). It would also improve insertion loss. For example, the lower clearing scenario band plan (Section I.B.2 of Verizon's initial comments) can be improved by increasing the duplex gap from 10 MHz to 11 MHz and by aligning that duplex gap across all markets so that there is a uniform 11 MHz duplex gap.

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[8] *See, e.g.*, Joint January 24 Letter; Alcatel-Lucent Comments at 22-23; Sony Comments at 2-4; *cf.* Motorola Mobility Comments at 12-13.

[9] *See* Verizon Comments at 7-14.

[10] *Id.* at 7 (Figure 1) & 11 (Figure 2).

Guard bands and duplex gaps that are larger than 10 MHz and 11 MHz, respectively, would be technically unnecessary and unreasonable from an engineering standpoint. First, they would result in spectral inefficiency because they would be larger than is appropriate to adequately protect licensed operations from interference. Moreover, a larger duplex gap can make devices more complex and less interoperable. For example, the larger duplex gap of 20 MHz or more proposed by Google and Microsoft, like the Commission's proposal, would substantially increase both the complexity and cost of devices, including by requiring device antennas supporting larger real-time bandwidth.[11] It would increase device size by requiring additional or larger antennas and/or additional tuners or other components. In addition, the larger the real-time bandwidth of an antenna, the greater the reduction in antenna efficiency/gain – particularly for lower frequency blocks – a phenomenon that would negatively and unnecessarily affect device performance if the size of the duplex gap were increased.[12] That same phenomenon would also negatively affect the generic nature of adjacent licensed frequency blocks. All of these drawbacks negatively affect the price and the attractiveness of devices to consumers, and therefore reduce the attractiveness of the auctioned spectrum to wireless operators.

Verizon's proposed band plan already accepts substantial device tradeoffs in order to achieve the goal of maximizing paired generic spectrum. For example, Verizon's high-clearing scenario band plan (Figure 1 in Verizon's initial comments) would require a larger antenna (approximately 30% larger than what is currently used in devices operating on the 700 MHz

[11] The real-time (or instantaneous) bandwidth is the bandwidth at which an antenna's transmit and receive can be active at the same time, given the antenna's efficiency (gain). *See, e.g.*, Qualcomm Comments at 13.

[12] *See* Qualcomm Comments at 14 fig. 3.

band) and an extra duplexer compared to a band plan based on a 25X25 MHz configuration.[13] Given the importance of maximizing the amount of paired spectrum to be made available at auction, those trade-offs are reasonable and on balance they increase the attractiveness of the auctioned spectrum.[14] But the additional compromises associated with a band plan with an even larger duplex gap – including compromised performance as well as larger, more costly components – would tip the balance in the wrong direction and would substantially reduce the attractiveness of the auctioned spectrum.

B. Most Parties Agree that Technical Considerations Preclude TDD Operations in the 600 MHz Band.

There is also broad agreement that the Commission should adopt its proposal to design a band plan based on the use of Frequency Division Duplexing (FDD) technologies.[15] Sprint and Clearwire request that the Commission instead accommodate Time Division Duplexing (TDD) technologies.[16] Technological flexibility is an appropriate goal, and TDD technologies such as TDD-LTE may be appropriate in other bands. But in the context of this proceeding, technical considerations require rejecting these proposals.

First, as Qualcomm demonstrates in Table 2 of its comments, placing any uplink transmissions below Channels 46 (668 MHz), as would occur with TDD, generates harmful harmonics that cause harmful interference to higher bands, including into the Global Navigation Satellite System (GNSS) band. That is one of the reasons why Verizon and others support only downlink operations (either the downlink sides of paired spectrum or supplement downlink

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[13] *See* Verizon Comments at 7-8.

[14] *Id.* at 8.

[15] *See, e.g.*, Joint January 24 Letter; Google and Microsoft Comments at 32-34; Research in Motion Comments at 3, 8-9; NCTA Comments at 11-17.

[16] Sprint Comments at 17-26; Clearwire Comments at 6-11.

blocks) in those channels.[17] Given that TDD blocks are used for uplink as well as downlink, they would cause such harmonic problems – yet Sprint and Clearwire propose no engineering solution.

Second, TDD operations in the 600 MHz band would create major co-existence and mutual interference problems among TDD operators and between TDD and FDD operators. Without synchronized transmission and a common uplink/downlink ratio, adjacent TDD operations create base station-to-base station and mobile-to-mobile interference.[18] For example, different operators with adjacent TDD operations have to coordinate their base station deployment strategy and time-synchronize their networks. Such coordination is particularly difficult with the macro network coverage areas associated with deployment in the 600 MHz band. Moreover, if one operator is using a 40/60 uplink/downlink ratio and an adjacent operator is using a 30/70 ratio, the uplink of the first operator will interfere with the downlink of the second operator, and the downlink of the second operator will interfere with the uplink of the first operator. Without the above-mentioned synergy among adjacent TDD operations to mitigate these interference concerns, there would need to be guard bands of 7 to 12 MHz between TDD blocks (meaning less spectrum to license through the auction) and/or additional (and expensive) filters on base stations between adjacent TDD operations.[19]

Sprint shrugs off these challenges in a footnote acknowledging that "TDD licensees would need to agree on an appropriate asymmetry ratio and synchronize their transmissions."[20]

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[17] *See* Verizon Comments at 18.

[18] *See* Nokia Siemens Networks, *Coexistence of Asynchronous TDD Networks*, *available at* http://br.nokiasiemensnetworks.com/file/17691/coexistence-of-asynchronous-tdd-networks, at 7-9 ("Nokia Coexistence Study"). Nokia Siemens concludes that the preferable solution is synchronization.

[19] *Id.* Nokia Siemens concludes that the preferable solution is synchronization. *Id.* at 9.

[20] Sprint Comments at 22 n.45.

But Sprint does not explain how that coordination would take place among diverse carriers whose preferences for different uplink/downlink ratios may vary.[21] Moreover, Sprint does not attempt to square the need to establish a single uplink/downlink ratio for TDD operations with its assertion that TDD is attractive because it purportedly "enables operators to *change* the asymmetry ratio" as traffic demands evolve.[22]

Sprint also fails to address the substantial inter-technology coexistence problems created by placing TDD operations adjacent to FDD. Industry coexistence studies also show a need for a 10 MHz guard band between any TDD operations in the 600 MHz block and the FDD operations in the adjacent 700 MHz block,[23] so Sprint's proposed guard band of 8 MHz adjacent to the 700 MHz band is inadequate. The same co-existence issue renders infeasible Clearwire's proposal that the Commission avoid choosing between TDD or FDD and instead adopt technology-neutral rules so the "marketplace" can "determine technology choices."[24] In the context of this band it is not possible to be agnostic about the TDD/FDD choice because any licensee using its block for TDD operations would preclude the use of the adjacent blocks for FDD operations absent substantial (10 MHz) guard bands between every licensed block. The unavoidable fact that the new 600 MHz band will begin next to FDD operations in the 700 MHz band also compels the use of FDD. [25]

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[21] The propagation characteristics of 600 MHz spectrum make such coordination more difficult than in other bands. For example, TDD operations can co-exist more easily where higher frequency bands are used for small cell deployment because the coverage areas are smaller and more predictable.

[22] *Id.* at 20 (emphasis added).

[23] *See* Nokia Coexistence Study.

[24] *See* Clearwire Comments at 3-6.

[25] Of course, the structures of TDD and FDD band plans would be different for other reasons, including the fact that an FDD band plan requires a duplex gap. The TDD/FDD decision is therefore a "gating" issue that requires resolution prior to establishing the band plan.

Because of the substantial guard bands needed to mitigate the extensive co-existence problems (both inter-operator and inter-technology), Sprint's proposed band plan would be far less spectrally efficient than Sprint asserts. Moreover, even setting aside the additional inter-operator guard bands required to implement a TDD plan, Verizon's 2X35 MHz band plan proposal (Figure 1 in Verizon's initial comments) results in the same amount of non-auctioned spectrum as Sprint's proposed band plan, while freeing up far more useful spectrum for auction.

Beyond the technical defects in the Sprint/Clearwire proposal is the fact that only Sprint and Clearwire support TDD operations. No one disagrees that maximizing the usefulness of the spectrum to forward auction bidders will maximize the chances of a successful auction, and most commenters advocate a band plan based on FDD. The record in short should reassure the Commission that it made the right call in proposing an FDD-based band plan.

II. VERIZON SUPPORTS AUTHORIZING UNLICENSED OPERATIONS IN THE GUARD BANDS AND DUPLEX GAP.

A. Authorizing Low-Powered Unlicensed Operations Will Meet the Statutory Requirement that they Not Cause Interference.

As Verizon noted in its initial Comments, it will be possible for the Commission to authorize low-powered operations in the guard bands, including duplex gap, of the band plan that Verizon proposes.[26] Recognizing that unlicensed spectrum has a place in the overall wireless ecosystem, Verizon supports making both the duplex gap and the guard bands available for unlicensed use. Verizon's proposed band plan, while maximizing the amount and quality of the paired spectrum available at auction, makes a substantial amount of guard band spectrum available for unlicensed use, including a uniform 10-11 MHz duplex gap that facilitates nationwide device development and deployment.

[26] Verizon Comments at 20.

Section 6407 of the Spectrum Act requires the Commission to authorize only unlicensed operations that do not cause harmful interference to licensed services.[27] Inadequate rules and standards governing unlicensed operations in the 600 MHz band would cause substantial harm to licensed operations and thereby compromise the generic nature of the licensed spectrum. To avoid that, there need to be adequate protections, including appropriate power limits, Out-of-Band Emissions (OOBE) requirements, and in general appropriate standards/rules for unlicensed operations in the guard bands and duplex gap. It may also be necessary to require internal guard bands within a guard band or duplex gap or geographic restrictions for unlicensed uses to avoid harmful interference and protect licensed operations.

As long as the duplex gap is uniform across the country (as Verizon proposes), unlicensed operations that meet the above standards could operate anywhere in the country in the duplex gap frequencies. The other guard bands, however, will not be located in the same frequencies across the country because they need to be located at different frequencies in different markets based on the amount cleared in each market. Therefore, apart from the adjacent channel interference issues discussed above, unlicensed operations in guard band frequencies raise co-channel interference issues. For example, an unlicensed device operating in one of the guard bands in a low-clearing market would cause co-channel interference with mobile operations in a higher-clearing market if it operates in the higher-clearing market. Therefore, geographic constraints on such unlicensed operations will need to be enforced (via a mechanism similar to the white spaces databases) to ensure that unlicensed operations in guard bands are geographically separated from mobile operations on the same frequencies.

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[27] Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, § 6407(e) 126 Stat. 156 (2012) (the "Spectrum Act").

B. Authorizing Unlicensed Operations in Guard Bands While Maximizing Licensed Spectrum Would Achieve Congress's Objectives.

Some parties ask the Commission to consider a band plan that includes more unlicensed spectrum than would be accommodated under a plan that optimizes the amount of auctioned spectrum. For example, Google and Microsoft argue that in order to create the "optimal mix of licensed and unlicensed spectrum," the Commission should establish a band plan with a duplex gap that is twice (or more) the size that is reasonable for a band plan that maximizes the amount of spectrum that is auctioned.[28] Similarly, NCTA urges the Commission to "widen" the duplex gap so it is large enough to accommodate "higher power" unlicensed operations.[29] The various policy arguments advanced in support of these proposals are misplaced because Congress made the express decision to auction the cleared spectrum in order to raise revenues to support certain statutory objectives. While it is appropriate to promote unlicensed use within the context of the balance that Congress has struck, the Commission does not have discretion to disregard that balance.

1. The Spectrum Act Mandates that All Auctionable Spectrum Be Repurposed via the Forward Auction.

Section 6402 of the Spectrum Act states that the purpose of this incentive auction is to clear broadcast spectrum "in order to" permit the assignment of "new initial licenses" via an auction (a "competitive bidding system"). Section 6403(a)(1) reinforces that mandate, stating that the Commission's task is to "make [the cleared] spectrum available for assignment through a system of competitive bidding." Section 6403(c) makes clear that a forward auction of licensed spectrum is the only mechanism the Commission may use to repurpose the spectrum that clears:

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[28] Google and Microsoft suggest that a duplex gap greater than 20 MHz and as large as 28 MHz may be "technically reasonable." *See* Google and Microsoft Comment at 31, 37. But as discussed in Section I, a band plan that maximizes auctionable spectrum needs a duplex gap no larger than 11 MHz.

[29] *See* NCTA Comments at 9.

> (c) Forward Auction.--
>
> (1) Auction required.-- The Commission shall conduct a forward auction in which--
>
> (A) the Commission assigns licenses for the use of the spectrum that the Commission reallocates under subsection (b)(1)(B)(ii)

The Commission is thus *required* to conduct a forward auction in which it will "assign licenses" for "the spectrum" that clears in the reverse auction.

The Act's only reference to unlicensed spectrum in the 600 MHz band appears in Section 6407. Section 6407(a) states that "[n]othing in" Sections 6402 and 6403 prevents the Commission from implementing "band plans with guard bands." Section 6407(a) thus recognizes the practical necessity of establishing guard bands in order to implement the auction requirement, and it exempts those guard bands from the auction mandate. By authorizing the Commission to establish guard bands *notwithstanding* that auction mandate, Section 6407(a) underscores that the Commission's authority to create guard bands exists only so that it can create a technically reasonable band plan that maximizes the amount of auctioned spectrum.

Then, subpart (b) of Section 6407 states that "such guard bands" (i.e., the guard bands in the band plan created to implement the auction requirement) may be no "no larger than is technically reasonable to prevent harmful interference between licensed services outside of the guard bands." Given that its authority to create guard bands (and to put unlicensed operations in them) is subsidiary to its obligation to repurpose cleared spectrum via auction, the Commission is not permitted to replace otherwise-auctionable spectrum with unlicensed spectrum. In other words, Congress has determined what the balance should be between licensed and unlicensed spectrum for this auction.

2. Proponents of Reducing Licensed Spectrum Fail to Defend the Legality of their Proposals.

Proponents of limiting auctionable spectrum in order to increase the amount of unlicensed spectrum make several unavailing attempts to square their proposals with the statute.

NCTA's lead argument is that the "technically reasonable" requirement does not apply to the duplex gap because a duplex gap allegedly is not a "guard band," and only "guard bands" must be technically reasonable under Section 6407 of the Act.[30] That does not pass muster. The Act defines "guard band" as a gap in the band plan put in place to "prevent harmful interference between licensed services" (Spectrum Act, § 6407(a)), which is precisely what a duplex gap does by preventing interference between "licensed" mobile uplink and downlink operations. In fact, in a different portion of its comments, NCTA acknowledges that the purpose of a duplex gap is to "separate *licensed* uplinks and downlinks."[31] There is therefore no support for the notion that the Commission may establish a duplex gap that is larger than what is "technically reasonable."

Equally misguided are assertions that the Commission has broad discretion under the "technically reasonable" standard to configure a band plan that reduces auctioned spectrum in order to create more unauctioned spectrum. Some parties argue that the determination of what is "reasonable" should be made in the context of designing a band plan that advances a dual policy of promoting both licensed and unlicensed spectrum.[32] But as discussed above, the Spectrum Act sets forth the balance between licensed and unlicensed operations. Where Congress sought

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[30] *See* NCTA Comments at 12.

[31] NCTA Comments at 9 (emphasis added). Various engineering manuals and papers confirm that the duplex gap is a type of guard band. *See, e.g.*, Netkrom Technologies, "Time Division Duplex (TDD) vs Frequency Division Duplex (FDD) in Wireless Backhauls," p. 2, *available at* http://www.netkrom.com/support/whitepapers/TDD_vs_FDD_in_wireless_backhaul_white_paper.pdf ("FDD Channel plans maintain a guardband between the downstream and upstream channels" which is "required to avoid self-interference"); Pierre Lescuyer, Frank Bott and F. Bott, *UMTS: Origins, Architecture and the Standard (Computer Communications and Networks)* (Dec. 2, 2003), p. 63.

[32] *See, e.g.*, Comcast and NBCUniversal Comments at 44-46; Free Press Comments at 3-4.

specifically to promote unlicensed uses in the Spectrum Act, it did so, directing the Commission to initiate a proceeding to allow unlicensed devices to operate in the 5 GHz band. By contrast, for the 600 MHz band, Congress authorized the Commission to consider unlicensed use only in the guard bands needed to implement the auction mandate. The Spectrum Act thus sets parameters on the amount of spectrum in the 600 MHz band that may be designated for unlicensed use and prevents the Commission from expanding the size of the guard bands without a technical rationale. Verizon supports including unlicensed operations in the guard bands – including unlicensed devices operating on a nationwide basis in the uniform duplex gap – but the Spectrum Act does not empower the Commission to override the balance that Congress enacted.

Moreover, the phrase "no larger than is technically reasonable" does not provide the broad discretion that some parties urge.[33] The Commission has discretion to determine the precise size of guard bands in a band plan that implements the auction mandate,[34] but not to disregard that mandate. Given that the authority to establish guard bands is subsidiary to the requirement to auction the cleared spectrum, the statute requires the Commission to first establish guard bands that are no larger than is "technically reasonable" for maximizing the spectrum available for the forward auction, and *then* to consider whether (and what) unlicensed services can be included in those guard bands. In a different portion of its comments, NCTA acknowledges that the Commission's routine practice is to do exactly that:

> As part of its spectrum planning, the Commission routinely establishes duplex gaps for licensed services and *then* determines what uses, if any, should be allowed in the gap. For instance, the initial band plan for the broadband personal communications

[33] *See, e.g.*, Google and Microsoft Comments at 35-36.

[34] For example, in the context of a band plan that optimizes auctioned spectrum, the Commission would have authority to implement Google's and Microsoft's request to dedicate "remainder" spectrum to guard bands. *See* Google and Microsoft Comments at 42-43. The guard band is the most reasonable place to locate such extra spectrum for device and auction design purposes. *See* Verizon Comments at 20 n.28.

> service (PCS) included a duplex gap to prevent interference between uplink and downlink transmissions within that service. The Commission *then* allocated that gap for unlicensed operations.[35]

Continuing to follow that practice is what the Spectrum Act requires, and what the *NPRM* correctly proposes.[36]

3. Compromising the Optimal Band Plan Would Jeopardize the Fiscal Targets of the Incentive Auction and Harm Consumers.

One of Congress's objectives for the incentive auction is to raise revenues to support the Public Safety Trust Fund and the interoperable nationwide broadband public safety network.[37] Moreover, the auction will fail completely if the forward auction does not generate sufficient revenues to cover at least the amounts paid broadcasters in the reverse auction, the amount needed to relocate broadcasters, and the costs of the auction.[38] Google and Microsoft advance several novel theories why their proposal to replace auctioned spectrum with non-auctioned spectrum might not jeopardize the auction's fiscal targets.[39] Setting aside the fact that the Commission does not have the discretion under the statute to adopt their proposal, the reality is that artificially constraining the supply of spectrum to be auctioned would reduce revenue and harm consumers.

Verizon agrees that unlicensed operations should be included in the band plan adopted in this proceeding. But Microsoft and Google urge the Commission to engage in the same behavior a monopolist may engage in: reduce supply and drive up prices. Their principal argument is that

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[35] NCTA Comments at 11-12 (emphasis added) (internal citations omitted).

[36] *See NPRM* ¶ 152 (proposing a specific guard band size and then proposing that the guard bands "may be used for low-powered unlicensed operations that are secondary and cannot cause interference").

[37] *See* § 6403(d)(4)(A).

[38] *Id.* § 6403(c)(2)).

[39] *See* Google and Microsoft Comments at 28-31.

by artificially reducing the supply of spectrum to be auctioned, the Commission could drive up the prices paid by auction participants and thereby "compensate" for the reduction in the amount auctioned.[40] In other words, Microsoft and Google ask the Commission to extract economic rents from forward auction participants that ultimately would be borne by consumers. But the losses in consumer welfare caused suppressing the supply of licensed spectrum are exactly the same as those caused by a private monopolist: costs to wireless operators would artificially increase, and otherwise-auctionable spectrum would be unavailable to operators to provide and expand service to their customers, thus reducing service quality, raising prices, or both.[41] Those are not outcomes the Commission should accept, much less promote.

Setting aside the consumer harms caused the Google/Microsoft proposal, there is no basis to embrace the fiction that the U.S. Treasury would remain whole if the Commission reduces the supply of spectrum to be auctioned. Google and Microsoft assert that the "per unit" price paid by forward auction participants would increase if the supply of spectrum is reduced, and they suggest that those higher per-unit prices could theoretically offset the losses incurred by the Treasury on the spectrum that is not auctioned.[42] But Google and Microsoft point to nothing indicating that increased per-unit prices on the spectrum that is auctioned would in fact make up for the losses incurred on the spectrum that is removed from the auction. In fact, the authors of the study that Google and Microsoft cite for their "offset" theory concede that they "are not

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[40] Google and Microsoft Comments at 29.

[41] The Commission has recognized that failure to make more spectrum available for wireless broadband risks "higher prices, poor service quality, an inability for the U.S. to compete internationally, depressed demand, and, ultimately, a drag on innovation." *See Connecting America: The National Broadband Plan*, at 77 (FCC 2010), *available at* http://download.broadband.gov/plan/national-broadband-plan.pdf.

[42] *Id.* at 29.

aware of convincing estimates of the aggregate demand for licensed spectrum."[43] Given the undisputed fact that the overall wireless industry faces a spectrum shortage, the spectrum that Google and Microsoft propose to withhold from the auction would be far more likely to increase total revenue when offered and sold in the auction than withholding it would contribute via the increase in per unit price for the remaining spectrum. Thus, artificially reducing supply would risk *significantly reducing* total auction revenue.

Google and Microsoft fall back on a paper suggesting that during the course of an auction the total bids may approximate the "aggregate budgets" that bidders have set aside for the auction.[44] They latch on to that theory to assert that reducing the amount of auctioned spectrum may not affect auction revenues.[45] That makes no sense. The paper cited by Google and Microsoft does *not* assert that bidders establish their budgets for spectrum auctions without regard to the amount of (or characteristics of) the spectrum to the auctioned.[46] Instead, it explores how bidders may behave during an auction given the budgets they have established for the auction.[47] The reality is that bidders will *establish* their budgets based on the nature and amount of spectrum to be auctioned, and with the understanding that the bandwidth available in the incentive auction is a substitute for licensed bandwidth in the secondary market, so if the Commission reduces (or impairs) the to-be-auctioned spectrum, the money set aside by operators to participate in the auction will be lower and auction revenue will fall. Conversely, bidders will go into the auction with larger budgets – and will bid more robustly – if the Commission

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[43] Paul Milgrom, Jonathan Levin, and Assaf Eilat, *The Case for Unlicensed Spectrum*, p. 23 (Oct. 2011) ("Milgrom et al."), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1948257.

[44] Google & Microsoft Comments at 29-30.

[45] *Id.*

[46] *See generally*, Jeremy Bulow, Jonathan Levin, and Paul Milgrom, *Winning Play in Spectrum Auctions* (2009), *available at* http://www.stanford.edu/~jdlevin/Papers/AWS.pdf.

[47] *Id.* at 2, 7-12.

maximizes the amount and attractiveness of the spectrum that will be available in the forward auction. Google and Microsoft would turn that common-sense fact on its head.

Finally, Google and Microsoft speculate that wireless operators might bid more for the auctioned spectrum because setting aside spectrum for unlicensed use might promote unlicensed services that are "complementary" to licensed services.[48] The paper Google and Microsoft cite theorizes that the availability of unlicensed spectrum could lead to the strengthening of the overall wireless ecosystem in ways that may increase the value of licensed wireless services – and if that does happen, they speculate, then the value of wireless licenses would rise and auction revenues would increase.[49] Whatever the merits of this theory, it provides no support for the notion that bidders might pay more *in this auction* based on speculation that unlicensed uses might, in the future, create "even higher consumer demand" for licensed services.[50] Neither the paper nor Google and Microsoft explain why bidders would pay more for licenses in the incentive auction based on such speculation.

III. THE COMMISSION SHOULD REJECT CALLS FOR RULES THAT WOULD FAVOR SOME BIDDDERS OR SUPPRESS BIDDING.

A. The Commission Should Not Imperil the Auction's Success by Imposing Eligibility or Bidding Restrictions.

1. This Is the Wrong Proceeding for Addressing Spectrum Holdings Issues.

Several commenters urge the Commission to establish rules that would constrain the ability of certain would-be forward auction participants to participate fully in the auction.[51] The Commission should reject those proposals. The Commission's overarching objective should be

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[48] *See* Google & Microsoft Comments at 30.

[49] Milgrom et al., p. 23-24.

[50] Google & Microsoft Comments at 30.

[51] *See* T-Mobile Comments at 23-33; Sprint Comments at 7-10; Competitive Carriers Association Comments at 8-10; United States Cellular Corporation ("US Cellular") Comments at 30; PISC Comments at 63-68.

to ensure the forward auction's success, and promoting that objective requires not injecting additional uncertainty into what is already a very complex undertaking. Moreover, to the extent any party asserts that spectrum ownership rules are needed, those arguments should be made in the context of the pending *Spectrum Holdings* rulemaking[52] – and the Commission's action there should not jeopardize the success of *this* proceeding.[53]

Of course, the 600 MHz spectrum auctioned here should be included in the Commission's spectrum aggregation screen, along with all other spectrum identified in the *Spectrum Holdings* rulemaking and in other proceedings, including applications for SoftBank's acquisition of control of Sprint and Clearwire. As discussed in detail below, if the Commission determines that the grant of a 600 MHz license might cause a party the exceed a spectrum holdings limit that the Commission puts in place, the right way to apply that spectrum limit – and the only policy that is permitted under the Spectrum Act – is to see what spectrum (if any) the party acquires during the auction and then to assess whether post-auction divestitures are necessary to prevent competitive harm.

2. All Interested Bidders Have a Statutory Right to Participate Fully.

As Verizon discussed in its initial comments, Section 6404 of the Spectrum Act codifies the Commission's longstanding practice of allowing all interested parties to participate fully in spectrum auctions. Proposals that restrict otherwise-eligible auction participants violate Section 6404. For example, T-Mobile proposes to bar a would-be participant from bidding in the forward auction unless it has divested itself – prior to the auction – of any spectrum that would

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[52] *Policies Regarding Mobile Spectrum Holdings,* Notice of Proposed Rulemaking, 27 FCC Rcd 11710 (2012).

[53] As stated by the Expanding Opportunities for Broadcasters Coalition ("EOBC"), "there will be many other opportunities, in other contexts and in other proceedings, to address concerns regarding concentration of wireless spectrum ownership," but "there will be only one opportunity to conduct a broadcast incentive auction under Section 6403." *See* EOBC Comments at 14.

place it over the spectrum cap that T-Mobile proposes.[54] T-Mobile's proposal would violate Section 6404 by directly blocking a person from participating in the auction even though it complies with the minimum requirements for participation (i.e., "auction procedures" and "other requirements to protect the auction process") and meets all "technical, financial, character, and citizenship qualifications."[55]

Sprint proposes a different version of the same eligibility restriction. It proposes to block operators with "more than one-third of the available spectrum below 1 GHz" from acquiring "more than one-sixth of the available 600 MHz spectrum" in the forward auction.[56] Sprint's proposal – which it candidly lists as an "eligibility restriction"[57] – also violates Section 6404 because it places a discriminatory "condition" on an otherwise-eligible party's participation.[58]

In contrast to Sprint and T-Mobile, the PISC acknowledges that the Spectrum Act "provides that the Commission may not prevent a person from participating in a system of competitive bidding."[59] While the Coalition fails to establish that a cap is appropriate in the first place, it correctly notes that under a properly designed cap, there "would in any case be no ineligibility at the auction stage, as an entity surpassing the threshold would decide what spectrum and how much to divest post-auction in each local market."[60] In other words, any

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[54] *See* T-Mobile Comments at 27-33.

[55] Spectrum Act § 6404, *codified at* 47 U.S.C. § 309(j)(17)(A).

[56] Sprint Comments at 9-10.

[57] *See* Sprint Comments at 9 (listing its proposed one-sixth cap one of the "eligibility restrictions" that purportedly would prevent "excessive concentration").

[58] Spectrum Act § 6404, *codified at* 47 U.S.C. § 309(j)(17)(A).

[59] *See* PISC Comments at 63.

[60] *Id.* at 63-64 (emphasis added).

generally applicable spectrum aggregation rule would apply *post-auction*, allowing carriers to fully participate in the auction.[61]

The legislative history of Section 6404 confirms that auction-specific rules are not permissible. Although there was disagreement among legislators about the scope of Section 6404, no one supported an interpretation under which the Commission could establish an *ex ante* rule. For example, Representative Waxman explained that in the context of a spectrum cap or screen, companies with large spectrum holdings "will be able to acquire new spectrum in an auction, but if the FCC determines the acquisition of that spectrum would diminish competition, the companies can be required to divest other spectrum before they get a license to the new spectrum."[62] Representative Upton confirmed that interpretation, noting that a rule regarding "particular carriers" or "particular auctions" is not a rule of "general applicability."[63] In short, neither the language nor legislative history of the Spectrum Act authorize or support the kinds of auction-specific rules that Sprint and T-Mobile propose.

3. No Party Identifies Any Competition Analysis for Which a Bidding Restriction Is an Appropriate Remedy.

Under 6404, the Commission may establish a rule on "spectrum aggregation" if it is (i) of "general applicability" and (ii) needed to "promote competition."[64] As discussed in Verizon's initial comments, eligibility and bidding restrictions by their very nature risk *harming* competition by failing to ensure that spectrum is assigned to the bidder that will put it to its highest and best use. As the Commission has explained, restricting auction participation risks

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[61] *See* Verizon Comments at 43.

[62] 158 Cong. Rec. E265, 266-67 (daily ed. Feb. 28, 2012) (speech of Hon. Henry A. Waxman).

[63] 158 Cong. Rec. E237, 238 (daily ed. Feb. 24, 2012) (speech of Hon. Fred Upton). He also noted that any such rule would need to be vetted in a separate rulemaking proceeding so that the Commission could "rigorously examine whether there is any need for action, as well as the pros, cons, and potential unintended consequences of any proposed measures." *Id.*

[64] Spectrum Act § 6404, *codified at* 47 U.S.C. § 309(j)(17)(B).

"reducing the likelihood that the party valuing the license the most will win the license and put it to use for the benefit of the public."[65] Accordingly, such restrictions are theoretically defensible only if their harmful effects are outweighed by a pro-competitive benefit. Yet no party advocating a restriction demonstrates a need for it – let alone a need that outweighs the likely harmful effects.

Rather than present evidence of market failure, foreclosure, or some other problem that needs to be remedied, some parties ask for "protectionist" regulation to limit the competition they would face in the auction.[66] T-Mobile, for example, asserts that "concentration of low-band spectrum stifles competition by increasing the costs of carriers such as T-Mobile to provide the extensive network coverage that consumers demand." But T-Mobile does not identify any "costs" that have been imposed on it. Nor does T-Mobile even *assert* that it is unable to "compete" with other carriers – either for customers or for spectrum.[67] Similarly, Sprint asserts a need "to guarantee that multiple operators have an ability to acquire low-band spectrum so that the economic and innovation opportunities inherent in using low-band spectrum can be fully realized" – but does not identify any opportunities it is currently unable to realize because of a lack of low-band spectrum.[68] In contrast to those conclusory assertions, unsupported by expert declarations, Verizon has explained in the *Spectrum Holdings* proceeding – supported by engineering and economist declarations – that there is no basis to conclude that below 1 GHz

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[65] *Service Rules for the 698-746, 747-762 and 777-792 MHz Bands,* Second Report and Order, 22 FCC Rcd 15289 at 15385, ¶ 259 (2007).

[66] *See, e.g.*, Sprint Comments at 9-10; T-Mobile Comments at 27-31; PISC Comments at 63-70.

[67] T-Mobile Comments at 26.

[68] Sprint Comments at 10.

spectrum has unique characteristics that could justify regulating it differently from higher-frequency spectrum.[69]

Sprint's and T-Mobile's own spectrum strategies totally undercut the notion that spectrum below 1-GHz is an indispensable part of an operator's portfolio, or that they need special preferences in order to be able to acquire such spectrum. Neither company even *asserts* that it has ever sought to purchase below 1 GHz spectrum – let alone that it has ever been "foreclosed" from obtaining any such spectrum. Neither Sprint nor T-Mobile participated in the 700 MHz auction, and in recent years neither has filed an application with the Commission to obtain any below 1 GHz spectrum in the secondary market.[70] To the contrary, both T-Mobile and Sprint have focused extensively (if not exclusively) on assembling *higher*-frequency spectrum holdings. T-Mobile participated in the higher-frequency AWS auction, purchased additional AWS spectrum from Verizon last year, and negotiated a merger breakup fee with AT&T that included only higher-frequency spectrum – and none of AT&T's below 1 GHz spectrum. And both T-Mobile and Sprint have decided to make multi-billion dollar investments in companies – MetroPCS and Clearwire – that own substantial higher-frequency spectrum but no (or virtually no) below 1 GHz spectrum. Sprint has touted the attractiveness of the higher-frequency spectrum it is acquiring via the Clearwire transaction.[71]

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[69] *See* Reply Comments of Verizon Wireless, *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269 (Jan. 7, 2013), at 19-27, Decl. of William H. Stone, & Decl. of Allan L. Shampine.

[70] In 2007, T-Mobile filed an application to acquire SunCom Wireless, and appears to have acquired one cellular license which was incidental to its overall acquisition of 27 higher-frequency PCS licenses. Verizon is not aware of any other acquisition by Sprint or T-Mobile of below 1 GHz licenses.

[71] *See, e.g.*, *See* Press Release, *Sprint to Acquire 100 Percent Ownership of Clearwire for $2.97 per Share*, *available at* http://newsroom.sprint.com/article_display.cfm?article_id=2477 (Dec. 17, 2012) ("Clearwire's spectrum, when combined with Sprint's, will provide Sprint with an enhanced spectrum portfolio that will strengthen its position and increase competitiveness in the U.S. wireless industry").

Remarkably, T-Mobile asks the Commission to impose a bright line cap on spectrum holdings precisely because it wants the Commission to *avoid* addressing the central question of whether there is a problem in need of a remedy. According to T-Mobile, the Commission should not get bogged down with the sort of "subjective" inquiries that the Commission undertakes under its existing spectrum screen analysis, such as whether potential entrants will be "foreclosed" and "whether rivals' costs would be increased to the extent that they would be less likely to be an effective competitive constraint."[72] But it is obviously not sound policy to impose a "remedy" based on the notion that the Commission should avoid deciding whether there is actually a *need* for a remedy.

Sprint is similarly disingenuous, asking the Commission for disparate regulation of industry participants. Regarding its transactions with Clearwire and SoftBank, Sprint urges the Commission to not count Clearwire's remaining BRS/EBS spectrum towards the spectrum screen even though Clearwire actively uses that spectrum for mobile operations.[73] Yet while seeking to avoid any Commission scrutiny of its *own* spectrum holdings, here Sprint urges the Commission to discriminate against *other* operators. These self-serving requests for bidding or eligibility restrictions should be rejected.

4. Restrictions Would Artificially Depress Auction Bid Amounts by Protecting Some Bidders Against Competition in the Auction.

As discussed in Section I.B.3 above, the Spectrum Act sets fiscal targets for the forward auction.[74] As Verizon explains in detail in its initial comments, those targets would be

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[72] T-Mobile Comments at 31-32 (internal quotations omitted).

[73] *See* Verizon Wireless Reply Comments, *Applications of Sprint Nextel Corporation, Transferor, SoftBank Corp. et al.*, IB Docket No. 12-343 (Feb. 25, 2013), at 1-2.

[74] *See* Spectrum Act § 6403(d)(4)(A).

jeopardized by bidding and eligibility restrictions.[75] Moreover, restricting auction participation or bidding would enable arbitrage by companies who take advantage of restrictions on their competitors to purchase spectrum at a discount and subsequently sell it for a profit on the secondary market.

T-Mobile suggests that its proposed *ex ante* spectrum cap may actually *increase* auction revenue by encouraging greater participation.[76] No other party advocating restrictions makes this extraordinary, undocumented claim. T-Mobile bases its theory on a 13-year old statement testimony given by an economist.[77] Notably, the first sentence of the cited passage (which T-Mobile omits) succinctly states: "Typically, spectrum caps lower auction revenues."[78] Dr. Cramton goes on to state there is a potential exception to that typical outcome: in a situation where "incumbent bidders" would otherwise have "an advantage," a cap could theoretically increase revenue because "the non-incumbents know that non-incumbents will win licenses, giving them the incentive and ability to secure the needed financing from capital markets."[79] But T-Mobile cites no evidence that such a situation might actually occur, or that the conditions necessary for such an extraordinary outcome are present here. T-Mobile does not identify the "incumbent bidders" whose participation should be restricted to make way for new entrants, explain why T-Mobile *itself* would not qualify as an "incumbent," or describe any "advantage" that some bidders might have over other bidders during the auction. Nor does T-Mobile assert that it (or any other potential bidder) will be unable to "secure the needed financing" if it is required to participate in the auction under the same terms as the other bidders. A 2012 study undercuts T-Mobile's unsupported theory, finding that the

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[75] *See* Verizon Comments at 38-43.

[76] T-Mobile Comments at 33.

[77] *Id.* (*citing* Peter Cramton, *Lesson Learned from the United States Spectrum Auctions*, Testimony before the United States Senate Budget Committee 3 (Feb. 10, 2000) ("Cramton 2000 Testimony")).

[78] Cramton 2000 Testimony at 3.

[79] *Id.*

empirical evidence indicates that "[i]n any scenario that excludes Verizon and AT&T from bidding, the wealth transfer from the Treasury to the buyers of spectrum would be certain."[80]

T-Mobile's and Sprint's request for special treatment and protection against bidding competition should be viewed against the backdrop of their financial ability to bid robustly for spectrum. These are not "mom and pop" businesses lacking the resources or sophistication to compete for the pool of available spectrum. T-Mobile has more than 34 million customers and annual revenues of more than $21 billion, has recently received a $3 billion cash breakup fee (in addition to valuable AWS spectrum) from AT&T in the wake of their aborted merger,[81] and is owned by Deutsche Telekom. That deep-pocketed parent, which is partly owned by the Government of Germany and which had revenues last year of nearly $59 billion, has provided T-Mobile with financing to acquire MetroPCS for $1.5 billion, thereby substantially improving T-Mobile's spectrum holdings and increasing its customer base by 25%.[82] And Sprint, whose revenue last year was over $35 billion, is in the midst of a $20 billion transaction with SoftBank that includes an $8 billion cash infusion provided specifically so that it can compete more effectively.[83] Both companies are clearly capable of bidding robustly to the extent acquiring 600 MHz spectrum fits into their business plans – and the auction will be successful only if they are

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[80] Ana-Maria Kovacs, *Neutral Spectrum Auctions: Maximizing Proceeds and Consumer Benefit*, 13 (Feb. 2012), *available at* http://www.gcbpp.org/files/EPV/EPV_Kovacs_SpectrumAuctions_21312.pdf.

[81] *See, e.g.*, Nadia Damouni & Paritosh Bansal, AT&T, T-Mobile USA Break-Up is $6 Billion, Reuters (May 12, 2011), *available at* http://www.reuters.com/article/2011/05/12/us-mobileusa-att-breakupfee-idUSTRE74B5H220110512 (noting that AT&T has disclosed that it agreed to a breakup fee including $3 billion cash and $2 billion worth of spectrum); T-Mobile USA, Inc., *Notice of Apparent Liability for Forfeiture*, 27 FCC Rcd 4405, ¶ 25, n.65 (2012).

[82] MetroPCS has told its investors that the combined company "will have the expanded scale, spectrum and financial resources to compete aggressively with the other larger U.S. wireless carriers." *See* MetroPCS Communications, Inc. Schedule 14A Filing with Securities & Exchange Commission (Feb. 26, 2013), Letter to Shareholders at 1.

[83] *Applications of Sprint Nextel Corporation, Transferor, SoftBank Corp. et al.*, IB Docket No. 12-343, Public Interest Statement, 1, 6, 14, 23 (Dec. 4, 2012).

required to engage in meaningful competition for the available spectrum on a level playing field with other bidders. The Commission should not countenance these companies' efforts to foreclose other carriers' access to spectrum and lower their own costs of obtaining spectrum to the detriment of the Spectrum Act's fiscal objectives.

5. Restrictions Could Cause Auction Failure.

In requesting comment on eligibility and mobile holdings issues, the Commission correctly notes that "it is of particular importance to have certainty for bidders in this auction."[84] But many of the proposed restrictions are not only unlawful but also are simply not workable, especially in the context of this already-complex incentive auction.

First, a number of parties propose that the Commission restrict the amount of spectrum that any party could acquire in any particular market to 1/3 the total available in the market, or, in the case of Sprint, 1/6 the total. As Verizon explains in detail in its initial comments, such a prohibition would be virtually impossible to comply with in the incentive auction.[85] Forward auction bidders will not know how much spectrum will ultimately clear, so they will not know ahead of time the amount of spectrum on which they can bid in a market without violating the cap. And the problem is further complicated insofar as different amounts of spectrum may be available in different geographic markets and at different stages throughout the auction, making it potentially impossible for a bidder to coordinate bids across multiple markets while complying with the cap everywhere. At a minimum, such uncertainty can be expected to suppress bidding because bidders will be cautious about potentially "overshooting" and accidentally acquiring too much spectrum; at worst, the unworkable nature of such a cap could cause auction failure.

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[84] *NPRM* ¶ 384.

[85] Verizon Comments at 42-43.

Such auction-specific caps are not the only types of restrictions that would complicate the auction process and imperil the auction's success. The *ex ante* spectrum aggregation cap proposed by T-Mobile and Sprint would cause equally harmful practical problems. Under the proposed rule, operators whose holdings place them at or around the cap would need to divest spectrum prior to the auction in order to get "headroom" so they can participate in the auction. But they would not know whether (or at what price) they could acquire the spectrum they need during the incentive auction. They may therefore choose not to participate in the auction at all to avoid the risk that they may divest valuable spectrum (possibly at a low price) prior to the auction and then fail to replace it (or need to pay a high price to replace it) during the auction. Putting potential bidders in that untenable position could substantially reduce auction participation and suppress auction revenue.[86]

B. The Commission Should Reject Requests to Provide Some Large Wireless Operators with Bidding Credits.

Verizon does not oppose leaving in place the existing Designated Entry program with its current level of bidding credits and eligibility rules. But there is no basis for the Commission to give certain large companies a regulatory hand-out (especially one which obviates the most basic efficiency provided by auctions, i.e., assigning licenses to firms that value them the most) so they can acquire spectrum in the forward auction at a substantial discount over the price that would otherwise be received. MetroPCS, joined by Leap and Cricket, urges that "rather than allocating designated entity (DE) credits by size, credits should be given to applicants in inverse proportion to the amount of attributable spectrum that the applicant holds in the auctioned license

[86] Ironically, T-Mobile suggests that companies potentially affected by its proposed spectrum cap might actually prefer an *ex ante* rule because it would purportedly provide greater "certainty" about where they can bid and how much they can acquire. T-Mobile Comments at 31. As explained above, such a rule would *increase* uncertainty, not reduce it.

territory."[87] Again, such protectionist regulation must be rejected. Under their proposal, they (and other entities that do not qualify as small businesses, such as T-Mobile and Sprint) could receive a discount of up to 60% off the otherwise-winning bid.[88] That would directly reduce auction revenue, would fail to ensure that spectrum is put to its highest and best use, and would facilitate arbitrage activity.

C. The Commission Should Adjust its Anti-Collusion Rules to Avoid Deterring Auction Participation.

In its comments, Verizon explains why and how the Commission should reassess and scale back the scope of its competitive bidding anti-collusion rules to facilitate a successful auction.[89] There is wide agreement among service providers and broadcasters alike that the Commission should not reflexively apply its existing anti-collusion rules and precedents to the incentive auction. Commenters confirm that burdensome anti-collusion rules risk discouraging broadcaster participation in the auction,[90] and would unnecessarily prohibit legitimate, normal business activities for forward auction participants.[91] The Commission should thus: (1) apply the rule only to direct discussions regarding bids or bidding strategies or the post-auction market structure, not to unrelated routine business discussions; (2) narrow the definition of "applicants" to cover controlling interests only; (3) shorten the period during which the rule is in effect; and (4) adopt no restrictions as between reverse and forward auction applicants.

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[87] MetroPCS Comments at 26; *see also* Leap Wireless International, Inc. and Cricket Communications, Inc. ("Leap and Cricket") Comments at 6.

[88] MetroPCS Comments at 27.

[89] Verizon Comments at 51-55.

[90] *See* Ass'n of Public Television Stations et al. ("APTS") Comments at 33-34; EOBC Comments at 23-24.

[91] *See* MetroPCS Comments at 15-16 (forward auction bidders "should be able to engage in other business transactions so long as no auction bidding information is shared" and "[t]he Commission should carefully evaluate whether the benefits of the current anti-collusion rules outweigh the clear burdens they impose, particularly when the length of the anti-collusion period is substantial").

In contrast, the Commission should not adopt two proposals that would expand the scope of the anti-collusion rules in this auction. Sprint's assertion that the rules should encompass communications among reverse and forward auction bidders because such communications "could create dangerous and anti-competitive informational asymmetries among bidders" is implausible and unwarranted, precisely because of the very "uncertainty … about the amount of spectrum and specific frequencies likely to be made available in each market" that Sprint describes in its comments.[92] As Verizon explained, broadcasters will engage directly with the Commission, not with forward auction participants, as to bidding options and bid amounts, and the amount of available spectrum will depend principally on other independent factors such as the application of the Commission's repacking formula and the extent of broadcaster participation and the nature of their bids.[93]

The Commission should also reject the National Association of Broadcasters' (NAB) proposal that the auction be deemed "open" until licenses are issued to forward auction participants.[94] This could extend the anti-collusion period by a significant duration, discouraging participation by broadcasters and service providers alike. It would also be inequitable to forward auction bidders if, as is the Commission's current practice, payments for winning bids must be submitted a short period after bidding concludes and the winning bidders are determined.[95] Moreover, the premise of NAB's assertion – that "winning bidders will not know their assigned frequencies … until after broadcast stations file their construction permit applications" – is

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[92] *See* Sprint Comments at 5 n.11.

[93] Verizon Comments at 54.

[94] *See* NAB Comments at 50-51.

[95] The auction closed and winning bids for Auction 73 (700 MHz) were announced shortly after bidding activity ceased, and final payments were due one month after close of the auction was announced. *See Auction of 700 MHz Band Licenses Closes* , Public Notice, DA 08-595 (2008).

incorrect.[96] To issue new 600 MHz licenses to winning bidders, the Commission merely needs to know the frequencies from which remaining broadcasters will relocate, and nothing precludes the Commission from granting winning bidders their licenses for those frequencies on a co-primary basis for an interim limited period until broadcasters cease their existing 600 MHz operations.

IV. THE REPACKING METHODOLOGYAND REVERSE AUCTION DESIGN SHOULD MAXIMIZE THE AMOUNT OF REPURPOSED SPECTRUM AND ENCOURAGE BROADCASTER PARTICIPATION.

A. The Record Affirms the Potential Benefits of Early Action on Several Key Issues.

Verizon and other commenters describe several measures that warrant expeditious Commission action. There is broad agreement that prompt resolution of these issues is both feasible and important to ensure that broadcasters in particular have certainty regarding the reverse auction and the post-auction repacking process, and adequate time to evaluate whether or how to participate.[97] The comments affirm that announcement of a minimum 120 MHz clearing target will send a strong signal to all stakeholders of the Commission's commitment to repurposing spectrum for mobile broadband.[98] They also support broad confidentiality protections for broadcasters' bids in order to encourage broadcaster participation.[99] Commenters also affirm that establishing incentives for early relocation of Channel 51 broadcast operations

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[96] *See* NAB Comments at 50-51.

[97] Verizon Comments at 23.

[98] *See* Verizon Comments at 22-23; Cisco Comments at 4, 9; EOBC Comments at 11-12; High Tech Spectrum Coalition Comments at 6; *see also* Broadcaster for the Promotion of Channel Sharing Arrangements at 1 ("recovering 120 MHz of spectrum in the voluntary auction is aggressive but achievable, even in the nation's largest markets, provided the Commission establishes the right incentives and *opportunities* for stations to participate"); CTIA Comments at 30 (supporting EOBC policy of 120 MHz).

[99] *See* Verizon Comments at 23. 29; APTS Comments at 19-23; Entravision Comments at 7; EOBC Comments at 22; State Broadcaster Ass'ns Comments at 16; Tribune Co. Comments at 6-8; *see also* AT&T Comments at 67.

would help achieve the Commission's repacking and repurposing objectives.[100] The Commission thus should take prompt action on those matters.

There is also broad support for a descending clock reverse auction.[101] Verizon agrees with EOBC that, in order to maximize the amount of spectrum repurposed for mobile broadband use, the Commission needs to ensure that initial bid amounts are set at prices that will encourage widespread broadcaster participation.

Finally, commenters uniformly agree that more complex issues, such as international coordination[102] and the repacking methodology,[103] warrant prompt Commission action because they are necessary for the Commission to resolve fundamental incentive auction components, such as the 600 MHz band plan and auction design.

B. The Spectrum Act Authorizes the Commission to Conduct the International Coordination Process and Implement the Incentive Auction Concurrently.

There is near-universal agreement by all stakeholders that the Commission should act promptly to initiate the necessary negotiations with the governments of Canada and Mexico to coordinate broadcast channel allotments and assignments on the border areas.[104] If the Commission determines that particular coordination measures could significantly increase the potential amount of available spectrum for mobile broadband service, it should pursue those efforts as a matter of good spectrum planning.

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[100] *See* Verizon Comments at 37-38; Alcatel-Lucent Comments at 18; Competitive Carriers Ass'n at 13-14; CTIA Comments at 28-30; MetroPCS Comments at 28-30; *see also* Nokia Siemens Comments at 12; Qualcomm Comments at 20; US Cellular Comments at 59-61.

[101] *See* Verizon Comments at 27-28; CEA Comments at 30; EOBC Comments at 4; Mobile Future Comments at 9-10; Prospective Reverse Auction Participant at 6.

[102] *See, e.g.,* CEA Comments at 33-34; EOBC Comments at 24-25; ABC Television Affiliates Ass'n, CBS Television Network Affiliates Ass'n, FBC Television Affiliates Ass'n, and NBC Television Affiliates ("Network Affiliates") Comments at 11-12; NAB Comments at 10.

[103] Verizon Comments at 21-22; AT&T Comments at 78; NAB Comments at 17-18.

[104] *See supra* note 102.

Several broadcasters, however, incorrectly assert that Congress required the Commission to *complete* international coordination prior to conducting the incentive auction.[105] Congress made clear in the Spectrum Act what measures require "completion" prior to repacking.[106] Congress has consistently recognized the Commission must engage in the international coordination process in implementing any new broadcast allotments and individual assignments in border areas, and that any final reassignments must reflect the outcome of that process. In the DTV transition, for example, the Commission adopted new DTV allotments and a future plan for assignments while anticipating that its plan could require adjustments to conform to the agreements.[107] It adopted channel election and repacking requirements even as international coordination remained incomplete for many stations.[108] And in August 2007, after Congress imposed a February 2009 deadline to complete the digital transition, the Commission adopted a new Table of Allotments that expressly left individual stations subject to the outcome of international coordination processes.[109] International coordination thus cannot reasonably be interpreted to put all other repacking, repurposing and incentive auction preparation on hold.

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[105] *See, e.g.*, CBS Corporation, Fox Entertainment Group, Inc., NBCUniversal Media, LLC, The Walt Disney Company, and Univision Communications Inc. ("Broadcast Networks") Comments at 8 (Commission must "complete coordination with Canada and Mexico … before finalizing rules relating to the repacking mechanism."); Eagle Creek Broadcasting of Laredo, LLC, et al. Comments at 3 (must "resolve international border coordination issues before the auction occurs.); State Broadcaster Ass'ns Comments at 12 ("full and mutually agreeable coordination with Canada and Mexico was intended by Congress as a condition to commencing the auction process"); *see also* Network Affiliates' Comments at 12 ("auction cannot go forward without changes to international treaties ….").

[106] *See* Spectrum Act § 6403(f)(2) ("no reassignments or reallocations under subsection (b)(1)(B) shall become effective *until the completion of"* the reverse and forward auctions (emphasis added)).

[107] *See Advanced Television Systems and Their Impact upon the Existing Television Broadcast Service*, Sixth Report and Order, 12 FCC Rcd 14588, ¶ 171 (1997), *reconsideration,* Memorandum Opinion and Order on Reconsideration of the Sixth Report and Order, 13 FCC Rcd. 7418, ¶¶ 138-140 (1998).

[108] *See Second Periodic Review of the Commission's Rules and Policies Affecting the Conversion To Digital Television*, Report and Order, 19 FCC Rcd 18279, ¶¶ 39, 71 (2004).

[109] *See Advanced Television Systems and Their Impact upon the Existing Television Broadcast Service*, Seventh Report and Order and Eighth Further Notice of Proposed Rulemaking, 22 FCC Rcd 15581, ¶¶ 103-105 (2007).

Nothing in the Spectrum Act shows that the Commission now has *less* flexibility to address international coordination issues in the context of the incentive auction, where technical issues associated with repacking must be resolved in a much shorter time period, than it did during the DTV transition from the 700 MHz band.

The Spectrum Act addresses broadcasters' legitimate concerns collectively through the coverage area and population provisions and the restrictions on repacking to VHF spectrum,[110] while also giving the Commission flexibility and discretion to address those concerns in a manner that maximizes the spectrum to be repurposed for mobile broadband.[111] The international coordination requirements should be viewed in a similar light. The Commission should therefore quickly determine what international coordination measures are appropriate for the auction to proceed consistent with Congress's Spectrum Act objectives, including the steps that can be undertaken in parallel with or after the auction.

C. A Flexible Repacking Formula Will Best Serve Congress's Spectrum Clearing Objectives.

Commenters disagree on the scope of the Commission's discretion under the Spectrum Act's "reasonable efforts" standard for preserving broadcasters' coverage areas and populations served. Verizon agrees with several commenters that Congress gave the Commission considerable flexibility in the repacking process in order to repurpose 600 MHz spectrum for mobile broadband services.[112] In contrast, NAB's and the Network Affiliates' assertions that Congress intended that the term "all reasonable efforts" means that broadcasters are entitled to

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[110] *See* Spectrum Act §§ 6403(b)(2)-(3).

[111] *See id.* § 6403(b)(2) (requiring "reasonable efforts to preserve" broadcasters' existing coverage area and population served); *id.* § 6403(f)(2) requiring reassignments of broadcast stations to new channels and reallocations of spectrum for mobile broadband to become effective simultaneously "to the extent practicable …."; *id.* § 6403(h) (Section 316 protest rights inapplicable).

[112] *See* AT&T Comments at 12, 76-77; CEA Comments at 15-16, 31-32; CTIA Comments at 34-35; Mobile Future Comments at 16-18.

their *exact* population and coverage area except in "extraordinary" or extremely limited circumstances is not supported by the statute.[113] This incorrect interpretation would also effectively nullify the statutory reference to OET Bulletin 69 by compelling the Commission to apply each individual station's application of the Bulletin prior to February 2012 and preclude the Commission from applying the uniform methodology and set of assumptions necessary to conduct the incentive auction. It also would hamstring the Commission's express authority to "make such reassignments of television channels as [it] considers appropriate" to achieve Congress's critical objective of repurposing spectrum for mobile broadband and competitive bidding in the forward auction.

NAB itself applies a more generous interpretation of the term "reasonable" in the repacking reimbursement context, appropriately recognizing that the Commission has discretion to determine eligible reimbursement costs under Section 6304(b)(4) of the Spectrum Act for repacked broadcasters and MVPDs.[114] Under this more sound interpretation of "reasonable," NAB advocates applying the word's "ordinary, natural meaning, in keeping with settled principles of statutory construction" – i.e., "not extreme or excessive," and "moderate, fair."[115] NAB's use of the term here appropriately applies to the repacking standard as well.

Finally, the Commission should ensure that using factors such as a station's operating or enterprise value risks as "scoring" criteria for reverse auction bids does not deter broadcaster

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[113] *See* Broadcast Networks Comments at 6 (increased interference permitted "if and only if all other reasonable efforts to avoid new interference have failed."); NAB Comments at 19; Network Affiliates Comments at 26-37; Sinclair Broadcasting at 10-12.

[114] *See* NAB Comments at 58-59; *see also* Comcast and NBCUniversal Comments at 24-29 (describing wide variety of costs that are appropriately reimbursable under the Spectrum Act); DIRECTV and DISH Comments at 6-10 (same); NCTA Comments at 18-21 (same).

[115] *See* NAB Comments at 58-59, n.87 (quoting *Webster's Ninth New Collegiate Dictionary* at 981 (1984)).

participation in the reverse auction.[116] Given Congress's spectrum repurposing objectives, scoring a bid more highly based on the amount of spectrum cleared is appropriate. If the additional criteria proposed in the *NPRM* risk deterring broadcaster participation – whether by creating uncertainty as to the Commission's potential devaluation of their bids, or unnecessarily complicating the bid acceptance and repacking processes – they could undermine the viability of the reverse auction and jeopardize Congress's Spectrum Act objectives.

D. Simultaneous Reverse and Forward Auctions Are Preferable to Sequential Auctions.

A variety of commenting parties addressing the Commission's proposed incentive auction design broadly support the concept of conducting the reverse and forward auctions simultaneously. While these commenters differ regarding the precise mechanics of the auction and some recommend departures from the approach described in the Auctionomics Paper, they broadly recognize that the simultaneous or multi-staged approach is preferable to the sequential approach described in the *NPRM*, with respect to both encouraging broadcaster participation and facilitating a quicker conclusion to the incentive auction and a more efficient outcome.[117] Verizon agrees.

The record also demonstrates all of the various incentive auction components – the 600 MHz band plan, repacking, and reverse and forward auction design – are interdependent, and that the mechanics and feasibility of any dynamic bidding approach are dependent on the effectiveness and predictability of the Commission's repacking methodology and software. In the meantime, the Commission should continue to engage auction experts and ensure that the repacking methodology is fully disclosed and tested, as broadcasters and mobile broadband

[116] *See* EOBC Comments at 18-20.

[117] *See* Verizon Comments at 24-27; EOBC Comments at 11; CEA Comments at 30-31; T-Mobile Comments at 42-43.

providers uniformly urged in their comments, and recalibrate its approach as necessary as the capabilities and limitations of the repacking methodology become known.

E. Offering Added Bid Options to Broadcasters Has Merit.

Many commenters reflecting a broad cross section of stakeholders share Verizon's view that the Commission should consider the feasibility of providing additional bid alternatives. These include accepting higher interference in order to provide the Commission more flexibility in the repacking process and potentially repurpose more 600 MHz spectrum for mobile broadband, and additional VHF band options.[118] These bidding options could present a win-win alternative for broadcasters and mobile broadband providers alike. The Commission should also consider the feasibility of EOBC's proposal that the Commission permit channel sharing bids that would require changes in a station's community of license by permitting a station to channel share with another in its DMA.[119] This could make it easier for stations to find channel sharing partners and potentially free more spectrum for repurposing.

While EOBC supports giving reverse auction bidders the flexibility to submit different bid options, it does not support expanding the types of available bids due to concern that such an approach would make the reverse auction too complex for broadcasters.[120] This is a fair concern, which underscores the importance of adopting a repacking formula to accommodate such bids.[121] If the Commission determines it cannot incorporate additional bid options without making that formula overly complex for itself and for broadcasters, then it should err on the side of a simpler

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[118] *See* CEA Comments at 13; CTIA Comments at 33; Entravision Comments at 9-10, 13; Harris Corporation Comments at 23-24; Mobile Future Comments at 8; Motorola Mobility Comments at 7; Qualcomm Comments at 24-25; TIA Comments at 13-14; Tribune Co. Comments at 4; US Cellular Comments at 6-8; *see also* APTS Comments at 35 (supporting high VHF bids).

[119] *See* EOBC Comments at 20-22.

[120] *See* EOBC Comments at 17-18; *see also* T-Mobile Comments at 51-52.

[121] *See* TIA Comments at 14.

formula. While T-Mobile similarly states that alternate bids are not amenable to administrable rules, Verizon presented in its initial comments a potential framework in this regard for higher interference bids that is based on straightforward, demonstrable criteria that broadcasters utilized in the DTV transition.[122] In any event, given the potential for higher interference bids to make additional spectrum available for clearing, it is important that the Commission determine the feasibility of alternative bids.

In addition, the Commission should allow bids to relocate to lower VHF, as Verizon recommended. Harris Corporation opposes that approach in order to preserve that band for only LPTV, AM and FM broadcasting.[123] Its restrictive approach, however, would impair the Commission's repacking options, and potentially undermine Congress's objectives of repurposing 600 MHz spectrum for mobile broadband while preserving meaningful opportunities for broadcasters to continue offering service.

V. THE FORWARD AUCTION AND SERVICE RULES SHOULD BE DESIGNED TO ENSURE MAXIMUM PARTICIPATION.

A. Service Providers and Manufacturers Should Retain Flexibility to Design Their Devices.

Historically the Commission has not imposed interoperability requirements when auctioning spectrum for wireless operations, wisely leaving to equipment manufacturers and carriers the development of device standards. Manufacturers and their customers have consistently and successfully worked out interoperability issues through industry-driven standard setting processes that facilitate a robust device ecosystem free of interoperability problems. Some parties in this proceeding point to industry's adoption of two band classes for the Lower 700 MHz band to support requests that Commission impose an "all-600 MHz band"

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[122] *See* T-Mobile Comments at 52; Verizon Comments at 32-35.

[123] Harris Corporation Comments at 23-24, 27-28.

interoperability requirement.[124] But the unique issues in the Lower 700 MHz band have no applicability here, and the Commission should not adopt any such requirement. Instead, it should facilitate interoperability by adopting a well-conceived band plan that minimizes interference issues and obviates the need to consider first-ever device regulation.

The challenges of Lower 700 MHz interoperability arise from that particular band's uniquely fragmented and non-generic nature. Because of impairments to and restrictions on the A block of the Lower 700 MHz band due to nearby high power broadcast operations, a band class was developed that included only the non-impaired blocks in the Lower 700 MHz band. As Verizon has explained, an industry-driven solution to the resulting interoperability problem can emerge once the Commission relocates Channel 51 broadcasters.[125] Those problems can be avoided here by ensuring that the band plan (i) avoids impairing blocks of licensed spectrum (e.g., by not placing broadcasters in duplex gap) and (ii) facilitates cost-effective development of devices that operate across the entire band. As discussed above and in Verizon's initial comments, Verizon's proposed band plan is based precisely on those principles: it minimizes impairments to licensed spectrum, and it facilitates the development of a single device with a single antenna (and, in the case of the lower-clearing scenario, a single duplexer). As discussed in Section I.A above, one of the numerous consumer benefits promoted by such a band plan is that it promotes interoperability.

The Commission's historical reliance on industry standard-setting processes to achieve device interoperability has gone hand in hand with its flexible use policy and has promoted the evolution of a strong, vibrant wireless ecosystem. For example, in the PCS auction, the

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[124] *See, e.g.*, T-Mobile Comments at 21; Leap and Cricket Comments at 7; MetroPCS Comments at 28; U.S. Cellular Comments at 23-30.

[125] *See* Comments of Verizon Wireless, *Promoting Interoperability in the 700 MHz Commercial Spectrum*, WT Docket No. 12-69 (June 1, 2012) at 1.

Commission rejected calls for an interoperability mandate in favor of "allow[ing] PCS to develop in the most rapid, economically feasible and diverse manner."[126] That historical policy, which departed from the command-and-control interoperability regime imposed on analog cellular, was a success. Interoperability has emerged through efficient, industry-driven processes. The Commission has recognized that such processes are preferable to government mandates because they are developed by industry participants through collaborative processes that enable, rather than displace, innovation and investment.[127]

By contrast, interoperability mandates – especially if combined with band plans (such as the Commission's proposal) that create substantial device challenges – can negatively affect investment and also reduce the value of the auctioned spectrum. It is already common for devices to have multiple antennas and duplexers in order to support existing bands, and the antennas required for 600 MHz spectrum will be larger than in higher frequency bands. Device complexity, size, and costs are very real factors in determining the attractiveness of auctioned spectrum, and there are limits to what components can be included in devices without reducing their economic viability.

Of course, some additional device complexity is inevitable for any band plan that takes advantage of a high-clearing scenario in order to repurpose a large amount of paired spectrum. For example, if the Commission repurposes 120 MHz or more on a nationwide basis, even under Verizon's proposal it would be necessary to include an extra duplexer in devices.[128] That high-clearing scenario, of course, would be a good "problem" to have. It is not a "problem" that

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[126] *Amendment of the Commission's Rules to Establish New Personal Communications Services*, Memorandum Opinion and Order, 9 FCC Rcd 4957, ¶ 162 (1994).

[127] *Id.* ¶ 164 (stating that "we do not want to discourage innovation in designing PCS services").

[128] Verizon Comments at 8.

invites *a priori* government intervention because such intervention would impede the efficient development of band classes that ensure interoperability. Notably, even under that high-clearing scenario, Verizon's band plan enables the use of a single tunable antenna to cover the entire band, thereby substantially reducing the potential device challenges that might arise.[129] The Commission should therefore promote interoperability by establishing a sound band plan that avoids the unique challenges of the Lower 700 MHz band, and should allow the industry standard setting process to drive the development of cost-effective interoperable devices.[130]

B. The Auction Should Use a Forward Ascending Clock Process, Generic 5 MHz Blocks, and Anonymous Bidding.

There is strong record support for the Commission's proposed ascending clock forward auction methodology or for another dynamic bidding approach that enables the Commission to complete the auction efficiently. While the approach used for the incentive auction will depend in large part on the effectiveness of the repacking formula, Verizon agrees with various commenting parties that this approach has the most potential to achieve a prompt and efficient forward auction.[131]

There is also broad support among potential forward auction participants for the Commission's proposal to use generic 5 MHz blocks as the bidding unit for the forward auction,

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[129] Verizon noted that under a high clearing scenario, it would be theoretically possible to auction even more paired spectrum than under Verizon's proposal by placing some paired spectrum below Channel 37. *Id.* However, both interference concerns and device issues (including the possible need for an additional antenna or tuner) militate against adopting such a band plan.

[130] T-Mobile also suggests that the Commission could theoretically ensure interoperability by assigning spectrum blocks to winning bidders on a random basis, thus forcing licenses to deploy devices that can operate across the entire band. T-Mobile Comments at 21-23. That ill-conceived proposal would reduce the value of the spectrum to potential bidders and would impose major costs on licensees, who would need to engage in post-auction swaps in order to convert their disjointed licenses into rational portfolios. *See* Section V.F, *infra*.

[131] *See* Verizon Comments at 44; AT&T Comments at 40-41; CEA Comments at 32; *see also* EOBC Comments Decl. of Jeffrey A. Eisenach at 7-8.

and the Commission should adopt that proposal.[132] US Cellular's proposal for non-generic licenses using different service areas would result in an inefficient and complex forward auction and further complicate the repacking formula, and none of its reasons for opposing generic blocks warrants a different approach. US Cellular's recommendation is also premised on the Commission conducting the reverse and forward auctions sequentially, which will make the reverse auction less appealing to broadcasters – thus undermining US Cellular's own stated objective of making "large amounts of spectrum" available to wireless service providers.[133] Given the broad support for generic blocks among a variety of wireless service providers, and the demand for additional spectrum for mobile broadband service (which US Cellular itself acknowledges),[134] the record does not support the conclusion that non-generic blocks are necessary to encourage adequate forward auction participation.

In any event, US Cellular's principal concern relates to the purported impact of generic blocks on "smaller" bidders. As Verizon explains in its initial comments, contrary to US Cellular's assertion, "an additional auction stage" to assign individual licenses would *not* be necessary and, in any event, the use of generic blocks helps ensure that the value of the licenses is reflected in the bidding *for the generic blocks*.[135] Moreover, assuring that winning bidders for multiple generic blocks are assigned licenses for contiguous blocks, with some consistency across EAs, will help ensure that the value of the licenses is realized in the forward auction bid prices (and thus by taxpayers) and not deferred to private parties in the secondary market.[136]

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[132] *See* Verizon Comments at 44; AT&T Comments at 40-41; CEA Comments at 20; CTIA Comments at 15; T-Mobile Comments at 19.

[133] *See* US Cellular Comments at 3, 20.

[134] *See* US Cellular Comments at 2.

[135] *See* US Cellular Comments at 20; Verizon Comments at 45-47.

[136] *See* Verizon Comments at 45-47.

Concerns that such procedures will result in interoperability challenges to the detriment of smaller bidders are misplaced. As discussed above, the interoperability issues of the Lower 700 MHz licenses can be avoided here, and US Cellular's speculation as to license assignment procedures does not provide a basis for the *NPRM*'s well-reasoned proposal for 5 MHz generic blocks.

Verizon supports anonymous bidding in the forward auction. Various commenters, however, assert that bidders' identities should be disclosed to improve the information available to other bidders – namely, who their competitors are and how they valuate the spectrum in question – information that purportedly is critical for smaller entities to meaningfully participate in the auction.[137] In adopting rules for the Lower 700 MHz auction, the Commission considered and rejected those precise arguments, and the Commission should do the same here.[138] Anonymous bidding ensures that bidders are focused on the value of the licenses to their business, not on other bidders and their bidding strategies, and thus ensures a more efficient – and competitive – auction outcome consistent with Congress's Spectrum Act objectives. As the Commission has explained, disclosing bidder interests and identities during the auction risks anti-competitive behavior and bidding strategies. While MetroPCS asserts that such information would enable it to bid more effectively against larger operators, evidence indicates that the opposite effect – avoiding such competition – is the more likely result.[139] Moreover, as with the 700 MHz auction, "[u]ncertainties regarding what market leaders and equipment manufacturers

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[137] Competitive Carriers Association ("CCA") Comments at 18; Leap and Cricket Comments at 8-9; MetroPCS Comments at 11-13.

[138] *See Service Rules for the 698-746, 747-762 and 777-792 MHz Bands*, et al., Second Report and Order, 22 FCC Rcd 15289 ¶¶ 280-84 (2007) ("*700 MHz Second Report and Order*").

[139] *See* MetroPCS Comments at 11-12; Peter Cramton and Jesse A. Schwartz, *Collusive Bidding: Lessons from the FCC Spectrum Auctions*, 17 Journal of Regulatory Economics, 229, 246 (May 2000) (finding that "smaller bidders were reluctant to bid against large bidders in the [broadband PCS] DEF auction" and underscoring the desirability of an anonymous auction).

might do in [the 600 MHz] band after it is licensed will not be substantially mitigated during the auction by information regarding the identities of parties placing bids."[140] The Commission should use anonymous bidding for this reason as well.

C. Economic Areas Are the Proper License Area for this Auction.

There is broad support by large and small carriers alike for the Commission's proposal to issue all licenses on an Economic Area ("EA") basis.[141] T-Mobile correctly states that larger service areas could facilitate a more efficient forward auction than EAs.[142] The Commission's proposed use of EAs, however, is an appropriate middle ground that balances the Commission's statutory and policy interest in ensuring that smaller carriers can meaningfully participate in the forward auction, while ensuring that the auction is manageable for the Commission's planned auction design and for forward auction participants. Moreover, T-Mobile concedes that package bidding can mitigate "geographic exposure risk" associated with EAs, and the Commission should address such risk through that mechanism instead.[143]

The Commission should not issue licenses on a CMA basis, or through a combination of CMAs and EAs, as US Cellular and other commenters propose.[144] As Verizon states in its comments, that approach would require inefficient aggregation during or after the auction.[145] Nor are service areas smaller than EAs necessary to promote buildout in rural areas, as US Cellular argues. Verizon is using 700 MHz spectrum (which the Commission licensed in even

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[140] *See 700 MHz Second Report and Order* ¶ 282.

[141] *See* Verizon Comments at 60-62; AT&T Comments at 54; Cellular South, Inc. Comments at 8; CCA Comments at 14-15; MetroPCS Comments at 18-19.

[142] *See* T-Mobile Comments at 15-17.

[143] *See* T-Mobile Comments at 17.

[144] *See* Leap and Cricket Comments at 4; National Telecommunications Cooperative Association ("NTCA") Comments at 3-5; US Cellular Comments at 10-19; RTG Comments at 2-7.

[145] *See* Verizon Comments at 60-61.

larger REAGs) to deploy LTE coextensively with its EV-DO network to serve literally hundreds of rural markets and, through innovative secondary market transactions such as the LTE in Rural America initiative, is working with many smaller carriers to promote LTE deployment in other rural areas. Reasonably small EA markets, together with construction benchmarks and the robust secondary market, remain the appropriate methods of promoting deployment in rural areas.

Finally, the use of CMAs will not enable the Commission to repurpose more spectrum for mobile broadband than EAs. Indeed, by US Cellular's own analysis of the potential impact of repacking alone (with no exiting broadcasters), the use of CMAs instead of EAs could not clear appreciably more spectrum throughout most of the Northeastern U.S., large swaths of the Midwest, Northern and Southern California, and significant geographic areas on the U.S.-Canada border west of the Great Lakes.[146] US Cellular's comments thus affirm that the Commission's spectrum repurposing objectives will require significant broadcaster participation and robust forward auction bidding – both of which would be undermined by the very licensing scheme and auction design that US Cellular proposes.

Moreover, US Cellular's analysis is based on the faulty premise that should the reverse auction fail to clear the entire band, the Commission will not auction licenses that are constrained by requirements to protect broadcasters remaining in the band. It is highly probable that the wireless use of frequencies co-channel with such a remaining broadcaster would be for downlink operations (transmissions from base stations), but wireless carriers can carefully engineer the coverage from base stations to meet any Commission interference requirements. Thus, US

[146] *See* US Cellular Comments, Att. A at 2-3.

Cellular's untenable position appears to be that, in the name of auction simplicity, spectrum should be kept idle.

D. Package Bidding Will Help Ensure that 600 MHz Licenses Are Assigned to Providers that Value Them Most Highly.

Several commenters agree with Verizon that accommodating a degree of package bidding that enables some regional aggregation of license bids during the forward auction will serve Congress's Spectrum Act objectives.[147] Parties opposing package bidding do not refute the economic efficiencies of such an approach, or that package bidding can help ensure that spectrum will be licensed to parties that value it most highly. Package bidding can also help mitigate the complexities of the assignment phase of the forward auction and, by promoting geographic consistency, can help promote efficient network buildout costs to consumers' benefit. Carriers may achieve substantial economies of scale, passing those costs savings on to consumers, by developing devices that can be deployed on a footprint-wide basis, but any potential holes in the footprint would affect those economies.

Given Congress's Spectrum Act objectives, CCA's opposition to package bidding on the basis that the rules "should allow bidders who value particular blocks of spectrum to have the opportunity to acquire that spectrum" is not valid; it is critical that the 600 MHz spectrum go to entities that value it *most highly*.[148] Leap's assertion that "package bidding may enable a large carrier to obtain valuable licenses at a significant discount from the actual prices at which it values the individual licenses" is inaccurate.[149] As Verizon explains, package bidding enables

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[147] Verizon Comments at 49-50; AT&T Comments at 7-9, 51-58; CEA Comments at 19; EOBC Comments Decl. of Jeffrey A. Eisenach at 8; Mobile Future Comments at 10, 12-14; T-Mobile Comments at 20.

[148] *See* CCA Comments at 18.

[149] *See* Leap and Cricket Comments at 9; *see also* CCA Comments at 18; RTG Comments at 9; US Cellular Comments at 51-57.

bidders to reflect the value of the EA alone *and* as part of a regional aggregation, which ensures that the value of the latter is reflected in the auction bid price paid to the Treasury rather than to another service provider in the secondary market.[150] Finally, US Cellular's assertions that package bidding would violate the Commission's Section 309(j) obligations are meritless;[151] the Commission's rules have long included package bidding as a competitive bidding design component.[152] To the extent the Commission is concerned that combination bids will increase computational complexity in administering the auction, it should be noted that they *reduce* complexity for bidders. Moreover, the Commission can considerably reduce complication by designating a set number of combinatorial bids options, such as REAGs or a national license.

E. Population-Based Performance Requirements and Prompt Timetables for Repacked and Exiting Broadcasters to Cease 600 MHz Operations Will Promote Rapid Service Deployment.

In its comments, Verizon explains how population-based performance requirements with a "keep what you use" component, consistent with those adopted for the AWS-4 and WCS services, appropriately balance the Commission's interest in efficient spectrum use, consumers' interests in prompt deployment of competitive mobile broadband services, and service providers' need for technically feasible and economically reasonable deadlines.[153] The record generally supports this approach, with Cellular South and NTCA in particular advocating a similar policy, and many parties opposing untested approaches like "use it or lease it" or "use it or share it."[154]

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[150] *See* Verizon Comments at 50.

[151] *See* US Cellular Comments at 55-56.

[152] 47 C.F.R. § 1.2103(a)(4); *Auction of Licenses in the 747-762 and 777-792 MHz Bands Scheduled for September 6, 2000, Comment Sought on Modifying the Simultaneous Multiple Round Auction Design to Allow Combinatorial (Package) Bidding*, Public Notice, 15 FCC Rcd 8809 (WTB 2000).

[153] *See* Verizon Comments at 64-68.

[154] *See* Cellular South, Inc. Comments at 5, 9-10; *see also* CCA Comments at 17; CTIA Comments at 38-41; NTCA Comments at 5-6.

CCA's proposal for a geographic area approach in certain rural areas, however, is unnecessary, particularly if the Commission uses the existing "keep what you use" approach that provides a substantial incentive to deploy service throughout an EA. Further, while some commenters assert that uniform construction requirements adversely affect smaller and rural service providers, they also agree that, if construction requirements are imposed, population-based requirements are appropriate, and they do not advocate more stringent performance requirements for larger entities.[155]

The record also affirms that construction deadlines must account for the need for repacked and exiting broadcasters to cease operations in the 600 MHz band.[156] Timely and predictable access to the repurposed 600 MHz spectrum is critical to ensure mobile broadband providers' interest in and demand for that spectrum.[157] Many broadcasters, however, support a lengthy construction period for repacked stations[158] – longer than three years in some cases.[159] Requiring winning forward auction participants to pay billions of dollars in winning bid amounts immediately after the auction concludes, while holding their license grants in abeyance or prohibiting them from deploying and launching service for years afterward, is not only inequitable but risks regulatory uncertainty to such a degree as to suppress forward auction bids. For similar reasons, the Commission should thus reject NAB's assertion that the agency cannot

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[155] *See* US Cellular Comments at 42-44 (asserting that uniform construction requirements disproportionately affect smaller and rural carriers); MetroPCS Comments at 22-24 (same but conceding population-based requirements); CCA Comments at 17 (population-based requirements).

[156] *See* Verizon Comments at 67-68; CTIA Comments at 39.

[157] *See* Verizon Comments at 67-68; AT&T Comments at 78-79; CEA Comments at 34; CTIA Comments at 34, 39-40; Leap and Cricket Comments at 10; Mobile Future Comments at 20; Sprint Comments at 12-13; TIA Comments at 17-18; US Cellular Comments at 57-59.

[158] *See* NAB Comments at 49-50, 53-54 (30 months); State Broadcaster Associations at 15 (at least 30 months).

[159] APTS Comments at 24-27; LIN Media Comments at 7; Post-Newsweek Stations Comments at 5-6.

issue 600 MHz licenses to forward auction bidders until repacked broadcasters file their construction permit applications.[160] Such an approach could further delay winning bidders' ability to commence deployment while subjecting them to the vagaries of the repacking and international coordination processes, and nothing prohibits the Commission from issuing licenses on a co-primary basis with broadcasters, akin to the Commission's approach toward broadband PCS licensees and incumbent private operational fixed licensees.

Verizon opposes Google/Microsoft's proposals to permit white space unlicensed use in the repurposed 600 MHz band until such time as service providers initiate service, and on a similar interim basis in areas where service providers do not meet their performance requirements. That would contravene Congress's mandate that the repurposed spectrum, other than guard bands, be assigned for licensed rather than unlicensed use.[161] Moreover, it would further complicate the prior coordination and notification processes necessary for mobile broadband providers to initiate service via their 600 MHz licenses and potentially require that detailed information about mobile broadband providers' coverage area, signal strength, and service launch plans be incorporated into a system similar to a white spaces database. Google/Microsoft's proposal also risks creating interference disputes between mobile operators and unlicensed users and database operators. The Commission's spectrum management efforts should focus on relocating existing users, including unlicensed white spaces users, *out* of the repurposed 600 MHz band – not on developing a new regulatory regime to enable those uses to remain in or reenter the band.

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[160] *See* NAB Comments at 51.

[161] *See supra* discussion at Section II.B.

F. The Commission Should Adopt Verizon's Proposal for an Administrative Rather than Competitive Bidding Assignment Phase.

Verizon and other commenters have underscored the importance of the license assignment phase to an efficient and effective forward auction.[162] No parties dispute the merits of contiguous and consistent blocks across EAs, which an assignment phase should facilitate.[163] Verizon agrees with AT&T and T-Mobile that the full value of the 5 MHz spectrum blocks should be reflected in the generic bids to the extent possible. Unlike AT&T, which would have the Commission use a competitive bidding process to achieve these objectives, Verizon submits the Commission should first determine the feasibility of administrative processes during the assignment stage, and rely on package bidding for the generic blocks and the liberal exchange of licenses after the auction[164] to achieve that objective.[165] Verizon's proposed default assignment rules could help ensure that the value of the licenses is reflected in the generic bids and that the assignment stage concludes expeditiously. T-Mobile's proposal that the Commission use an administrative process of random assignment to achieve that objective, however, could discourage or distort bidding and shift a segment of bid prices from the generic bids to the post-auction secondary market and thus would be contrary to Congress' Spectrum Act objectives.

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[162] *See* Verizon Comments at 45.

[163] *See NPRM* ¶ 64 ("[T]he assignment procedures would assign contiguous blocks to bidders that bid for multiple blocks in the same geographic area and could take into account the need to coordinate frequencies across adjacent areas."); *see also* Research In Motion Comments at 7 (auction design should promote contiguous spectrum blocks for winning bidders).

[164] *See* Verizon Comments at 27; *see also* Nokia Siemens Comments at 14 (winning bidders might want to exchange licenses to mitigate technical and interference issues that may arise).

[165] *See id.*; AT&T Comments at 58-63.

G. The 700 MHz Technical and Service Rules Are Appropriate for the 600 MHz Band.

Verizon and other commenters, including, notably, equipment vendors, overwhelmingly support use of the 700 MHz technical and service rules as a model for 600 MHz facilities and services.[166] Commenters also support a flexible use regulatory approach for 600 MHz licensees.[167] The Commission should thus reject various other service or technical rule proposals that unnecessarily delay or restrict 600 MHz licensees' flexible use operations. Specifically, no special coordination or notice procedures are warranted for secondary BAS licensees to cease 600 MHz operations beyond the 30-day notice period proposed in the *NPRM*.[168] This proposal would unnecessarily delay the deployment of licensed mobile broadband services. In addition, the Commission should not tailor its OOBE limits for 600 MHz licensees to protect wireless

[166] *See* Alcatel-Lucent Comments at 28-29; CEA Comments at 26; *see also* CTIA Comments at 30; Harris Corporation at 27; Qualcomm Comments at 24; TIA Comments at 18.

[167] *See* Verizon Comments at 58-60; CEA Comments at 16, 21; CTIA Comments at 30.

[168] *See* Network Affiliates' Comments at 41-42 (proposing 90 days instead of 30 days notice prior to commencing operations).

microphones in adjacent bands.[169] This proposal would afford secondary users rights at the expense of new 600 MHz licenses in a manner contrary to Congress's objectives for the repurposed band.

Respectfully submitted,

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Attorneys for Verizon and Verizon Wireless

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Of Counsel

March 12, 2013

[169] *See* Shure Comments at 38.

ATTACHMENT 8

Letter from Leora Hochstein (Verizon) to
Marlene H. Dortch (FCC)
March 26, 2013

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March 26, 2013

Ex Parte

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Secretary
Federal Communications Commission
445 12th Street, SW
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Re: Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, GN Docket No. 12-268

Dear Ms. Dortch:

On March 22, 2013, Kathleen Grillo, Charla Rath, Christopher Oatway and I met with David Goldman, Senior Legal Advisor, and Alex Hoehn-Saric, Policy Director for Commissioner Rosenworcel, to discuss band plan and auction design issues in the incentive auction proceeding.

Consistent with our comments, we expressed support for the Commission's alternative "down from Channel 51" band plan proposal, which separates wireless operations from broadcast services. This approach has a number of advantages over the Commission's lead proposal, which intersperses broadcast and wireless operations. The "down from Channel 51" band plan avoids harmful interference between the two services and, by placing mobile uplink and downlink operations in relative proximity to one another, allows for the development of cost-effective handsets that would not have to span a wide bandwidth. In addition, this plan maximizes the amount of paired generic spectrum available for auction on a nationwide basis.

On auction design, we urged that the Commission not adopt bidding eligibility or spectrum aggregation limits, which would restrict the ability of parties to participate fully in the forward auction, artificially depress auction revenues, and protect some bidders from competition. We also stated our preference for a simultaneous auction. Running the reverse and forward auctions simultaneously would likely encourage broadcaster participation as broadcasters would not have to reveal prices they would accept under hypothetical band plans, and it should facilitate a quicker conclusion to the auction. On bidding, we explained that allowing package bidding would enable bidders to reflect the value of a license as part of a regional aggregation, which ensures that the license's value is included in the auction bid price and thus would help to maximize auction revenues. Finally, we discussed the importance of assigning contiguous blocks of spectrum to winning bidders.

Sincerely,

ATTACHMENT 9

Letter from Leora Hochstein (Verizon) to
Marlene H. Dortch (FCC)
May 6, 2013

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May 6, 2013

Ex Parte

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Re: Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, GN Docket No. 12-268

Dear Ms. Dortch:

On May 2, 2013, Charla Rath, Christopher Oatway and I met with Commissioner Ajit Pai, his Chief of Staff, Matthew Berry, legal advisors Nicholas Degani and Courtney Reinhard and intern Benjamin Tarbell. We discussed band plan and auction design issues in the incentive auction proceeding.

We urged the Commission to maximize the amount of spectrum available for auction and expressed support for the Commission's alternative "down from Channel 51" band plan proposal, which separates wireless operations from broadcast services. In addition, we supported a band plan that could allow for varying the amounts of spectrum in different parts of the country, but also discussed the challenges presented by that approach given the potential for co-channel interference between broadcasters and wireless providers operating on the same channel in adjacent markets. We stated that we would examine this issue more closely once we have more information about expected clearing scenarios. We reiterated our support for unlicensed operations in the guard bands (including duplex gap) provided such services do not cause harmful interference to licensed services.

On auction design, we urged that the Commission not adopt bidding eligibility or spectrum aggregation limits, which would restrict the ability of parties to participate fully in the forward auction, artificially depress auction revenues, and protect some bidders from competition. In addition, we expressed support for licensing spectrum on an economic area basis and stated our preference for a simultaneous auction. Furthermore, we explained that allowing package bidding would enable bidders to reflect the value of a license as part of a regional aggregation, which ensures that the license's value is included in the auction bid price and thus would help to maximize auction revenues.

Finally, because understanding the results of broadcaster repacking is critical to a number of issues, including to determining the optimal approach to the band plan, Verizon encouraged the Commission to promptly establish the methodology and process it will use.

Sincerely,

Leora Hochstein

ATTACHMENT 10

Letter from Leora Hochstein (Verizon) to
Marlene H. Dortch (FCC)
August 29, 2013

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August 29, 2013

Ex Parte

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Re: Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, GN Docket No. 12-268

Dear Ms. Dortch:

On August 27, 2013, Charla Rath, Leora Hochstein, Christopher Oatway, Robert Morse, and Dan Vincent, Professor of Economics, University of Maryland, on behalf of Verizon, met with Gary Epstein and Edward Smith of the Incentive Auction Task Force; Brett Tarnutzer, Martha Stancill, Kate Matraves, Margy Wiener and Sasha Javid of the Wirelesss Telecommunications Bureau; Evan Kwerel and Steve Wildman of the Office of Strategic Planning and Policy Analysis; and Paul Milgrom, Ilya Segal and Jon Levin of Auctionomics. We emphasized that the Incentive Auction will only be successful if there is robust participation by both broadcasters and wireless operators. As the Commission has repeatedly stated, the goal of encouraging robust participation requires keeping the auction design as simple and straightforward as possible. We explained that T-Mobile's recent "Dynamic Market Rule" (DMR) proposal, combined with the bidding restrictions that T-Mobile and others urge the Commission to impose on Verizon and AT&T, would add substantial unnecessary complexity to what is already a very complicated two-sided auction. The result would be suppressed revenue compared to an unrestricted auction and a heightened risk of auction failure.

First, we noted that proposals to restrict Verizon's and AT&T's ability to participate in the Incentive Auction lack a factual foundation. For example, firms advocating bidding restrictions for Verizon and AT&T provide no evidence that they would be unable to acquire 600 MHz spectrum in the auction in the absence of such restrictions. Nor do they assert that they have been unable to acquire the spectrum they need in other auctions or in the secondary market. Furthermore, these firms do not demonstrate that they face spectrum constraints that would prevent them from competing effectively absent rules giving them special preferences in the Incentive Auction.

Second, we discussed the evidence supporting the common sense conclusion that prohibiting parties with an interest in acquiring licenses from participating fully in the Incentive Auction would artificially constrain demand. This, in turn, would prevent prices from rising to the levels they would under real demand conditions in an open bidding process. One of Congress's goals for the Incentive Auction is to raise money for public safety (FirstNet), but economic analyses prove that restricting Verizon and AT&T would risk substantially suppressing revenue.[1]

Proponents of bidding restrictions speculate that restrictions will instead promote the participation of smaller firms that might otherwise be discouraged by the unrestricted presence of larger firms. However, they supply no empirical evidence to support this claim. On the contrary, this conjecture is contradicted by the empirical evidence from spectrum auctions in the United States, which makes clear that smaller firms are not "discouraged" by the presence of larger firms. For example, in Auction No. 66 (the AWS auction), it was known that Verizon, AT&T and T-Mobile would participate without restrictions, yet a total of 168 qualified bidders registered for the auction and a total of 104 bidders won licenses during the auction.[2] This result is inconsistent with the assertion that "smaller" firms would be deterred from participating in the Incentive Auction if the Commission does not adopt bidding restrictions.

Third, we explained that far from mitigating the harmful effects of bidding restrictions, the Dynamic Market Rule proposal would overcomplicate an already complex auction and would heighten the risk of auction failure. The DMR proposal would restrict the number of 600 MHz licenses that Verizon and AT&T could each acquire in any particular market to one, or in some cases, two licenses. Under the proposal, the restrictions would gradually be relaxed on a round-by-round and market-by-market basis if a "revenue target" is not met during the auction.[3] Professor Vincent endorsed the critique of the DMR proposal written by economists Yeon-Koo Che and Philip Haile,[4] which captures the serious flaws inherent in the proposal, including increased bidder risk, lower auction revenues and significant strategic complexity. Professor Vincent explained that the DMR concept could not be modified to avoid these shortcomings and that introducing them to an already complex, multi-layered two-sided trading mechanism would greatly reduce the likelihood of a successful auction.

---

[1] *See, e.g.*, Michael L. Katz, Philip A. Haile, Mark A. Israel, and Andres V. Lerner, *Spectrum Aggregation Policy, Spectrum-Holdings-Based Bidding Credits, and Unlicensed Spectrum*, Mar. 12, 2013, p. 20; Robert J. Shapiro, Douglas Holtz-Eikin, and Coleman Bazelon, *The Economic Implications of Restricting Spectrum Purchases in the Incentive Auction*, Apr. 30, 2013, p. 13.

[2] *See* http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=66.

[3] Gregory Rosston and Andrzej Skrzypacz, *A Dynamic Market Rule for the Broadcast Incentive Auction: Ensuring Spectrum Limits Do Not Reduce Spectrum Clearance,* July 2013 (filed with *ex parte* letter dated July 31, 2013 from Trey Hanbury, counsel to T-Mobile US, Inc., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268).

[4] Yeon-Koo Che and Philip A. Haile, *Comments on T-Mobile's "Dynamic Market Rule" Proposal*, Aug. 13, 2013 (filed with e*x parte* letter dated Aug. 13, 2013 from David L. Lawson, counsel for AT&T, to Marlene H. Dortch, Secretary, FCC, in GN Docket No. 12-268).

Reduced Revenue Relative to an Unrestricted Auction. Professor Vincent also made clear that one fundamental problem with the proposal is that it would risk leaving billions of dollars on the table because it would result in lower revenues than an unrestricted auction. Whatever revenue target is set effectively becomes a revenue ceiling because unrestricted bidders would have an incentive to bid strategically to provide *just enough* revenue for the auction to close – but no more – in order to ensure that the restrictions on Verizon and AT&T are not relaxed. That way, the unrestricted bidders can avoid competing with Verizon or AT&T for the spectrum and thus acquire their spectrum at discount prices.

Strategic Bidding and Exposure Risks. Professor Vincent noted that one of the benefits of the simultaneous multiple round ("SMR") auction format that the Commission is contemplating is that bidders have the ability to alter their bidding strategies in real time in response to price information acquired in the course of the auction. The DMR proposal would short-circuit that important feature and would force bidders to express a demand that is insincere, expose bidders to an increased likelihood of a failed aggregation or, possibly more likely, induce bidders not to participate at all in order to avoid the risk of overpaying for an inefficiently small license or an incomplete portion of a desired footprint.

For example, to address one of the many strategic bidding issues created by their proposal (the concern that restricted bidders may withhold bids during early rounds to ensure that restrictions are lifted), T-Mobile's economists propose the following rule: restrictions would be lifted only on a market-by-market basis and only for restricted bidders who are actively bidding in particular markets. But that "fix" illustrates that adding additional complex rules to an already complex contingent reauction mechanism will *not* result in an auction that can be expected to function well. One exposure risk problem created by the proposed market-specific activity rule is that bidders would be unable to move demand across geographic markets, eliminating one of the important efficiencies enabled by the SMR framework. Another is that restricted bidders may be required to bid for an unrestricted license they do not want on its own in order to combine it with the additional restricted license that may or may not become available in subsequent rounds. The potential revenue-suppressing effect of that exposure risk is substantial. If a constrained bidder decides to avoid the risk of obtaining an inefficiently small license by not bidding in early rounds, the demand from that bidder will be lost for the remainder of the auction (and any subsequent relaxation of licenses or reduction of clearing targets would be less effective since this constrained bidder will be absent).

***

The Commission should reject calls to prevent Verizon and AT&T from participating on equal footing with competitors. Not only are bidding restrictions unnecessary and contrary to the Commission's sound policy of assigning spectrum to its highest and best use, but they would suppress revenue and risk auction failure. Far from mitigating the revenue-suppressing effects of bidding restrictions, the DMR proposal would exacerbate them.

Sincerely,

ATTACHMENT 11

Letter from Tamara Preiss (Verizon) to
Marlene H. Dortch (FCC)
September 18, 2013

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September 18, 2013

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Ex Parte

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Gary Epstein, Chief, Incentive Auctions Task Force
William Lake, Chief, Media Bureau
Federal Communications Commission
445 12th Street, SW
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Re: <u>Expanding the Economic and Innovation Opportunities of Spectrum through Incentive Auctions, GN Docket No. 12-268</u>

Verizon submits the attached study by Dr. Leslie Marx, former FCC Chief Economist and expert in auction economics. Dr. Marx demonstrates the lack of empirical evidence to support claims that some carriers are at risk of foreclosure from access to spectrum unless the Commission restricts Verizon's and AT&T's participation in the upcoming Incentive Auction. She further explains that, in any event, Verizon and AT&T lack the incentive and ability to implement a foreclosure strategy. Dr. Marx's analysis also dispels any claims that the FCC could impose significant bidding restrictions without materially reducing auction revenues and risking outright auction failure. To the contrary, her study of previous auctions suggests that restrictions could reduce revenues by as much as 45 percent.

The study, "Economic Analysis of Proposals that Would Restrict Participation in the Incentive Auction," establishes that:

<u>The Economic Evidence Does Not Support a Risk of Foreclosure.</u>

- Claims by some wireless carriers that they are at risk of being foreclosed from access to low-frequency spectrum are inconsistent with those firms' own behavior. These carriers have repeatedly passed on opportunities to acquire that spectrum at auction and on the secondary market.
- An economic analysis of Sprint's and T-Mobile's pricing plans adds to the extensive evidence already in the record showing that <u>neither</u> of those carriers faces a capacity constraint that could render it susceptible to being foreclosed from access to spectrum needed to compete effectively.
- Any attempt by Verizon or AT&T to foreclose rivals would be costly and difficult to implement. For example:

- In a two-sided Incentive Auction, higher bids on the part of buyers result in a greater quantity of spectrum being offered by sellers, thus increasing the costs of foreclosure.
- In a blind (anonymous) bidding auction, it would be very difficult for AT&T and Verizon to know whether they are bidding against foreclosure targets or one another. Indeed, in the 2008 700 MHz auction, head-to-head competition between AT&T and Verizon contributed more than $4.2 billion in auction revenues, undermining any suggestion that the carriers pursued a foreclosure strategy.
- Verizon and AT&T would each have an incentive to "free ride" on the other's willingness to pay supra-competitive prices for spectrum to foreclose other carriers, reducing any theoretical gains from foreclosure.

<u>Bidding Restrictions Would Depress Revenues and Risk Auction Failure.</u>

- Simulations of past auctions using actual bids show that, without Verizon and AT&T, revenue in the 2008 700 MHz auction would have been 45 percent lower and revenue in the 2006 AWS auction would have been 16 percent lower.

  - These findings are consistent with data from a range of auction settings, including Department of Interior auctions for off-shore oil leases and Forest Service timber auctions, showing that more bidders lead to higher winning bids.

- Analysis of restrictions short of outright exclusion, such as caps on aggregation of spectrum below 1 GHz, demonstrates that any measure that materially reduces the demand that AT&T and Verizon bring to the Incentive Auction risks a substantial reduction in auction revenue.

- Simulation of a two-sided auction shows that the risks created by imposing bidding restrictions are greater than in a traditional auction. Indeed, the model shows that bidding restrictions in a two-sided auction reduce both the maximum possible revenue and the maximum possible quantity of repurposed spectrum that can be achieved, thus jeopardizing both goals of the incentive auction legislation.

- Some parties hypothesize that bidding restrictions could increase revenue by encouraging small firms to participate in the auction, but that conjecture lacks any factual basis and is undermined by the historical fact that smaller firms routinely compete successfully at auction despite the unrestricted presence of larger bidders.

- T-Mobile's proposal to ease bidding restrictions if the auction does not achieve a revenue target not only fails to avoid the revenue-suppressing effects of those restrictions, but would actually exacerbate them. In fact, the added complexity and incentives for strategic bidding associated with that proposal would heighten the risk of outright auction failure.

The record in this proceeding is filled with speculative claims that the FCC can impose restrictions on AT&T and Verizon without reducing auction revenues. In contrast, the conclusions presented in the attached study are based on empirical evidence and state-of-the-art economic analysis. Not only does the study make clear that arguments for bidding restrictions fail to address any real world problems (other than their proponents' desire to acquire spectrum at a discount), it lays to rest the counter-intuitive notion that the Commission could restrict participation by the two largest wireless carriers without adversely and materially affecting auction revenues. Instead, the study confirms the common-sense expectation that limiting participation by carriers that place a high value on spectrum will reduce auction revenues and increase the risk that the auction will fail altogether. Rather than compromising the revenue and spectrum re-allocation goals central to the Incentive Auction, the Commission should adopt policies that encourage the broadest possible participation by broadcasters and wireless carriers alike.

This letter is being filed pursuant to Section 1.1206 of the Commission's Rules. Should you have any questions, please contact the undersigned.

Sincerely,

Attachment

ECONOMIC ANALYSIS OF PROPOSALS THAT WOULD RESTRICT PARTICIPATION IN THE INCENTIVE AUCTION

BY
LESLIE M. MARX, PHD
Robert A. Bandeen Professor of Economics, Duke University
and former Chief Economist, Federal Communications Commission

September 18, 2013

Table of Contents

I. Executive summary 1
I.A. Empirical evidence and economic theory contradict assertions that there is a risk of foreclosure if all bidders are permitted to participate fully in the Incentive Auction 2
I.B. The economics literature confirms that bidding restrictions are expected to reduce auction revenue 3
I.C. Bidding restrictions in past FCC auctions would have substantially reduced revenue 4
I.D. Bidding restrictions in the Incentive Auction would risk auction failure 4

II. Introduction and scope of submission 5
II.A. Relevant qualifications 5
II.B. Background and scope of analysis 6

III. There is no evidence that Sprint and T-Mobile have been foreclosed from access to low-frequency spectrum 8
III.A. Sprint and T-Mobile were not foreclosed from acquiring spectrum in the 700 MHz and AWS spectrum auctions 8
III.A.1. 700 MHz Auction 8
III.A.2. AWS spectrum auction 9
III.B. Evidence from secondary market transactions shows that Sprint and T-Mobile have not been foreclosed 10
III.B.1. Sprint and T-Mobile buy and sell spectrum in the secondary market 11
III.B.2. Neither T-Mobile nor Sprint has chosen to acquire low-frequency spectrum in the secondary market despite significant opportunities to do so 12
III.B.3. Sprint and T-Mobile have failed to act on opportunities to purchase low-frequency spectrum in rural areas 14
III.C. Evidence from pricing plans suggests a pattern of capacity constraints that makes foreclosure unlikely 15

IV. Verizon and AT&T are unlikely to have the incentive or ability to foreclose Sprint and T-Mobile in the Incentive Auction 18
IV.A. As a policy tool to prevent foreclosure, build-out requirements have significant advantages over bidding restrictions 19
IV.B. Incentives to free ride imply that there is unlikely to be a unilateral incentive for significant foreclosure by either Verizon or AT&T 20
IV.C. Anonymous auction design makes foreclosure less likely 21
IV.D. Uncertainty about the level and elasticity of supply in an incentive auction makes a foreclosure strategy difficult to implement 21
IV.E. The market for wireless services is unlikely sufficiently concentrated to make foreclosure profitable 22

V. Effects of bidding restrictions in the economics literature 23
V.A. Papers on auction design suggest that bidding restrictions are likely to reduce revenue and efficiency 23
V.B. Assertions that bidding restrictions might not suppress revenue are based on unrealistic hypothetical scenarios 24
V.C. Empirical evidence from timber auctions further undermines the revenue theory advanced by Sprint and T-Mobile 26

VI. Simulating the effects of bidding restrictions in past spectrum auctions suggests large negative effects on revenue 27
VI.A. Procedure 30

VI.B. Results—Auction 66 - AWS spectrum auction 33
VI.C. Results—Auction 73 - 700 MHz auction 34

VII. Bidding restrictions in a simulated incentive auction 36
VII.A. Procedure 37
VII.B. Results 38
VII.B.1. Exclusion of bidders in a two-sided mechanism worsens the choices available to an auctioneer 40
VII.B.2. Exclusion of bidders in a two-sided mechanism can cause revenue and transaction goals to be unattainable 42
VII.C. Proposals for a contingent auction would distort the auction process and potentially contribute to auction failure 44

VIII. Conclusion 45

Appendix A. Curriculum vitae of Leslie M. Marx, PhD A-1

Appendix B. Secondary market transactions, all bands B-1

Appendix C. Band plans for spectrum auctioned in the AWS and 700 MHz auctions C-1

Appendix D. Results assuming CMA-only licenses D-1

Appendix E. Modeling details for the simulated incentive auction E-1

Table of Figures

Figure 1 Number of B-block licenses won by top bidders in rural and non-rural CMAs in 700 MHz Auction 9

Figure 2 Number of A-block licenses won by top bidders in rural and non-rural CMAs in AWS spectrum auction 10

Figure 3 Secondary market transactions by band, January 2007–May 2013 11

Figure 4 MHz*POPs traded, all bands, January 2007–May 2013 (whole licenses only).....12

Figure 5 Number of transactions of low-frequency whole licenses, January 2007–May 2013 13

Figure 6 MHz*POPs of low-frequency spectrum transacted from January 2007 to May 2013 (whole licenses only) 13

Figure 7 Number of transactions of low-frequency rural licenses traded, January 2007–May 2013 (whole licenses only) 15

Figure 8 Rural MHz*POPs of low-frequency spectrum transacted January 2007–May 2013 (whole licenses only) 15

Figure 9 Comparison of individual 2013 (Jan-Jun) post-paid plans including unlimited anytime minutes and unlimited text messaging—monthly charge ($) and corresponding included data usage (GigaBytes).....17

Figure 10 The effect of spectrum aggregation caps on Verizon's and AT&T's ability to bid in the Incentive Auction.....29

Figure 11 AWS spectrum auction simulation example (license AW-REA001-F).....31

Figure 12 700 MHz auction simulation example (license WY-CMA167-B) 32

Figure 13 Summary of simulated revenue reductions in the AWS spectrum auction.....34

Figure 14 Summary of simulated revenue reductions in the 700 MHz auction 35

Figure 15 Expected number of trades and auction revenues in a simple two-sided auction.....40

Figure 16 Impact of exclusion in a simple two-sided auction (max trades under no exclusion=100; max auctioneer revenue under no exclusion=100) 41

Figure 17 Exclusion may cause the illustrative two-sided auction to fail 43

Figure 18 Number of transactions, all bands, January 2007–May 2013 (whole and partial licenses) B-1

Figure 19 Auction 66 (AWS-1) band plan, reserve price, and minimum opening bids C-1

Figure 20 Auction 73 (700 MHz) band plan, reserve prices, and winning bids..... C-1

Figure 21 Simulated auction revenue change with artificial CMA-only AWS spectrum auction licenses in different scenarios of Verizon and AT&T exclusion..... D-2

Figure 22 Simulated percent change in the MHz*POP with CMA-only AWS spectrum auction licenses in different scenarios of Verizon and AT&T exclusion..... D-2

I. Executive summary

(1) This report analyzes proposals to restrict Verizon's and AT&T's participation in the Federal Communication Commission's (FCC's) upcoming Incentive Auction. My key conclusions are:

Foreclosure

- Proposals to restrict the participation of Verizon and AT&T in the Incentive Auction do not address any real world problem. The assertion that some smaller wireless operators are at risk of being foreclosed from the spectrum necessary for them to compete is inconsistent with those firms' own behavior, including their repeated decisions to forego opportunities to acquire low-frequency spectrum. Other evidence, including Sprint's and T-Mobile's marketing of unlimited usage plans, further belies the assertion that those operators face capacity constraints that could be exploited though a foreclosure strategy.
- Even if (despite the evidence to the contrary) a strategy by Verizon and AT&T to attempt to foreclose rivals were rational, implementing it would be difficult. A foreclosure strategy is particularly difficult to implement in the context of the Incentive Auction because higher bids on the part of buyers result in a greater quantity of spectrum being made available from sellers, thus increasing the costs of foreclosure. In addition, in an auction with anonymous bidding, it would be difficult for AT&T and Verizon to know whether they are bidding against the foreclosure targets or against one another. Furthermore, even if a foreclosure strategy were feasible, Verizon and AT&T would each have an incentive to "free ride" on the other's willingness to pay supra-competitive prices for spectrum.

Bidding Restrictions

- Based on the economics literature, empirical data from past FCC auctions, and a model of a two-sided auction mechanism, I conclude that restricting Verizon and AT&T in the Incentive Auction would put at risk its twin priorities of raising significant revenue and reallocating a substantial amount of spectrum from broadcast to mobile wireless services.
  - My simulations of past auctions show that, without Verizon and AT&T, revenue in the 700 MHz auction would have been 45% lower and revenue in the AWS-1 auction would have been 16% lower.
  - I also analyze bidding restrictions that would not fully exclude Verizon or AT&T, such as spectrum aggregation caps. The evidence indicates that any restriction that causes a material reduction in the participation of Verizon and AT&T risks a significant reduction in auction revenue and a failure of the auction.
- Parties supporting auction restrictions speculate that they might actually increase revenue by ensuring that smaller firms are not discouraged from participating. But they support that conjecture only with hypothetical examples. Their theories are undermined by the empirical evidence, including the historical fact that smaller firms routinely compete successfully in auctions despite the unrestricted presence of larger bidders. Although Sprint's and T-Mobile's economists speculate that restricting larger bidders might encourage small bidders to participate more robustly, they do not assert that their own clients would choose not to participate because of the unrestricted presence of Verizon and AT&T.

- I also analyze T-Mobile's complex proposal to successively ease the proposed restrictions, after each round and on a market-by-market basis, if the restrictions cause the auction to fall short of an unspecified revenue target. That proposal would not avoid the revenue-suppressing effects of the auction restrictions. In addition, the added complexity and incentives created for strategic bidding threaten to distort auction outcomes.

(2) Both the risks and costs of auction failure are further heightened by the overall complexity of the Incentive Auction and the significant difficulties associated with reallocating spectrum from broadcast to mobile wireless at a later date, if it is not reallocated as part of the Incentive Auction. Therefore, in the absence of evidence that anticompetitive foreclosure is likely (which has not been presented by any party), the FCC should avoid imposing restrictions on participation in the Incentive Auction. And if the FCC nevertheless believes that evidence of a foreclosure risk does exist, it can be addressed through other policies, such as build-out requirements, that do not present the same risk of auction failure.

I.A. Empirical evidence and economic theory contradict assertions that there is a risk of foreclosure if all bidders are permitted to participate fully in the Incentive Auction

(3) There is no basis for assertions that Sprint or T-Mobile has been foreclosed from acquiring low-frequency spectrum. The evidence points instead to a *choice* by Sprint and T-Mobile not to compete for low-frequency spectrum, rather than foreclosure from access to it. These carriers have not purchased it in the secondary market, where there were 2,153 licenses available since 2007: Sprint bought none and T-Mobile bought only one. And they did not purchase it in the FCC's recent auction of low-frequency spectrum, the 700 MHz auction in 2008, despite the claimed need for the low-frequency spectrum on offer there. It is particularly notable that Sprint and T-Mobile, despite the claimed need for low-frequency spectrum in order to build out rural areas, have acquired *no* such spectrum in rural markets despite numerous opportunities to do so.

(4) Evidence on pricing plans is inconsistent with a finding that Verizon and AT&T have an incentive to "warehouse" spectrum in order to keep T-Mobile and Sprint capacity-constrained. Sprint and T-Mobile both tend to offer plans with unlimited data usage, and T-Mobile explicitly touts its network as being less congested than that of its competitors. By contrast, Verizon and AT&T tend to offer plans that require incremental payments for data use beyond a specified level. That pattern is the opposite of what would be expected under theoretical conditions where the smaller national competitors' access to a key input is constrained.

(5) Head-to-head competition between AT&T and Verizon where no other bidders were present accounted for more than $4.2 billion in revenue during the 700 MHz auction. Those dollars would

not have been spent by Verizon and AT&T if the purpose of their bidding had been simply to keep spectrum out of the hands of other operators.

(6) Concerns that Verizon and AT&T might pursue a foreclosure strategy against Sprint and T-Mobile also ignore a number of key features of the market and the Incentive Auction. First, the FCC can directly address the issue using tools that would not create a risk of auction failure, such as imposing build-out requirements on licenses won in the Incentive Auction. Second, free-rider issues make foreclosure less likely because Verizon and AT&T would each prefer that the other incur the costs of such a strategy. Third, anonymous auction design makes a foreclosures strategy difficult and costly to implement. Fourth, a foreclosure strategy is particularly difficult to implement in the context of an incentive auction because higher bids on the part of buyers result in a greater quantity of spectrum being made available from sellers. Fifth, the market for mobile wireless services does not appear to be sufficiently concentrated to support the profitability of a foreclosure strategy.

I.B. The economics literature confirms that bidding restrictions are expected to reduce auction revenue

(7) The theoretical literature concludes that excluding bidders reduces auction revenue. In addition, empirical evidence on the effects of bidding restrictions at U.S. Forest Service timber auctions shows that set-asides reduced auction revenue and the amount of timber sold. The literature also identifies key ways in which a two-sided auction differs from the more familiar one-sided auction. In particular, a two-sided auction can be more sensitive to the exclusion of buyers than a one-sided auction.

(8) Thus, the literature indicates that regulators should expect reductions in revenue and the quantity transacted as a result of restrictions on bidders at the Incentive Auction. In addition, a reduction in the amount of spectrum transacted in the Incentive Auction means that less spectrum will be reallocated from broadcast use to mobile wireless services. This potentially has broader economic consequences given that there appears to be a consensus that the wireless industry as a whole is likely to suffer from a spectrum shortage as data usage continues to increase. Failure to promote the FCC's goal in its National Broadband Plan to repurpose a substantial amount of spectrum for wireless operations could lead to higher prices for consumers, reduced quality of services, and stalled innovation.[1]

[1] See, e.g., National Broadband Plan: Connecting America at p.xii.

I.C. Bidding restrictions in past FCC auctions would have substantially reduced revenue

(9) I simulate the effects of bidding restrictions in two previous FCC auctions, Auction 66, the AWS spectrum auction, and Auction 73, the 700 MHz auction. The simulation results show that bidding restrictions at these past FCC auctions would have lowered revenues and prices and negatively affected efficiency. The results show that, in the absence of Verizon and AT&T, auction revenues would have been 16% lower in the FCC's 2006 AWS spectrum auction and 45% lower in the 2008 700 MHz spectrum auction. In the AWS auction, T-Mobile would have benefited from a substantial subsidy if bidding restrictions had been imposed on Verizon and AT&T: in the simulation, the average price per MHz*Pop that T-Mobile pays for the licenses it wins falls by 18%.

(10) I also analyze the impact of spectrum share caps that, as proposed by some parties, fall short of outright exclusion, and find revenue reductions of 15% in the AWS spectrum auction and of 41% in the 700 MHz auction. While the simulation of such caps in past auctions cannot be expected to provide precise estimates of the impact of such policies in the Incentive Auction, the empirical evidence indicates that any policy that leads to a significant reduction in the participation of Verizon and AT&T risks a significant negative revenue impact. The larger the reduction in participation, the larger will be the negative impact on revenue. As these simulations show, the loss of Verizon and AT&T as active competitors in the auction leads to substantial reductions in revenue.

I.D. Bidding restrictions in the Incentive Auction would risk auction failure

(11) I simulate the effects of bidding restrictions in a two-sided auction using a theoretical model of buyer and seller behavior in a two-sided auction, one where sellers must be enticed to give up their assets by the magnitude of the buyers' bids. This model illustrates how the risk of auction failure is heightened where bidding restrictions are imposed in the context of a two-sided auction.

(12) Bidding restrictions would reduce the maximum possible revenue and the maximum possible quantity of repurposed spectrum that can be achieved. In fact, the entire set of possible outcomes is shifted in the direction of lower revenue and a lower quantity of repurposed spectrum. If a minimum combination of revenue and quantity is required in order for the auction to succeed, then the elimination of two buyers could make that objective impossible to achieve, causing the auction to fail.

(13) Moreover, it is my understanding that there may be a minimum amount of spectrum the FCC will need to clear in the reverse auction in order to offer spectrum in the forward auction that is attractive to a majority of wireless operators. Specifically, it is my understanding that in any market where less than 72 MHz of spectrum is available to be sold to wireless operators, it may be challenging or even

impossible to configure a technically viable band plan featuring paired spectrum. To the extent that technical considerations dictate a quantity floor below which the Incentive Auction may not fall, the risk that auction restrictions would cause auction failure is increased.

II. Introduction and scope of submission

(14) I have been asked by Verizon to evaluate the claim that Verizon (possibly in conjunction with AT&T) has an incentive and ability to foreclose Sprint and T-Mobile from gaining access to low-frequency spectrum through the FCC's upcoming Incentive Auction, which is meant to reallocate spectrum from broadcasters to providers of mobile wireless services.[2] In addition, I have been asked to analyze the likely effects of some of the proposals to limit Verizon's and AT&T's participation in the Incentive Auction.

(15) A number of parties argue in submissions to the FCC that, because of purported concerns about foreclosure of Sprint, T-Mobile, or other wireless operators, the FCC should limit Verizon's and AT&T's participation in the Incentive Auction.[3] However, the principal goals of the Incentive Auction are to reallocate spectrum to a higher-valued use and to raise revenue to fund other priorities. Therefore, limiting participation in the Incentive Auction by two buyers that have shown that they place a high value on spectrum puts the goals of the Incentive Auction at risk.

II.A. Relevant qualifications

(16) I am the Robert A. Bandeen Professor of Economics at the Fuqua School of Business at Duke University. In addition, I am a Partner at the economic consulting firm Bates White, LLC. I received my PhD in Economics from Northwestern University. I served as Chief Economist for the FCC from August 2005 to August 2006 and served as a consultant to the Wireless Telecommunications Bureau of the FCC from August 2006 to August 2007. I have published numerous articles on various industry organization topics and on auction theory, and have recently focused on the economics of two-sided auctions. My CV is attached as Appendix A.

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[2] For background on the FCC's Incentive Auction, see http://www.fcc.gov/incentiveauctions. For additional discussion, see Simon Loertscher, Leslie M. Marx, and Tom Wilkening (2013), "A Long Way Coming: Designing Centralized Markets with Privately Informed Buyers and Sellers," Working Paper, Duke University, available at https://faculty.fuqua.duke.edu/~marx/bio/papers/incentiveauction.pdf. An early proposal suggesting that the FCC put in place an incentive auction type of mechanism was put forward by Evan Kwerel and John Williams (2002), "A Proposal for a Rapid Transition to Market Allocation of Spectrum," OPP Working Paper No. 38, Federal Communications Commission.

[3] See, e.g., U.S. Department of Justice, "Ex Parte Submission of the United States Department of Justice," WT Docket No. 12-269, April 11, 2013 (DOJ ex parte).

(17) My opinions are based on my training and experience as an economist, including my experience working with the FCC, and my analysis of the available evidence and data.

II.B. Background and scope of analysis

(18) In 1993, the U.S. Congress directed the FCC to design and implement auctions to assign spectrum licenses to providers of mobile wireless services. Although nothing like that had been done before, the first auction was held in 1994, and since then the FCC has held more than 80 auctions, issued more than 36,000 licenses, and raised more than $50 billion for the United States Treasury.[4]

(19) In 2012, the U.S. Congress directed the FCC to design and implement a new type of auction. The upcoming Incentive Auction will create a centralized market for the exchange of spectrum licenses in the 600 MHz frequency band from broadcasters to providers of mobile wireless services.

(20) The authorizing legislation for the Incentive Auction states that, in order for any transactions to occur, the sale of licenses to providers of wireless services must raise funds sufficient to cover: (i) the accepted bids of the television broadcasters, (ii) the FCC's out-of-pocket costs of conducting the auction, and (iii) the expected reimbursement costs of broadcasters and certain other parties associated with the license reassignments occurring as part of the auction.[5] The legislation authorizing incentive auctions does not explicitly require the FCC to raise any additional revenue, but it does state that any additional revenue shall be transferred to the Public Safety Trust Fund for various enumerated purposes.[6] Statements by members of Congress and FCC Commissioners indicate that the auction is expected to generate sufficient revenue to fund the FirstNet public safety network.[7]

(21) At the same time, the Department of Justice (DOJ) and various parties to the *Spectrum Holdings* and *Incentive Auctions* proceedings have expressed concerns about allowing AT&T and Verizon to

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[4] Congressional Hearing on "Keeping the New Broadband Spectrum Law on Track" (U.S. House Energy and Commerce Committee, 12 Dec. 2012), statement of FCC Commissioner Jessica Rosenworcel.

[5] Public Law 112-96, Section 6403(c)(2)(B), http://www.gpo.gov/fdsys/pkg/PLAW-112publ96/pdf/PLAW-112publ96.pdf.

[6] See § 6403(d)(4)(A).

[7] In Congressional Hearings on "Keeping the New Broadband Spectrum Law on Track" (U.S. House Energy and Commerce Committee, 12 Dec. 2012), FCC Commissioner Ajit Pai argued that if the incentive auction did not yield any net revenues, "That would mean no money for the First Responder Network Authority (FirstNet) to build out a nationwide, interoperable public safety broadband network; no money for state and local first responders; no money for public safety research; no money for deficit reduction; and no money for next-generation 911 implementation. Most of the problem stems from the structure of the proposed auction. The only closing condition set forth in the NPRM is that the revenues from the forward auction must cover the costs of the reverse auction." In the question-and-answer portion of the hearing, the FCC Commissioners were asked, "Should the commission ensure that the auction raises $7b [for a nationwide interoperable public safety network]?" The responses were: "Pai: Yes, we should focus on maximizing revenue. Rosenworcel: Yes, absolutely. Clyburn: Absolutely. McDowell: Yes. Genachowski: Yes."

acquire spectrum licenses at the Incentive Auction.[8] DOJ expressed particular concerns that Verizon and AT&T might acquire the low-frequency spectrum in rural areas only to hamper the ability of other carriers to compete in those markets. DOJ argues that low-frequency spectrum is particularly important for providing coverage in rural areas and Sprint and T-Mobile have "virtually none."[9]

(22) Assistant Attorney General Bill Baer later clarified in testimony to the Senate Judiciary Committee that the DOJ's submission was designed to "urge the FCC… to take a look … at whether or not the playing field is already tilted in favor of big guys who may or may not – we were not making a factual judgment -- … [be] using what they already have and use that as a factor in deciding what rules to set in the auction."[10]

(23) Nonetheless, DOJ states that, "The Commission's policies, particularly regarding auction of new low-frequency spectrum, can potentially improve the competitive landscape by preventing the leading carriers from foreclosing their rivals from access to low-frequency spectrum."[11] It goes on to say, "[f]or instance, rules that ensure that the two smaller nationwide carriers are not foreclosed from access to more spectrum, and particularly low-frequency spectrum, could benefit consumers. Auction rules of this nature would ensure the smaller nationwide networks, which currently lack substantial low-frequency spectrum, would have an opportunity to acquire it."[12]

(24) In addition, in reply comments to the FCC on the design of the Incentive Auction, other commenters suggest the imposition of rules that would restrict the acquisition of additional spectrum by certain firms.[13]

(25) As I show in this report, there is substantial conflict between the desire to raise revenue and reallocate spectrum through the Incentive Auction and the proposals to restrict the ability of Verizon and AT&T to compete in the auction. Such restrictions would potentially overcomplicate an already complex auction and put at risk achieving the dual goals of raising revenue and reallocation of spectrum. In addition, I show that historical bidding behavior indicates that restrictions on Verizon and AT&T are

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8 DOJ ex parte.

9 DOJ ex parte at p.14.

10 Senate Judiciary Hearing, April 16, 2013, available at http://www.judiciary.senate.gov/resources/webcasts/index.cfm.

11 DOJ ex parte at p.14.

12 DOJ ex parte at p.23.

13 As reported in the communications trade press, "[a]mong the areas of continuing disagreement is whether the FCC should impose a cap on the ability of Verizon Wireless and AT&T to buy spectrum in the auction." ("Sharp Disagreements Remain on Incentive Auction Rules," Communications Daily, March 15, 2013) See, for example, the comments by T-Mobile: "One of the strongest deterrents to widespread participation in the 600 MHz auction is the prospect that bidding will be pointless if the nation's two largest carriers – each of which has a market capitalization roughly ten times that of its next largest competitor – are given an unfettered ability to acquire all of the spectrum offered. Most commenters, therefore, support imposing a cap on spectrum acquisitions...." (Reply Comments of T-Mobile USA, Inc., GN Docket No. 12-268, March 12, 2013, pp.iv–v, available at http://apps.fcc.gov/ecfs/document/view?id=7022130363, accessed March 20, 2013) Other examples include the reply comments of the Competitive Carriers Association and Cellular South, Inc. in the same docket.

unlikely to substantially affect the allocation of licenses in rural areas, which appeared to be the key concern of DOJ.

III. There is no evidence that Sprint and T-Mobile have been foreclosed from access to low-frequency spectrum

(26) Throughout this submission, I define low-frequency spectrum as spectrum that is at a frequency below one GHz.[14] Data on the availability of low-frequency spectrum—both at auction and on the secondary market—are relevant for two reasons. First, to the extent that there are significant opportunities for wireless operators to acquire low-band spectrum through vehicles other than the Incentive Auction, such firms have the ability to bypass any theoretical "foreclosure" by Verizon and AT&T. Second, assertions that Sprint's and T-Mobile's ability to compete are reduced if they are not guaranteed access to low-frequency spectrum in the Incentive Auction can be tested against the conduct of these carriers in pursuing recent opportunities to acquire such spectrum.

(27) I conclude, based on the empirical evidence, that the existence of a liquid market for low-frequency spectrum undercuts the assertion that there is a risk that AT&T and Verizon could foreclose rivals from such spectrum by buying up all available spectrum. I also conclude that the behavior of Sprint and T-Mobile, who have consistently failed to purchase low-frequency spectrum even when given numerous recent opportunities to do so, undercuts the assertion that either of those firms is at risk of being "foreclosed" from an input that is crucial to their ability to compete.

III.A. Sprint and T-Mobile were not foreclosed from acquiring spectrum in the 700 MHz and AWS spectrum auctions

III.A.1. 700 MHz Auction

(28) The 2008 700 MHz auction was a large, relatively recent auction where the FCC auctioned 80 MHz of low-frequency (700 MHz) spectrum. It concluded in March 2008. Licenses sold in the 700 MHz auction can be used for mobile wireless services, including voice and mobile broadband, among other things.

(29) Neither T-Mobile nor Sprint participated in the 700 MHz auction. By contrast, Verizon and AT&T, along with 99 other entities, actively participated. That 99 other entities participated is evidence that Verizon's and AT&T's participation in that auction did not discourage other interested buyers from bidding in the auction.

[14] This is a common definition of "low frequency" in this context as noted in the DOJ ex parte at p.12.

(30) It is useful to focus on the 700 MHz B-block licenses because these licenses cover areas the size of Cellular Market Areas (CMA) and thus can be easily defined as rural or non-rural.[15] As reported in Figure 1, the majority of rural CMA-level licenses (72% in terms of numbers of licenses and 62% in terms of MHz*POPs[16]) were won by entities other than Verizon and AT&T.[17] Thus, DOJ's concern that Verizon and AT&T may foreclose other buyers of the low-frequency spectrum in rural areas is misplaced.

Figure 1 Number of B-block licenses won by top bidders in rural and non-rural CMAs in 700 MHz Auction

Bidder	Non-Rural		Rural	
	Licenses	MHz*POPs	Licenses	MHz*POPs
AT&T	150	1,881	77	229
Verizon	34	489	43	66
Qualcomm	1	2	2	3
Frontier (Dish)	0	0	0	0
T-Mobile (chose not to participate)	0	0	0	0
SpectrumCo (Sprint; chose not to participate)	0	0	0	0
Other	118	261	303	485
Total	303	2,634	425	783

Source: Calculations based on the FCC data and documentation.

III.A.2. AWS spectrum auction

(31) In order to further evaluate claims that Sprint and T-Mobile have been foreclosed from acquiring spectrum suitable to expand coverage in rural areas, I analyze data from the 2006 AWS spectrum auction. The AWS spectrum auction, referred to as the "AWS-1 Auction," was another large, relatively recent auction. It concluded in September 2006. Licenses sold in the AWS-1 spectrum auction can be used for mobile wireless services, including voice and mobile broadband. In this section, I focus on the AWS-1 A-block licenses, which are 20 MHz licenses defined over the 734 CMAs. It is useful for the purposes of this section to focus on the A-block licenses because CMA-sized areas can more easily be defined as either rural or non-rural.

[15] In fact, the FCC identifies certain CMAs as rural areas.

[16] The term "MHz-POPs" is defined as the product of the number of megahertz associated with a license and the population of the license's service area, both of which affect the value of a license. Because trades can involve licenses of different sizes, both in terms of MHz and population coverage, an examination of the MHz*POP associated with trades provides additional information.

[17] 72% is calculated by dividing the number of rural licenses won by participants other than Verizon and AT&T (305) by the total number of rural licenses (425). Similarly 62% is calculated by dividing 488 by 783.

(32) Figure 2 reports the number and MHz*POPs of A-block licenses won by bidder broken down by rural and non-rural CMAs. The vast majority of these rural licenses (96% in terms of numbers of licenses and 95% in terms of MHz*POPs) were won by an entity other than Verizon, AT&T, T-Mobile, or Sprint. This suggests that Sprint and T-Mobile had an opportunity to acquire additional spectrum that would have expanded their rural coverage, but chose not to, even though Verizon and AT&T were not actively bidding on these licenses themselves either to acquire the spectrum or to keep it out of the hands of Sprint and T-Mobile.

Figure 2 Number of A-block licenses won by top bidders in rural and non-rural CMAs in AWS spectrum auction

Bidder	Non-Rural		Rural	
	Licenses	MHz*POPs	Licenses	MHz*POPs
T-Mobile	83	1,827	10	47
Cricket	38	715	35	136
AT&T	20	769	1	10
Verizon	2	11	5	10
SpectrumCo (Sprint)	0	0	0	0
Other	160	1,063	358	1,065
Total	303	4,384	409	1,268

Source: Calculations based on the FCC data and documentation.

III.B. Evidence from secondary market transactions shows that Sprint and T-Mobile have not been foreclosed

(33) The availability of low-frequency spectrum on the secondary market would make it difficult for Verizon and AT&T to implement a successful foreclosure strategy at the Incentive Auction. AT&T and Verizon cannot prevent other providers from purchasing low-frequency (or any other) spectrum on the secondary market, unless they stand ready to purchase all or most of the available supply—and the evidence shows that they have not.

(34) In addition, past secondary market transactions suggest that Sprint and T-Mobile have not been particularly interested in acquiring low-frequency spectrum—a fact that undercuts the assertion that they are at risk of being foreclosed.

(35) Verizon gave me data, taken from the publicly available sources, on all of the assignment and transfer applications that the FCC received from January 8, 2007, to January 30, 2013. These transactions were consummated between February 16, 2007, and May 10, 2013. I use these data to investigate whether the empirical evidence supports the claim that Sprint, T-Mobile, or other wireless operators have not had opportunities to substantially increase their holdings of low-frequency spectrum.

(36) The secondary market transactions data contain 5,153 spectrum trades.[18] Eighty-eight percent of these transactions (4,510 out of 5,153) involved the transfer of the whole license. In the remaining 12% of transactions, the license was partitioned or disaggregated. When only one part of a license is transferred, the database does not report the fraction of the total licensed spectrum that was traded.

(37) Figure 3 reports the number of whole and partial license transactions and the MHz*POPs million[19] transacted as a part of whole license transfers. Because only 12% of transactions involved the partial assignment of a license and because the data do not specify the size of the partial assignment, I exclude these transactions from my analysis of secondary market transactions.

Figure 3 Secondary market transactions by band, January 2007–May 2013

	Counts of trades			MHz*POP (millions) traded, whole license trades only
Band	Whole license	Partial assignment	Total	
Cellular	1,110	1	1,111	6,360
Lower 700 MHz	984	56	1,040	7,091
Upper 700 MHz	2	0	2	16
sub-total: below 1 GHz	*2,096*	*57*	*2,153*	*13,466*
PCS	1,547	334	1,881	41,476
AWS	804	249	1,053	17,684
WCS	63	3	66	7,171
subtotal: above 1 GHz	*2,414*	*586*	*3,000*	*66,331*
Total	4,510	643	5,153	79,797

Source: Calculations based on FCC data and documentation.

III.B.1. Sprint and T-Mobile buy and sell spectrum in the secondary market

(38) By looking at all transactions, not just low-frequency transactions, I establish that Sprint and T-Mobile actively participated in the secondary market, engaging in approximately the same number of buy transactions as sell transactions. That active participation suggests that Sprint and T-Mobile were able to acquire useful spectrum through this channel, but as I show below, they did not take advantage

[18] I excluded 23 internal trades between two entities both under Verizon's control (2) or AT&T's control (21).

[19] Because trades can involve licenses of different sizes, both in terms of MHz and population coverage, an examination of the MHz*POP associated with trades provides additional information.

of the secondary market to acquire low-frequency spectrum. Figure 18 in Appendix B reports the number of transactions by buyer and seller.

(39) As shown in Figure 4 below, the evidence in terms of MHz*POPs traded (based on the 4,510 trades involving whole licenses) shows that both Sprint and T-Mobile were net buyers of spectrum in secondary market transactions, including purchases of spectrum from Verizon and AT&T. Furthermore, the data show that Sprint and T-Mobile could have purchased an additional 24,233 million MHz*POPs that spectrum holders other than Verizon and AT&T put up for sale. (These 24,233 million MHz*POPs correspond roughly to an 80 MHz license covering the entire United States.) Figure 4 shows that T-Mobile was able to increase its spectrum holdings substantially through secondary market transactions and that it could have purchased about six times more from sellers other than Verizon and AT&T than it decided to buy. (T-Mobile purchased 4,180 million MHz*POPs from "Other" sellers, but 24,233 million MHz*POPs sold by those other sellers were purchased by "Other" buyers.) The fact that Sprint only purchased 304 out of 24,233 million MHz*POPs from "Other" sellers suggests that although the secondary market was relatively active across most commercial spectrum bands, Sprint failed to take advantage of opportunity to acquire spectrum. The evidence from these secondary market transactions does not support claims that Sprint and T-Mobile have been anticompetitively foreclosed from acquiring spectrum.

Figure 4 MHz*POPs traded, all bands, January 2007–May 2013 (whole licenses only)

MHz*POP (millions) traded		Buyer					
		Verizon	ATT	T-Mobile	Sprint	Other	Total
Seller	Verizon		2,609	593	47	415	3,664
	ATT	629		1,297	4	431	2,360
	T-Mobile	1,914	1,169		20	343	3,447
	Sprint			22			22
	Other	19,298	22,289	4,180	304	24,233	70,303
	Total	21,841	26,068	6,092	375	25,422	79,797
	buy/sell ratio	*5.96*	*11.04*	*1.77*	*16.82*	*0.36*	

Source: Calculations based on FCC data and documentation.

III.B.2. Neither T-Mobile nor Sprint has chosen to acquire low-frequency spectrum in the secondary market despite significant opportunities to do so

(40) Since January 2007, there have been 2,153 transactions of low-frequency spectrum. T-Mobile bought one license and Sprint did not buy any.[20] Although Verizon and AT&T have been active buyers of

[20] T-Mobile bought a 25 MHz Cellular A license from SunCom Wireless Holdings covering CMA 629 (South Carolina 5 – Georgetown) where about 375,000 people currently reside. This was a part of T-Mobile's acquisition of SunCom Wireless Holdings, Inc. that was announced in September 2007 and consummated in February 2008. In addition to one 25 MHz Cellular A license, T-Mobile also received 27 PCS licenses as part of the acquisition.

low-frequency spectrum, a significant proportion of the spectrum transacted did not involve Verizon or AT&T and thus could not have been subject to foreclosure by Verizon and AT&T.

(41) In particular, focusing on the 2,096 low-frequency transactions that involved the transfer of a whole license, Figure 5 shows that—at a minimum—Sprint or T-Mobile could have been the buyer in 729 transactions when the buyer and seller were firms other than Verizon or AT&T. Figure 6 reports the quantities of low-frequency spectrum transacted in MHz*POPs rather than in numbers of transactions. Approximately thirty percent of the MHz*POPs of low-frequency spectrum transacted (3,691 million out of 12,832 million) were sold and purchased by a firm other than Verizon or AT&T and thus could not have been subject to foreclosure by Verizon or AT&T; this is roughly the same MHz*POPs as a 12 MHz license covering the entire United States. This evidence supports the conclusion that Sprint and T-Mobile have had opportunities to purchase low-frequency spectrum but have chosen not to.

Figure 5 Number of transactions of low-frequency whole licenses, January 2007–May 2013

Counts of trades		Buyer					
		Verizon	ATT	T-Mobile	Sprint	Other	Total
Seller	Verizon	n/a	81	0	0	79	160
	AT&T	4	n/a	0	0	1	5
	Other	450	751	1	0	729	1,931
	Total	454	832	1	0	809	2,096

Source: Calculations based on FCC data and documentation.

Figure 6 MHz*POPs of low-frequency spectrum transacted from January 2007 to May 2013 (whole licenses only)

MHz*POP (millions) traded		Buyer					
		Verizon	ATT	T-Mobile	Sprint	Other	Total
Seller	Verizon	n/a	207	0	0	402	609
	AT&T	23	n/a	0	0	2	25
	Other	2,726	6,406	9	0	3,691	12,832
	Total	2,749	6,613	9	0	4,095	13,466

Source: Calculations based on FCC data and documentation.

(42) Verizon offered for sale all of its licenses in two blocks of the Lower 700 MHz band in 2013. This spectrum could have provided significant coverage in low-frequency spectrum for T-Mobile or Sprint, but neither company bought any of these licenses. The CFO of Deutsche Telekom said, “We

are not interested in 700 megahertz spectrum at this time […] [T]his spectrum is nothing which would be attractive for us."[21]

III.B.3. Sprint and T-Mobile have failed to act on opportunities to purchase low-frequency spectrum in rural areas

(43) In the previous section, I show that there were opportunities for firms to purchase low-frequency spectrum on the secondary market, but that Sprint and T-Mobile did not take advantage of those opportunities. The evidence shows that they passed up these opportunities even in rural areas. This is noteworthy because DOJ has indicated a particular concern about potential foreclosure in rural markets, where low-frequency spectrum can facilitate deployment of wireless service with fewer cell sites because of its ability to propagate signals further.

(44) The 2007-2013 data show that there were significant opportunities to purchase low-frequency spectrum in rural areas, which the FCC defines as areas where population density is currently below 100 inhabitants per square mile.[22] According to the transactions data, Sprint and T-Mobile made *no* purchases of low-frequency spectrum in rural areas.

[21] Q1 2012 Investor call (May 10, 2012).

[22] "We establish a baseline definition of 'rural area' as those counties (or equivalent) with a population density of 100 persons per square mile or less, based upon the most recently available Census data." *Facilitating the Provision of Spectrum-Based Services to Rural Areas and Promoting Opportunities for Rural Telephone Companies to Provide Spectrum-Based Services*, Report and Order, 19 FCC Rcd 19078, at ¶¶ 11, 79 (2004).

(45) Figure 7 and Figure 8 below report transactions of low-frequency spectrum in rural areas. A significant proportion of the transactions involves neither Verizon nor AT&T as either the buyer or seller and thus could not have been subject to anticompetitive foreclosure by either. Yet of these 469 low-frequency licenses sold in rural areas, Sprint and T-Mobile bought none.

Figure 7 Number of transactions of low-frequency rural licenses traded, January 2007–May 2013 (whole licenses only)

Counts of trades		Buyer					
		Verizon	ATT	Sprint	T-Mobile	Other	Total
Seller	Verizon	n/a	74	0	0	53	127
	ATT	1	n/a	0	0	1	2
	Other	311	374	0	0	469	1,154
	Total	312	448	0	0	523	1,283

Source: Calculations based on FCC data and documentation.

Figure 8 Rural MHz*POPs of low-frequency spectrum transacted January 2007–May 2013 (whole licenses only)

MHz*POP (millions) traded		Buyer					
		Verizon	ATT	Sprint	T-Mobile	Other	Total
Seller	Verizon	n/a	176	0	0	171	347
	ATT	3	n/a	0	0	2	5
	Other	1,092	1,603	0	0	1,537	4,232
	Total	1,095	1,778	0	0	1,710	4,583

Source: Calculations based on FCC data and documentation.

(46) There may be limitations to secondary market opportunities, and engaging in a sequence of small secondary market transactions may not be attractive for a carrier because of the risk that the carrier may be unable to purchase sufficient licenses at attractive prices to support its business plan. But T-Mobile's and Sprint's failures to make any meaningful attempts to acquire low-frequency spectrum, particularly rural low-frequency spectrum, suggest that they have chosen to target other bands of spectrum, not that they have been foreclosed. And the active secondary market for spectrum, including for rural low-frequency spectrum, would make it difficult for Verizon and AT&T to successfully execute a foreclosure strategy in the future.

III.C. Evidence from pricing plans suggests a pattern of capacity constraints that makes foreclosure unlikely

(47) DOJ states that, "[a]bsent compelling evidence that the largest incumbent carriers are already using their existing spectrum licenses efficiently and their networks are still capacity-constrained, the

Department would normally expect the highest use value for new spectrum that is in the public interest to come from rivals to the leading firms that could effectively make use of additional spectrum to expand capacity, improve coverage, or introduce new services in an effort to challenge the dominant firms."[23]

(48) This report does not address the extent to which mobile wireless service providers are capacity constrained. That question has been separately addressed by economists and industry analysts. For example, Allan Shampine submitted a declaration on behalf of Verizon in which he calculated the customers per MHz*POP of various wireless operators and concluded that Verizon and AT&T use their spectrum more intensively than other operators, including T-Mobile and Sprint.[24] And a recent market research report by Deutsche Bank labels Sprint the "new spectrum powerhouse" and emphasizes that Sprint has "more bandwidth available for LTE than all of its national competitors combined."[25] Similarly, Macquarie Capital recently commented that Sprint and T-Mobile have a "strong spectrum and network capacity position" and that Verizon and AT&T "will need to purchase additional spectrum" within the next two years.[26]

(49) Additional economic evidence speaking to the issue can be found in a review of pricing plans offered by the four national providers. On the one hand, if a wireless carrier is relatively unconstrained in terms of its network capacity, one would expect that it would offer pricing plans that allow for customers to use large amounts of data or even offer plans with unlimited data usage. On the other hand, one would expect carriers that are more capacity constrained to offer plans that encourage customers to conserve on network capacity.

(50) Statements by the FCC and industry analysts support the economic logic that wireless operators' pricing plans can be expected to reflect their relative capacity constraints. For example, in the Fifteenth Annual CMRS Competition Report, the FCC stated: "In late 2009 […] the chief executive of AT&T's wireless operations hinted that the company would eventually shift from unlimited data pricing to charging subscribers based on the amount of data used in order to encourage high-usage customers to curb demand for network capacity and improve the operator's ability to manage its network. Analysts have long anticipated the introduction of usage-based wireless data pricing, arguing that a departure from the unlimited data pricing model is only a matter of time. In June 2010, AT&T became the first national operator to move from unlimited data pricing to usage-based tiered data pricing for smartphones." [27] In the Sixteenth CMRS Competition Report, the FCC confirmed

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[23] DOJ ex parte at p.12.

[24] Declaration of Allan L. Shampine, In the Matter of Policies Regarding Mobile Spectrum Holdings, Docket No. 12-269 (Nov. 26, 2012), at 18-19, *available at* http://apps.fcc.gov/ecfs/document/view?id=7022067975.

[25] *See* Brett Feldman et al., Deutsche Bank Market Reports Research, *Sprint Nextel Corp. The New Spectrum Powerhouse; Restating Coverage at Buy* at 1, available at http://apps.fcc.gov/ecfs/document/view?id=7520931274.

[26] July 29, 2013 Macquarie Capital report, "US Telecom Services: Spectrum and network capacity vs. traffic demand for the Big 4 wireless carriers."

[27] See In the Matter of Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993 Annual

that more wireless carriers facing capacity constraints are shifting to usage-based data plans: "the Fifteenth Report […] had focused on the industry's shift from unlimited data pricing to tiered, usage-based data pricing for smartphones. As discussed in the Fifteenth Report, this shift was a response to the effects of increased bandwidth consumption by smartphone users on network utilization and capacity constraints." The report also stated that Sprint has an "unlimited data pricing [….] and T-Mobile reintroduced an unlimited smartphone data pricing option."[28]

(51) Figure 9 compares the individual post-paid plans of Verizon, AT&T, T-Mobile, and Sprint. During the first half of 2013, Sprint and T-Mobile offered service plans to their customers that allow those customers to increase their data use in an unlimited way at zero incremental cost to those customers. Sprint offered an unlimited data plan at $110 per month, and T-Mobile offered an unlimited data plan at $90 per month during the first quarter and $70 per month during the second quarter, for an average price of $80 per month. This type of pricing is consistent with a lack of binding capacity constraints. If network capacity were a problem for T-Mobile and Sprint, I would have expected to see pricing plans that encourage customers to conserve on network usage. In fact, a recent T-Mobile advertisement portrays AT&T's network as overcrowded but T-Mobile's network as having ample capacity.[29] Similarly, Sprint recently announced that customers who choose the "New Unlimited, My Way Plan" starting at $80 per month would receive the "Sprint Unlimited Guarantee," an offering that allows the customers "to lock-in unlimited talk, text and data not for just the next two years, but for life."[30]

Figure 9 Comparison of individual 2013 (Jan-Jun) post-paid plans including unlimited anytime minutes and unlimited text messaging—monthly charge ($) and corresponding included data usage (GigaBytes)

	Sprint	T-Mobile	Verizon	AT&T
Data usage	Unlimited	Unlimited	4GB	4GB
Average 2013 price ($ per month)	110	80	110	110

Source: Verizon.

Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services, WT Docket No. 10-133 (2011) ("Fifteenth CMRS Competition Report"), at ¶¶87-88.

28 The FCC also reported that "[t]he same network management issues motivating the ongoing shift from unlimited data pricing to tiered smartphone data plans in the postpaid segment – namely, the impact of higher bandwidth consumption by smartphone users on network utilization and capacity constraints – are also beginning to induce changes in the pricing and service terms and conditions of high-end prepaid plans for users of smartphone data." ¶167; see In the Matter of Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993 Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services, WT Docket No. 11-186, released March 21, 2013 ("Sixteenth CMRS Competition Report").

29 See, e.g., PhoneArena.com, "T-Mobile ad attacks AT&T for having slow pipes," *available at* http://www.phonearena.com/news/T-Mobile-ad-attacks-AT-T-for-having-slow-pipes_id42743, site accessed July 4, 2013; T-Mobile "Pipes" Apple iPhone 5 Commercial, *available at* http://www.youtube.com/watch?v=h2Scc6fGz9o, site accessed July 4, 2013.

30 See, e.g., "Sprint Launches Unlimited Guarantee and New Unlimited, My Way Plan," *available at* http://newsroom.sprint.com/news-releases/sprint-launches-unlimited-guarantee-and-new-unlimited-my-way-plan.htm?view_id=2933, site accessed July 23, 2013.

(52) In contrast, Verizon and AT&T have commonly offered service plans that cap the amount of data that is available to customers at zero incremental cost. Most recently, both Verizon and AT&T offered plans that allow for 4 GB of data usage at $110 per month. Plans that limit the data usage that is available at no incremental cost are consistent with the kind of pricing that I would expect from a wireless carrier that is capacity constrained relative to carriers offering unlimited plans.

(53) Therefore, the pricing behavior of the four national wireless operators is not consistent with the assertion that Verizon and AT&T are purchasing spectrum they do not need for their operations in order to ensure that their competitors remain capacity constrained.

IV. Verizon and AT&T are unlikely to have the incentive or ability to foreclose Sprint and T-Mobile in the Incentive Auction

(54) In its submission, DOJ expresses concern that Verizon and AT&T will engage in a form of predatory bidding that will drive up the price of spectrum in the Incentive Auction to such an extent as to deny Sprint and T-Mobile the ability to acquire low-frequency spectrum in rural areas, which DOJ claims is needed to improve network coverage. But the DOJ paper includes no data or other evidence to support its concern, and DOJ subsequently clarified that it has not made any judgment about what the FCC will find when it undertakes the factual analysis needed to evaluate the concerns.[31]

(55) Verizon and AT&T could have an incentive to purchase spectrum with the intent of withholding it from the market and thus decreasing supply in order to raise or maintain price levels only if smaller rivals are already constrained in terms of spectrum and Verizon and AT&T are not. However, the pricing plan evidence that I present in section III.C suggests that the opposite is true.

(56) If margins are high and either Verizon or AT&T faces spectrum-capacity constraints in the coming years, then purchased spectrum will most likely be deployed in order to expand output at the high margins rather than withheld from the market. Furthermore, if smaller rivals are already unconstrained by their spectrum holdings, then withholding additional spectrum from them is unlikely to have any effect, while at the same time being costly to the larger wireless carriers. Therefore, if, as the evidence suggests, Verizon and AT&T are capacity-constrained relative to their smaller rivals, Verizon and AT&T would have no incentive to foreclose by purchasing spectrum to keep it out of the hands of their rivals.

(57) Additionally, DOJ suggests that its concerns about low frequency spectrum may extend beyond rural markets if carriers require that spectrum to “offer[] coverage across a broad service area.” (DOJ ex parte at 14). But Sprint already has low frequency spectrum in the 800 MHz band, which it is using

[31] Senate Judiciary Hearing, April 16, 2013, available at http://www.judiciary.senate.gov/resources/webcasts/index.cfm.

for its LTE deployment.[32] And T-Mobile's senior management has made clear that any coverage constraints it may face can be remedied with the acquisition of a small amount of low-band spectrum: according to an analyst at Jefferies who recently met with T-Mobile's leadership, T-Mobile believes it only needs a 5x5 block of low frequency spectrum to improve its coverage "dramatically."[33] This suggests that Verizon and AT&T would have to buy up almost all of the low frequency spectrum at the 600 MHz auction to succeed in a foreclosure strategy targeting DOJ's potential non-rural concerns.

(58) In the remainder of this section, I first address a much more direct remedy at the FCC's disposal that, unlike bidder participation restrictions, does not risk the success of the Incentive Auction. Then, I discuss some additional reasons why foreclosure by bidding up the price of spectrum in the Incentive Auction is unlikely to be an effective or profitable strategy for Verizon and AT&T: (1) Given the high costs associated with foreclosure and the uncertain benefit, both Verizon and AT&T would have an incentive to free ride on the efforts of the other to bid up the cost of spectrum. (2) Anonymous auction design would make the implementation of a foreclosure strategy difficult and costly. (3) The supply of spectrum is likely to increase as Verizon and AT&T bid up the price, increasing the cost of implementing a foreclosure strategy (4) The market does not appear to be sufficiently concentrated to make the foreclosure strategy profitable enough to justify the costs to Verizon and AT&T.

IV.A. As a policy tool to prevent foreclosure, build-out requirements have significant advantages over bidding restrictions

(59) If, despite the evidence to the contrary, the FCC believes that foreclosure by purchasing spectrum with the intent of withholding it from use is likely, then a more direct and less risky remedy is available to the FCC.

(60) The FCC can defeat a foreclosure strategy simply by imposing build-out requirements for licenses purchased at the Incentive Auction. DOJ notes in its ex parte submission that bidders may consider both use value and foreclosure value of spectrum when bidding. But bidders must also consider holding costs of any spectrum won, which offsets the perceived value. Holding costs of spectrum are increased by the extent to which the FCC requires that holders of spectrum pursue the build out of capacity in order to make use of acquired spectrum. Thus, the FCC has a tool at its disposal by which it can directly reduce the likelihood that firms will find it profitable to withhold spectrum from the market through a warehousing strategy.

[32] See Sprint Q2 2013 Earnings Call (July 30, 013).

[33] August 28, 2013 Jefferies report, "T-Mobile USA". ("… T-Mobile believes that its coverage would improve dramatically with just a small (5x5) channel of low band spectrum.").

(61) The imposition of a build-out requirement does not have to cause the significant risks and distortions that bidding restrictions do. Suppose that, as the evidence suggests, neither Verizon or AT&T (or anyone else) has any intention of purchasing spectrum in the Incentive Auction to withhold it from the market. Then a properly designed build-out requirement would only minimally impact bidding behavior, if at all. In such a case, however, bidding restrictions would unnecessarily put at risk the goals of the Incentive Auction and interfere with the efficient allocation of spectrum. Therefore, build-out requirements will tend to be a much more efficient means of deterring foreclosure than bidding restrictions.

(62) In addition, because increases in the supply of spectrum reduce the profitability of a foreclosure strategy, the FCC can address foreclosure concerns by taking steps to accelerate the reallocation of spectrum, such as that currently assigned to the Federal Government, to use for commercial mobile wireless services.

(63) Moreover, if DOJ is concerned about foreclosure in rural areas, it could examine the results of the auction and bring challenges if it uncovers anticompetitive conduct. For the reasons described in this report, I think it is unlikely that Verizon and AT&T would have an incentive to engage in foreclosure, but DOJ could easily determine whether AT&T and Verizon had purchased all or almost all of the relevant spectrum in the auction at prices significantly in excess of expectations, and then DOJ could investigate whether that was in pursuit of foreclosure. DOJ could use such a post-auction review to challenge foreclosure instead of a prophylactic rule restricting bidding by Verizon and AT&T.

(64) Because the FCC could impose build-out requirements and the DOJ could examine bidding behavior post-auction in rural areas, policy tools exist for addressing foreclosure concerns that avoid the undesirable effects of bidding restrictions.

IV.B. Incentives to free ride imply that there is unlikely to be a unilateral incentive for significant foreclosure by either Verizon or AT&T

(65) Free rider concerns suggest that a foreclosure strategy may be difficult for AT&T and Verizon to implement. DOJ's theory involves Verizon and AT&T both being willing to warehouse all or almost all the rural spectrum up for auction to prevent Sprint and T-Mobile from gaining access to that spectrum. That means that a significant portion of the foreclosure costs borne by Verizon or AT&T will benefit the other firm.

(66) The effect of this will be to greatly reduce Verizon's and AT&T's unilateral incentives (if any) to foreclose well below the incentive that a single large firm would have. A single large firm would internalize all of the additional profits from the foreclosure strategy. When benefits are shared,

however, each firm sharing the benefits would prefer to free ride on the other's efforts, leading to significantly less foreclosure than would have occurred if the benefits were not shared.

IV.C. Anonymous auction design makes foreclosure less likely

(67) The FCC can make auction design choices that reduce concerns related to foreclosure. In past auctions, the FCC has used anonymous bidding procedures in order to limit the scope for strategic bidding. By using anonymous bidding in the Incentive Auction, the FCC can prevent bidders from knowing the identity of rivals for a particular license, making a foreclosure strategy more difficult and costly to implement.

(68) In the context of an auction with anonymous bidding, it would not be possible for Verizon or AT&T to know when one of them (as opposed to one of the firms supposedly a target of their foreclosure strategy) has won a license. The result is that Verizon and AT&T would not know when to stop bidding. Notably, as discussed in Section VI.C below, in the 700 MHz Auction, Verizon and AT&T competed head-to-head with one another for spectrum in various markets, even after all other participants had stopped bidding. In fact, that head-to-head competition between Verizon and AT&T contributed to more than $4.2 billion in additional revenues that would not have been received if AT&T and Verizon had stopped bidding as soon as one of them was guaranteed to acquire the license. None of the parties asserting that there is foreclosure risk has put forth a theory explaining how foreclosure could take place in the context of anonymous bidding and direct competition between Verizon and AT&T.

IV.D. Uncertainty about the level and elasticity of supply in an incentive auction makes a foreclosure strategy difficult to implement

(69) A foreclosure strategy is particularly difficult to implement in the context of an incentive auction because higher bids on the part of buyers result in greater quantity being made available from sellers.

(70) In an incentive auction, unlike other auctions the FCC has run, there is significant uncertainty regarding the ultimate supply of spectrum to the market. The nature of the Incentive Auction involves broadcasters making decisions about the price at which they are willing to supply spectrum to the market. It will be difficult for participants to predict before the auction how much will be supplied at a given price level. A company seeking to implement a foreclosure strategy that involves bidding up the price of spectrum so as to purchase that spectrum in order to withhold it from the market already faces uncertainty over how high it will have to bid in order to keep spectrum away from rival bidders. An incentive auction introduces additional uncertainty associated with how much spectrum will have

to be purchased at inflated bids. This uncertainty makes planning and implementing this foreclosure strategy difficult and costly.

(71) The extent to which higher prices stimulate sellers to offer more spectrum for sale is reflected in the elasticity of supply. If supply is highly elastic, then a small increase in price results in a large increase in the quantity of spectrum supplied. To analyze the effects of supply elasticity, auction theorists consider the set of equilibria of an auction, where an equilibrium is a specification of bidding strategies, one for each bidder, that are mutual best responses. These equilibria provide predictions on likely outcomes for the auction. The theory for one-sided auctions suggests that the elasticity of supply and uncertainty regarding that elasticity affects the set of equilibria in these auctions, with greater uncertainty and more elastic supply eliminating certain equilibria that may be undesirable from the perspective of the auction designer.[34] It seems likely that uncertainty regarding the elasticity of supply in the Incentive Auction would further inhibit attempts by bidders to coordinate on a foreclosure strategy. For example, if bidders are unsure about the elasticity of supply, they may be unsure about whether coordination on foreclosure strategies can be supported as an equilibrium, or if their beliefs about the elasticity of supply differ, they may disagree regarding foreclosure strategies.

IV.E. The market for wireless services is unlikely sufficiently concentrated to make foreclosure profitable

(72) In all models of competition that I am aware of, the effects of foreclosing a rival diminish as the number of firms already effectively competing in the market increases. For example, a monopolist that is able to foreclose an entrant in order to remain a monopolist rather than sharing a duopoly profit will find that foreclosing that rival is significantly more profitable than foreclosing a rival that, had it been able to enter, would have become the third competitor rather than the second. Similarly, foreclosure of a fourth rival is significantly less profitable than foreclosing the third.

(73) For example, consider a market consisting of symmetric firms competing by setting quantities facing inverse demand equal to $p = 100 - q$, where p is the market price and q is the total quantity supplied to the market. This is an example of a model of Cournot competition.[35] Assuming that firms produce at zero cost, the equilibrium price is equal to $100/(n+1)$, where n is the number of symmetric firms in the market. Equilibrium profit of each firm is equal to $(100/(n+1))^2$. The aggregate value to the remaining firms of foreclosing one potential entrant decreases as the number of firms in the market increases. Specifically, if there are two potential competitors but one is foreclosed, the value of

[34] See Paul Milgrom (2004), *Putting Auction Theory to Work*, Cambridge University Press, Chapter 7.2, showing that when bidders at a multi-unit auction face elastic supply rather than inelastic supply, some low-revenue equilibria may be eliminated.

[35] See, e.g., Jean Tirole (1989), *The Theory of Industrial Organization*, Cambridge, MA: MIT Press, Section 5.4.

foreclosure is approximately 1,389.[36] If there are three potential competitors but one is foreclosed, the joint value of foreclosing the third firm for the two other firms is approximately 972.[37] If there are four potential competitors but one is foreclosed, the joint value of foreclosing the fourth firm for the three other firms is 675.[38]

(74) The current market structure for mobile wireless services in the United States involves a significant number of national and regional competitors of various sizes and strengths. The potential foreclosure that is described by DOJ does not involve the complete foreclosure of a rival by a monopolist but rather is marginal in nature. It involves (theoretically) foreclosing rivals' access to a small subset of the available input when there are already many small, medium, and large-sized rivals and therefore the value of that foreclosure and its effect would likely be small.

(75) In addition, the costs of a successful foreclosure strategy are likely to be large because it would require a firm to purchase licenses for large amounts of spectrum and then to fulfill any build-out requirements associated with those licenses.

(76) In sum, in the Incentive Auction, bidders likely will not know whom they are bidding against, making a targeted foreclosure strategy difficult or impossible to implement. In addition, a firm will not know whether a higher bid will have the effect of increasing the total amount of spectrum available in the market. This uncertainty, together with the limited benefits and high costs of a foreclosure strategy, suggests that firms will not have the incentive to engage in such a strategy.

V. Effects of bidding restrictions in the economics literature

V.A. Papers on auction design suggest that bidding restrictions are likely to reduce revenue and efficiency

(77) Economic theory supports the intuitive conclusion that a seller should be able to raise more money when running an auction that does not exclude any bidder than an auction that excludes even a single bidder. Bulow and Klemperer (1996) prove a theorem that shows that, when the auctioneer's goal is to raise the highest amount of money possible, "an auction with $N + 1$ bidders beats any standard mechanism for selling to N bidders."[39]

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[36] The profit of a monopolist is 2500, whereas the profit of a duopolist is approximately 1111, where 2500-1111=1389.

[37] With three firms, each firm has profit 625, but with two each has profit 1111, and 2(1111)-2(625)=972.

[38] With four firms, each firm has profit 400. Using the prior result, 3(625)-3(400)=675.

[39] Jeremy Bulow and Paul Klemperer (1996), "Auctions Versus Negotiations," The American Economic Review, Vol. 86, No. 1, pp. 180-194.

(78) The authors show that this conclusion requires only that the bidders are "serious," that is, they value the object for sale more than the seller, and holds true under fairly general conditions. In particular, the conclusion that there is nothing as valuable to a seller as attracting one extra bona fide bidder to a competitive auction holds true both under "private values" conditions, "common value" conditions, and anything in-between. In a "private value" scenario, each bidder knows how much she values the object for sale; this information is private to herself and would not affect the values of other bidders if that information were revealed to them. In contrast, in a "common value" scenario, the value of the object for sale is the same for all bidders, but it is unknown at the time of the auction (e.g., the amount of oil that can be extracted after winning an oil lease auction).

(79) This result suggests that a seller should generally focus on maximizing the number of bidders. In the authors' own words: "A simple competitive auction with $N + 1$ bidders will yield a seller more expected revenue than she could expect to earn by fully exploiting her monopoly selling position against N bidders."[40]

(80) Combining theoretical and empirical analysis, Brannman, Klein, and Weiss (1987) show that having more bidders results in higher winning bids both in theory and in the data in a range of different auction settings, including underwriters' spreads on tax-exempt general obligation bonds and on tax-exempt revenue bonds, U.S. Department of Interior offshore oil lease auctions, and oral ascending and sealed-bid auctions of National Forest Service timber in the Pacific Northwest.[41]

V.B. Assertions that bidding restrictions might not suppress revenue are based on unrealistic hypothetical scenarios

(81) In his March 12, 2013, declaration on behalf of T-Mobile,[42] Prof. Jonathan B. Baker posits the following theoretical exception to the typical revenue result expected when bidding restrictions are imposed: "Given the non-trivial fixed costs of auction participation, a firm expecting to be outbid

[40] See also Vijay Krishna (2002), *Auction Theory*, New York: Academic Press. More nuanced effects are possible in models with participation costs and investments. For example, in Flavio M. Menezes and Paulo K. Monteiro (2000), "Auctions with endogenous participation," *Review of Economic Design* 5, 71-89, the authors distinguish between the number of bidders who pay the participation costs required to *actually* participate in an auction and the number of bidders who could *potentially* participate in an auction. The auctioneer's expected revenue always increases in the number of bidders who actually participate in an auction, but they show that an increase in the number of bidders who could potentially participate could in theory cause the auctioneer's expected revenue to decrease, although they conclude that not much can be said in general about the likelihood of this effect. In Richard J. Gilbert and Paul Klemperer (2000), "An Equilibrium Theory of Rationing," *RAND Journal of Economics* 31(1), 1-21, the authors consider a model in which the seller sets its pricing policy and then each of two buyers must make an initial sunk investment that determines probabilistically whether its value is positive or zero. In this case, the seller's prices must provide incentives for investment and the seller may prefer to commit to sell to only one buyer in order to promote investment.

[41] Lance Brannman, J. Douglass Klein and Leonard W. Weiss (1987), "The Price Effects of Increased Competition in Auction Markets," *Review of Economics and Statistics* 69(1), pp. 24-32.

[42] Jonathan B. Baker, "Spectrum Auction Rules That Foster Mobile Wireless Competition," paper submitted on behalf of T-Mobile, *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269.

could readily be deterred from participating in the auction in the first place. If auction participation is thin as a result of this dynamic, the large incumbent firms that are in principle willing to pay to obtain foreclosure benefits may enjoy these benefits without bidding up the auction price to a level that pays for those benefits fully, leaving the public with a less competitive wireless sector and the government with lower revenues than could be obtained." Similarly, in their paper on behalf of Sprint, economists Dr. Stanley M. Besen, Dr. Serge X. Moresi, and Prof. Steven C. Salop state that: "*Economic theory* has shown that unrestricted auctions *can* discourage some potential bidders and lead to the result that auction revenues fall far short of expectations."[43]

(82) However, both T-Mobile's and Sprint's economists limit themselves to hypothetical examples illustrating how the typical outcome—a reduction in revenue—might not occur (under their theories) if certain theoretical conditions are met. They present no evidence that the conditions that they claim might lead to a revenue-enhancing outcome are present in the context of the Incentive Auction or any other spectrum auction in the United States.

(83) For example, neither Dr. Baker nor Sprint's economists provide evidence that in the Incentive Auction smaller bidders will face "non-trivial fixed costs" to participate, or that such costs would cause them to be discouraged from participating if larger bidders are permitted to participate without restrictions.

(84) The data indicate that the hypothetical conditions posited by T-Mobile's and Sprint's economists do not appear to be present. For example, in the AWS auction, it was known that Verizon, AT&T, and T-Mobile would participate without restrictions, yet 168 qualified bidders registered for the auction and 104 bidders won licenses during the auction.[44] One of those bidders was T-Mobile, which won more licenses and spent more money than either Verizon or AT&T. Similarly, in the 700 MHz auction, there were 214 qualified bidders, of which 101 won licenses. Neither T-Mobile's nor Sprint's economists explain how the substantial number of active participants in those past actions is consistent with their apparent assumption that "non-trivial fixed costs" of auction participation may deter smaller bidders from participating in future U.S. spectrum license auctions.

(85) Sprint's and T-Mobile's economists do not appear to assert that their clients are among the "smaller" firms that may be deterred from participating in auctions if there are not restrictions on Verizon and AT&T. Given those companies' substantial financial resources and their proven historical ability to acquire spectrum when they seek to acquire it, there does not appear to be a basis to conclude that the presence of "non-trivial fixed costs" for participating in the Incentive Auction would discourage their participation. Indeed, even if they provided factual support for their conjecture that *smaller* firms

[43] Stanley M. Besen, Serge X. Moresi, & Steven C. Salop, *Why Restricting Participation in Spectrum Auctions Can Increase Bidder Participation, Increase Auction Revenues, and Increase Competition in Wireless Markets,* Mar. 12, 2013 (filed with Sprint's reply comments in Docket No. 12-268), p. 3, emphasis added.

[44] See http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=66.

may be deterred by the presence of unrestricted *larger* firms (and they do not), Sprint and T-Mobile do not explain why their own presence would not similarly deter smaller rivals from participating.

V.C. Empirical evidence from timber auctions further undermines the revenue theory advanced by Sprint and T-Mobile

(86) U.S. Forest Service timber auctions are an apposite and instructive real-world test for Sprint's and T-Mobile's conjecture about likely outcomes when smaller bidders face non-trivial fixed costs to participate in auctions. When the U.S. Forest Service sells the rights to harvest timber in a given area ("tract") by auction, it allows would-be participants to survey the tract to gather information about the value of the timber to be harvested. The evaluations of the idiosyncratic features of each tract are typically done through on-foot surveys of each tract by experienced experts known as "cruisers."[45] These surveys represent a non-trivial fixed cost of auction participation for small loggers who may consider participating in the auction in competition with large mills.[46] The U.S. Forest Service sets a fraction of harvesting contracts aside for small firms, thus providing the FCC with what economists call a "natural experiment" about the effects of bidder participation restrictions in a non-trivial context — timber sales were about $1.5 billion per year in the early 1980s (although now they are about 1/10 of that amount).[47]

(87) Athey, Coey, and Levin (2013) estimate that, far from increasing revenue, set-asides reduced revenue from U.S. Forest Service auctions by 5% between 1982 and 1989 (around that time, timber sales were slightly less than $1 billion per year) and reduced auction efficiency by 17%.[48] Brannman and Froeb (2000) estimate that, between 1974 and 1989, eliminating the set-aside program would have increased

[45] As stated in Baldwin, Marshall, and Richard (1997) "Bidder Collusion at Forest Service Timber Sales"" *Journal of Political Economy*, 105: 657-699 at page 666, "Certain other facts regarding Forest Service sales are relevant to our study. … Second, old-growth timber is highly heterogeneous. Bidders invest significant resources in assessing its value through 'cruises.' Cruises are analogous to geological reports for offshore oil tract sales."

[46] Athey, Levin, and Seira (2011) "Comparing Open and Sealed-Bid Auctions: Evidence from Timber Auctions," *Quarterly Journal of Economics*, 126: 207–257, state that "the costs of surveying a tract can run to several thousand dollars" and estimate the median survey cost to be about $3,000 in the Northern forests and about $5,000 in the California forests. The authors also report that the median expected profit from winning an auction is roughly $45,000 gross of surveying costs. For smaller bidders who tend to win half or a quarter of the auctions that are won by a median sized bidder, expected profit would tend to be 50 to 25 percent of $45,000 or $22,500 to $11,500. Therefore, survey costs for such small bidders would represent a relatively large percentage of the overall expected profit from bidding in an auction.

[47] See historical summary and graph of Forest Service cut and sold data, available at http://www.fs.fed.us/forestmanagement/documents/sold-harvest/documents/1905-2012_Natl_Summary_Graph.pdf.

[48] Susan Athey, Dominic Coey, and Jonathan Levin, (2013), "Set-Asides and Subsidies in Auctions," *American Economic Journal: Microeconomic*, 5(1): 1–27. The authors find that set-asides did increase small firms' participation, but argue that bidding subsidies targeted at small firms would have increased small firms' profits and the U.S. Forest Service revenues with a much more limited "efficiency" cost in terms of reduced quantity harvested.

auction revenues by 15%. In that period, the U.S. Forest Service timber auction revenues were slightly more than $1 billion per year.[49]

(88) Thus, set-asides failed to increase auction revenue and the amounts traded in timber auctions, even though a theoretical argument could be made for large bidders having an advantage over smaller ones in those auctions. It is thus unreasonable to expect that set-asides primarily benefitting large bidders, such as Sprint and T-Mobile, would increase auction revenue (and auction efficiency as well) in the Incentive Auction.

VI. Simulating the effects of bidding restrictions in past spectrum auctions suggests large negative effects on revenue

(89) In this section, I describe my simulation analysis and results of the impact of bidding restrictions if they had been imposed on the FCC's AWS spectrum auction (Auction 66) and 700 MHz auction (Auction 73). These are two large, relatively recent auctions in which Verizon and AT&T participated. Sprint and T-Mobile participated in the AWS spectrum auction, making that auction of interest for examining how bidding restrictions on Verizon and AT&T might affect those firms. The 700 MHz auction involved low-frequency spectrum, similar to the Incentive Auction. Thus, these two auctions provide useful test cases for the effects of bidding restrictions.

(90) I simulate the effects of a number of different bidding restrictions, all of which would have a significant effect on the licenses that Verizon and AT&T would be able to bid on in the Incentive Auction:

a. outright exclusion of AT&T and Verizon from the auction;

b. a 33% cap on low-frequency (below 1 GHz) spectrum holdings, applied pre-auction by market, such that a carrier would be excluded from bidding at auction in any market where its pre-auction spectrum holdings exceed 1/3 of the low-frequency spectrum in that market;

c. a 33% cap on low-frequency spectrum holdings applied post-auction by market, assuming that both AT&T and Verizon purchase 20 MHz of spectrum at auction.[50]

[49] Lance Brannman and Luke M. Froeb, (2000) "Mergers, Cartels, Set-Asides, and Bidding Preferences in Asymmetric Oral Auctions," *Review of Economics and Statistics*, 82(2): 283-290. These authors concur with the Athey, Coey and Levin (2013) conclusion that a policy of granting bidding preference to targeted bidders is superior to set-asides.

[50] One of the problems with Sprint's and T-Mobile's proposals is that it is not clear what amount of to-be-auctioned spectrum would be included in the denominator for purposes of determining a bidder's share of low-frequency spectrum. Given that the quantity of supply is unknown prior to the Incentive Auction, how a spectrum aggregation cap affects a participant's ability to bid in a particular market depends on how much additional spectrum is cleared in the

(91) The range of restrictions that I model is designed generally to cover the types of restrictions being proposed that would limit participation by AT&T and Verizon in the Incentive Auction. Differences between past auctions and the Incentive Auction, such as different license sizes (both spectrally and geographically) and different amounts of auctioned spectrum, make it difficult to model precisely some of the specific proposals that have been presented. For example, I understand that Sprint and T-Mobile have proposed that if AT&T or Verizon would be completely excluded from bidding in a particular market under their proposed 1/3 cap on low-frequency spectrum holdings, a "safety valve" may be appropriate under which they could bid on a small amount of spectrum (e.g., 10 MHz or 1/6 of the to-be-auctioned spectrum). Although precise modeling of the effects of such a policy is challenging, based on my findings regarding the effects of restrictions that fall short of outright exclusion, it is clear that any measure that materially reduces the demand that AT&T and Verizon bring to the Incentive Auction risks a material reduction in auction revenue.

auction, which is an unknown variable in the context of the Incentive Auction. That constitutes a significant uncertainty regarding how the cap would be applied. In the post-auction share cap exclusion scenarios, I assume that a total of 70 MHz is reallocated in the Incentive Auction. In other words, I assume the denominator used to calculate the firm's share includes the presently-available low-frequency spectrum plus 70 MHz of to-be-auctioned spectrum. That is consistent with T-Mobile's proposal that the FCC adopt a band plan featuring 35x35 MHz of paired spectrum.

(92) Currently, both Verizon's and AT&T's individual shares of low-frequency spectrum are at least 33% in many of the 172 Economic Areas (EAs) into which the United States was divided by the Bureau of Economic Analysis of the U.S. Department of Commerce at the time of the first FCC auctions.[51] Any Incentive Auction participation rule that prevents a carrier from participating in the bidding if its pre-auction low-frequency spectrum holdings are above the 33% threshold would be equivalent to excluding AT&T and Verizon, as reported in Figure 10. The calculations are based on 134 MHz of available low-frequency spectrum.

Figure 10 The effect of spectrum aggregation caps on Verizon's and AT&T's ability to bid in the Incentive Auction

			Excluded population as a % of total U.S. population	
POPs in EAs* where carrier could not bid when exclusion condition is:	Verizon	AT&T	Verizon	AT&T
Pre-auction low-frequency* holdings ≥ 33%	267,527,458	229,194,228	85%	73%
Post-auction low-frequency holdings ≥ 33% under a total of 70 MHz being re-allocated and named carrier seeking two 5x5 licenses	171,723,755	221,109,342	55%	71%

* U.S. EAs only, that is, excluding Puerto Rico (EA #173), U.S. territories (EAs #174-175) and Gulf of Mexico EA (#176).
Note: assumes Verizon's current Lower 700 MHz block B holdings are assigned to AT&T and Grain, pursuant to transfer applications recently approved by the FCC.
Source: Calculations based on current spectrum holdings data provided by Verizon.

(93) Figure 10 also reports how extensive the restraint on Verizon and AT&T would be under apparently less stringent participation rules based on post-auction low-frequency holdings. For illustrative purposes, I assume that the Incentive Auction would reallocate 70 MHz of spectrum. I then report the population in EAs where Verizon or AT&T could not win 20 MHz of spectrum because that additional spectrum would bring them above the 33% threshold (that is, above 68 MHz).[52] Figure 10 highlights how limits, seemingly less stringent than outright exclusion, would still have the effect of preventing Verizon from procuring spectrum to serve over half of the U.S. population.

[51] In 2004 the Bureau of Economic Analysis redefined its EAs, increasing their number from 172 to 179. See http://www.bea.gov/SCB/PDF/2004/11November/1104Econ-Areas.pdf. For the purposes of the AWS and 700 MHz Auctions, there were 176 EAs (see the band plans in Appendix B).

[52] If Verizon and AT&T theoretically sought to acquire only a single 5x5 license, the proposed cap would exclude Verizon from markets representing 50% of the population and AT&T would be excluded from markets representing 30%. Although historical purchasing patterns suggest that Verizon might not be interested in making a 5x5 MHz purchase, I simulated this scenario and found that it would have led to revenue reductions in both of the auctions. Even assuming that those smaller licenses would have substantial value by themselves (a questionable assumption given the fixed costs Verizon and AT&T would incur deploying spectrum in a new band class), my analysis indicates revenue reductions of up to 25% under the simulation methodology described below. That reduction likely understates the revenue effect because I did not attempt to account for the lower levels of demand (i.e., only a 5x5 license instead of the amount actually acquired in the past auction) that AT&T and Verizon would have brought to the auction under this assumption.

VI.A. Procedure

(94) For each auction under consideration, I identify the following data:

1. The complete set of bid amounts and net bid amounts (the actual paid amount including the bidding credit) submitted by each participant in every round for each license offered in that auction.
2. Information on whether particular bids were withdrawn or dropped and the tie-breaking random numbers associated with each bid.
3. Information on whether any of the bidders raised their own bid even though they did not need to do so to remain the highest bidder and the provisional winner in a particular round.

(95) To determine the ranking of bidders, I first look at the bidders' round-specific highest bids. If there are ties, those are resolved by using the tie-breaking random numbers assigned by the FCC.

(96) In my AWS spectrum auction and 700 MHz auction simulations, in order to simulate the effects of bidder participation restrictions, I assume that all bids in the auctions remain as they were submitted, but I remove the bids of AT&T and Verizon as appropriate for the particular restriction scenario. For example, consider the effect of the exclusion of Verizon in the bidding over a particular license. As demonstrated in Figure 11, Verizon wins license AW-REA001-F in round 16 and pays $1,335 million (highlighted in yellow). The provisional winning bid for each round (shown in bold) is defined as the round-specific highest bid (as in round 9). If there are ties, I use the tie-breaking random numbers assigned by the FCC to determine the provisional winning bid (as in rounds 10 or 12). Now assume that Verizon is not permitted to bid. The second-highest bidder, in this case T-Mobile, wins and pays an amount that exceeds the bid submitted by the third-highest bidder or equals the bid of the third-highest bidder but has a higher tie-breaking random number. In this example, T-Mobile pays $644 million (highlighted in green), a bid that exceeds Dolan's $537 million submitted in round 10. I refer to this as the "As bid" method. I make adjustments for reserve prices, the absence of other bidders, and ties.

Figure 11 AWS spectrum auction simulation example (license AW-REA001-F)

		Actual Bids		"As Bid" simulation	
Round	Bidder	Bid ($ millions)	Random number	Bid ($ millions)	Random number
9	Verizon	248	0.16		
	Denali	248	0.65	248	0.65
	Dolan	273	0.40	273	0.40
	SpectrumCo (Sprint)	447	0.87	447	0.87
	Wireless DBS LLC	248	0.56	248	0.56
10	Verizon	537	0.21		
	Dolan	537	0.32	537	0.32
12	Verizon	644	0.66		
	T-Mobile	644	0.15	644	0.15
13	T-Mobile	773	0.27	773	0.27
14	Verizon	927	0.12		
15	T-Mobile	1,113	0.74	1,113	0.74
16	Verizon	1,335	0.68		

Source: FCC documentation.
Note: The provisional winning bids for each round are in bold. The original win is highlighted in yellow and the simulated win is in green.

(97) As another example, if Verizon were the second-highest bidder and so determined the price paid by the winner, then, when excluding Verizon, I assume that the same bidder wins but pays only the bid amount that would have been just enough to outbid the third-highest bidder, again adjusting appropriately for reserve prices. For instance, as demonstrated in Figure 12, AT&T wins license WY-CMA167-B in round 26 and pays $3.17 million (highlighted in yellow). If Verizon and AT&T are not permitted to bid, the second highest bidder, in this case MetroPCS, becomes a winner. MetroPCS pays $1.66 million if I use the "As bid" method (highlighted in blue) because in round 21 MetroPCS has to overbid Verizon's $1.51 million submitted in round 20. But if Verizon and AT&T are unable to bid, MetroPCS only needs to overbid Alltel, which submitted $0.96 million in round 12. Hence, it is enough to bid only $1.15 million submitted in round 13 by AT&T (highlighted in green). I refer to this as the "Minimum required bid" method and use it in the analysis that follows. This method is preferable to the "As bid" approach because it uses a more accurate model of bidding behavior. In particular, bidders would rationally bid only as much as it is necessary to overbid the preceding highest bid.

Figure 12 700 MHz auction simulation example (license WY-CMA167-B)

		Actual Bids		"As Bid" vs. "Minimum required bid" simulation	
Round	Bidder	Bid ($ millions)	Random number	Bid ($ millions)	Random number
12	Alltel	0.96	0.51	0.96	0.51
	AT&T	0.96	0.09		
13	AT&T	1.15	0.73	1.15	0.73
	Verizon	1.15	0.59		
18	Verizon	1.28	0.07		
19	AT&T	1.38	0.53		
20	Verizon	1.51	0.88		
21	AT&T	1.66	0.81		
	MetroPCS	1.66	0.80	1.66	0.80
22	Verizon	1.88	0.66		
	MetroPCS	1.88	0.27	1.88	0.27
23	AT&T	2.15	0.04		
	MetroPCS	2.15	0.64	2.15	0.64
24	AT&T	2.47	0.58		
	Verizon	2.47	0.31		
25	Verizon	2.84	0.56		
26	AT&T	3.17	0.36		

Source: FCC documentation.
Note: The provisional winning bids for each round are shown in bold. MetroPCS wins and pays $1.66 million under the "As Bid" simulation method (highlighted in blue) and only $1.15 million under the "Minimum required bid" method (green).

(98) This methodology does not provide a perfect measure of the effects of excluding bidders, but it has the advantage of relying on the bids actually submitted at the auction to estimate effects. On the one hand, it will understate the revenue loss from excluding Verizon and AT&T in the following types of cases. Suppose bidder A would like to purchase one of two different licenses, which it views as substitutes, and that in the auction it wins one license and finishes as the second-highest bidder on the other, losing to Verizon. When I reevaluate the bids without Verizon, my methodology will predict that bidder A wins both licenses, when bidder A, who wants only one of the two licenses, might not have bid in such a way as to win both (even though prices are lower in the absence of Verizon). On the other hand, this methodology could theoretically overstate the revenue loss from excluding bidders if the absence of bidders such as Verizon and AT&T causes bidders to win licenses they would not have otherwise, and the acquisition of these licenses increases their value for other licenses due to complementarities, causing them to bid more aggressively on those other licenses. In addition, my methodology could theoretically overstate the revenue loss from exclusion if, for example, knowledge of the exclusion of certain bidders prior to the auction induces additional entry into the auction (in expectation of lower prices) thus increasing the competitiveness of the auction. However, I am not aware of any reason to expect that either the understatement or overstatement effect that is possible in my methodology would dominate.[53]

(99) This approach allows a detailed examination on a license-by-license basis of the potential impact of excluding specific bidders in specific markets that I believe is informative as to the likely effects of restrictions on bidder participation. In the absence of Verizon and AT&T, I expect that the bidding of other auction participants would have been largely similar (especially given the anonymous bidding format of 700 MHz Auction). Thus, I view the simulation results as informative as to the revenue reductions that one might expect to observe as a result of restrictions on the ability of Verizon and AT&T to participate.

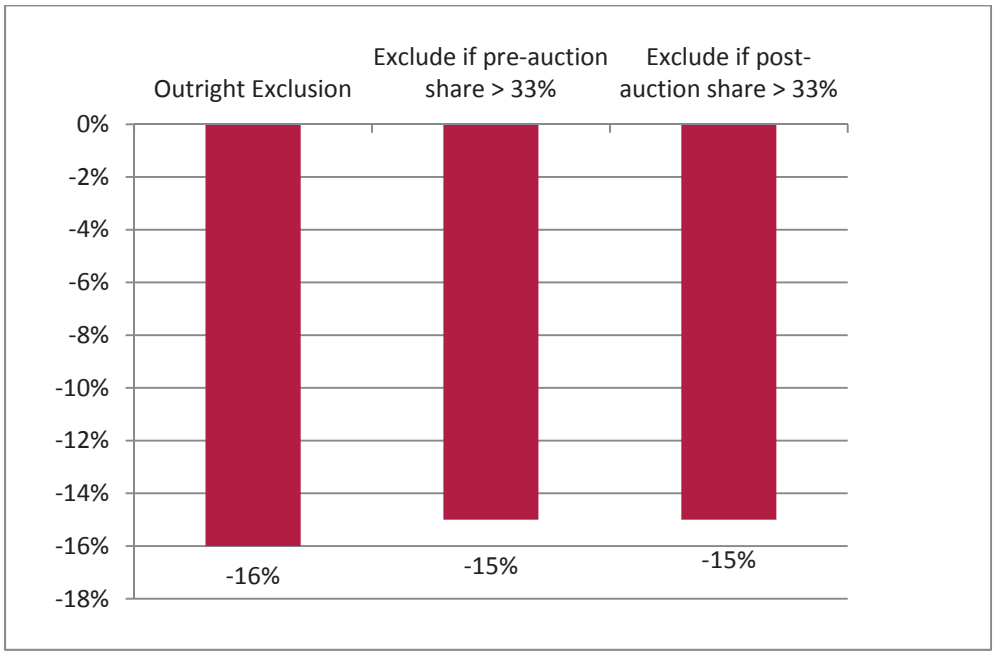
VI.B. Results—Auction 66 - AWS spectrum auction

(100) In this section I describe simulation results for the AWS auction. Appendix C describes the band plan for this auction.

(101) As previously described, I considered three scenarios: outright exclusion of AT&T and Verizon, a pre-auction 33% share cap applied to AT&T and Verizon, and a post-auction 33% share cap assuming purchase of 20 MHz in the market applied to AT&T and Verizon. Simulating the effects of these exclusion scenarios results in a 15% to 16% reduction in revenue.

[53] As discussed in Section V.C above, the empirical evidence appears to undercut the suggestion by some parties that bidding restrictions on Verizon and AT&T might increase revenue by encouraging the participation of other bidders.

Figure 13 Summary of simulated revenue reductions in the AWS spectrum auction



Source: Calculations based on the FCC data and documentation.

(102) As Figure 13 reports for the three scenarios, the simulation estimates a revenue drop of between 15 and 16%. This implies that a pre- or post-auction share cap of 33% would have had almost the same effect as outright exclusion of Verizon and AT&T in the AWS auction.

(103) I simulated the changes in the average price paid by top bidders as a result of the exclusion of Verizon and AT&T. T-Mobile enjoys the largest decrease in the average price per MHz*POP as a result of the exclusion – 18%. SpectrumCo (Sprint) enjoyed a 6% decrease in the average price it paid per MHz*POP.

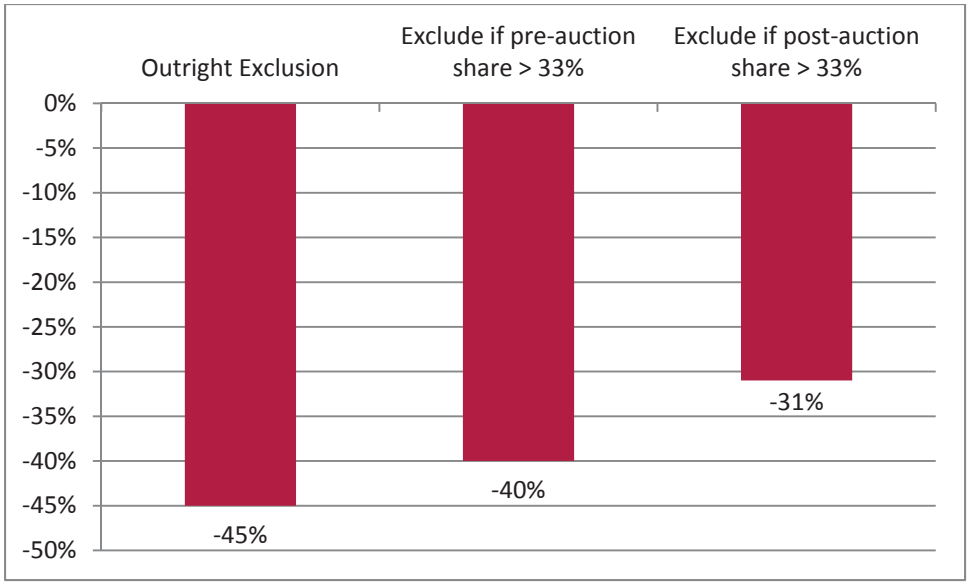
(104) Also, I calculated the results of a hypothetical version of the AWS auction in which all of the licenses were auctioned on a CMA basis. This provides a robustness check and offers a way to reduce effects related to the presence of small numbers of large licenses. The results, which are set forth in Appendix D, are similar to the results of the simulation of the actual auction.

VI.C. Results—Auction 73 - 700 MHz auction

(105) I ran a similar simulation in the 700 MHz auction. This auction involved six categories of licenses referred to as Blocks A through F. Appendix C describes the band plan for this auction.

(106) I simulate 700 MHz auction results under the same restriction scenarios as in the AWS spectrum auction simulations. Figure 14 summarizes my results.

Figure 14 Summary of simulated revenue reductions in the 700 MHz auction



Source: Calculations based on the FCC data and documentation.

(107) In this auction, the revenue drop is even more dramatic. This is likely because of the particularly intense competition between Verizon and AT&T during that auction. In the 700 MHz Auction, AT&T and Verizon often competed against each other when bidding for 12 MHz of Block B CMA-level licenses. AT&T won 227 CMA-level licenses and paid $6,637 million. Verizon won 77 CMA-level licenses and paid $2,052 million.

(108) If, hypothetically, AT&T and Verizon had not bid against each other in the auction,[54] my analysis of the auction data suggests that they would still have won all 304 CMA-level licenses, but would have paid only $4,453 million instead of $8,689 million. Thus, absent competition between AT&T and Verizon, 700 MHz auction total revenues would be $14,722 million instead of $18,958 million—22% lower. That result confirms that restrictions on Verizon and AT&T in the Incentive Auction would limit not just the participation of two significant buyers, but two significant buyers who have historically competed aggressively against one another, to the benefit of auction revenues.

(109) The fact that head-to-head competition between Verizon and AT&T was robust also contradicts the suggestion that Verizon and AT&T were pursuing a foreclosure strategy: they collectively paid over

[54] There is no basis to expect, and no party appears to assert otherwise, that Verizon and AT&T would risk violating both the FCC's bidder collusion rules and the antitrust laws by agreeing to not bid against one another.

four and a half billion dollars *more* for their spectrum than they would have had to if their goal had been to keep the spectrum out of the hands of competitors.

VII. Bidding restrictions in a simulated incentive auction

(110) In addition to the revenue simulations described above, I also simulate the effects of restricting the participation in the Incentive Auction using a theoretical model of a two-sided auction.[55] Although the model does not capture all the complexity of the Incentive Auction, it does model the important interaction between supply and demand in a two-sided auction.

(111) The interaction between supply and demand in a two-sided auction makes the problem of designing an incentive auction fundamentally different from the problem of designing a standard auction. The auctioneer does not know how much buyers are willing to pay nor how much sellers would require in order to be willing to sell. The auction mechanism must elicit this information from buyers and sellers, determine the quantities to be exchanged, and determine the amounts to be charged to buyers and paid to sellers, retaining the difference between the total amount received from buyers and the total amount paid to sellers as revenue to the auctioneer. Key ways in which a two-sided incentive auction differs from the standard one-sided auction include: [56]

1) **Fully efficient two-sided mechanisms do not generate positive revenue.** In a two-sided market, in order to guarantee that goods are reallocated to their highest-value use—in the case at hand, making sure that this one-time opportunity to reallocate broadcast spectrum to higher-value wireless services does not go to waste—the market designer must be willing to take a loss in order to induce both sides of the market to reveal their true valuation of the object. In the Incentive Auction, as previously noted, Congress and the FCC seek to generate positive revenue, so a fully efficient mechanism is not an option.

2) **The revenue-efficiency trade-off is steeper in an incentive auction.** In order to maximize revenue, the market designer must give up more in terms of the market's ability to allocate licenses to the highest valuing users than in a standard auction. Parties involved need to

[55] Our model is based on the two-sided auction mechanism of Simon Loertscher and Claudio Mezzetti (2013), "A Dominant Strategy Double Auction with Multi-Unit Traders, " Working Paper, University of Melbourne, *available at* http://www.simonloertscher.net/data/downloads/12120/LM-DoubAuc3.pdf. This paper introduces a double auction mechanism in which buyers and sellers with multi-unit demand and supply have a dominant strategy to bid truthfully. The mechanism produces nonnegative revenue for the auctioneer and traders never regret participating (ex-post individual rationality is satisfied). In this Loertscher-Mezzetti double auction, the short side of the market trades at a single price, while the long side trades at prices determined by the well-known in the economics literature Vickrey-Clarke-Groves (VCG) mechanism (with a reserve price).

[56] The discussion in this paragraph is based on Simon Loertscher, Leslie M. Marx, and Tom Wilkening (2013), "A Long Way Coming: Designing Centralized Markets with Privately Informed Buyers and Sellers," Working Paper, Duke University, available at https://faculty.fuqua.duke.edu/~marx/bio/papers/incentiveauction.pdf.

appreciate the negative efficiency consequences of demands for revenue on the Incentive Auction.

3) **The exclusion of strong buyers can have more severe consequences in an incentive auction.** An incentive auction can be more sensitive to the exclusion of a strong buyer than a standard auction. The effect is more pronounced the stronger is the strong buyer and less pronounced as the number of other buyers increases. In addition, in the Incentive Auction, a reduction in the amount of spectrum transacted has broader implications because it means that less spectrum will be reallocated from broadcast use to mobile wireless services and could potentially affect the repacking of the remaining broadcast licenses.

(112) The simple two-sided auction model that I present in this section illustrates the trade-offs that the auctioneer faces and how the exclusion of bidders negatively affects the outcomes that the auctioneer may expect to realize. The auctioneer's two conflicting goals are auction revenue maximization on one hand and efficiency maximization on the other (i.e., the goal of facilitating all transactions for which the buyer values the good more than the seller).

(113) If the auctioneer knows how much each seller and each buyer values the goods for sale, the auctioneer can achieve both goals by allowing all the trades where the buyer values the good more than the seller, and then requiring that each trading pair surrender the (positive) difference between their two values. However, in real world situations, the auctioneer will not know how much each seller and each buyer values the goods for sale, and therefore the auctioneer needs to design a mechanism to induce them to reveal such private information through their bids. In order to earn revenue, the auctioneer necessarily must reduce the number of trades below the efficient level. The distortion in the number of transactions may be large if the auctioneer seeks to maximize its revenue from the two-sided auction at the expense of efficiency.

(114) In what follows, I show how market conditions, including the number of potential traders and their uncertain valuations from the auctioneer's point of view, give rise to a range of possible outcomes. These outcomes reflect the inherent trade-off in two-sided markets between auctioneer revenue and the efficiency of the auction. The outcome implemented by an auctioneer will depend on the auctioneer's preferences between the two conflicting goals. I show that the exclusion of bidders can substantially worsen the range of outcomes available to the auctioneer.

VII.A. Procedure

(115) I calculate a relatively simple example to illustrate the trade-off between auctioneer revenue and efficiency and the effect of bidder exclusion. Given that this model is purely illustrative and not meant to be a quantitative prediction of the effects of exclusion, I do not attempt to calibrate it to

expected parameter values. In my set-up, 10 potential sellers each holding 1 unit of a homogenous good face 5 potential buyers, each interested in purchasing up to 4 units.

(116) The auctioneer does not know how much the potential sellers value the units that they own. The auctioneer only knows that the value for any given seller is between $0 and $1 and that values between $0 and $1 are equally likely. Thus, I assume that the auctioneer expects that, on average, an individual seller values her unit at $0.50, but the auctioneer knows that among the 10 sellers some sellers will randomly draw values much less than $0.50 (and hence, relatively more willing to sell) and some sellers will randomly draw values much more than $0.50 (hence, relatively less willing to sell). In particular, the auctioneer expects that, if it could see the valuations and line them up from lowest to highest, there would be a range of seller values spread between $0 and $1.[57]

(117) Similarly, the auctioneer does not know how much potential buyers are willing to pay for each of the 4 units each buyer is interested in. The auctioneer only knows that the value any given buyer places on a unit is between $0 and $1, but I assume that values greater than $0.50 are relatively more likely so that the auctioneer expects that, on average, an individual buyer will value an individual unit at $0.75.[58]

(118) To illustrate the trade-off between auction revenue and auction efficiency, I consider the outcomes the auctioneer can expect to achieve if it runs a two-sided auction mechanism based on the work of Loertscher and Mezzetti (2013). We can view the mechanism as a two-sided version of a multi-unit Vickrey auction with a reserve price,[59] which is a multi-unit extension of a second-price auction, in which bidders submit bids and the high bidder wins but pays only the amount of the second-highest bid. In Appendix E, I provide the technical details behind the illustrative simulations results presented in this section.

VII.B. Results

(119) A two-sided auction can be designed to emphasize revenue or to emphasize efficiency through the selection of auction design parameters. In the model I use, a design that provides relatively high payments to sellers encourages them to supply more units, which tends to increase efficiency but reduce expected auctioneer revenue. A design that provides relatively low payments to sellers not only lowers the price paid to sellers but also reduces the number of units supplied, which increases

[57] I assume that sellers draw values randomly from the uniform distribution over the unit interval.

[58] More formally, I assumed that each buyer's value for a given unit is a random variable with support [$0, $1] and cumulative distribution $F(x) = x^3$.

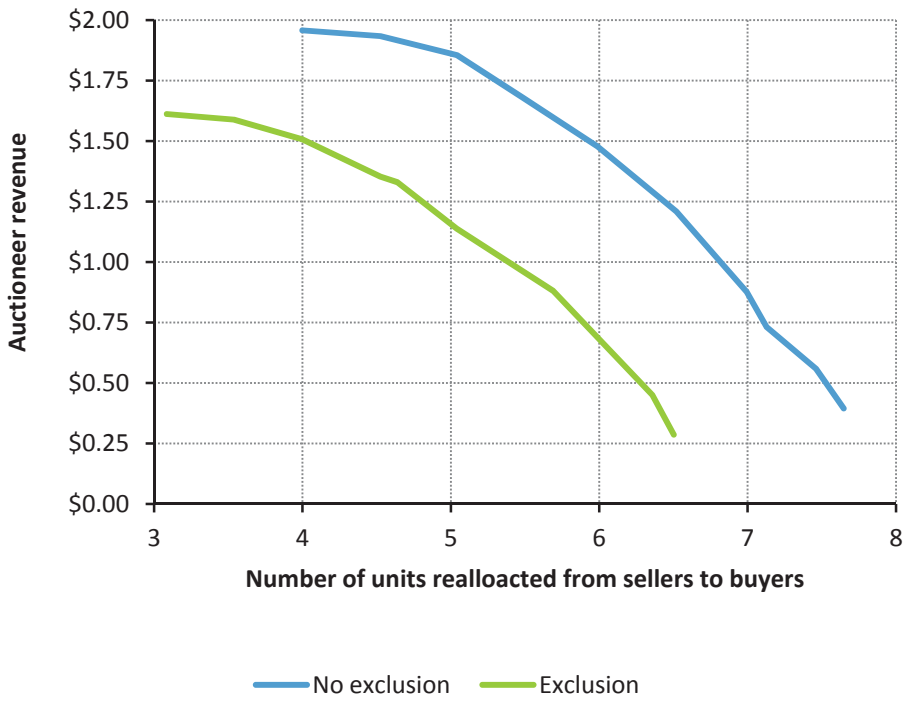
[59] See Vickrey, William (1961), "Counterspeculation, Auctions, and Competitive Sealed Tenders," *Journal of Finance*, 16: 8-37. This mechanism is sometimes referred to as a Vickrey-Clarke-Groves auction, as Clarke and Groves independently reached similar conclusions, see Clarke, E.H. (1971), "Multipart Pricing of Public Goods," *Public Choice*, XI, 17-33, Groves, Theodore (1973), "Incentives in Teams," *Econometrica*, 41: 617-31.

competition among the buyers and thus increases the average price buyers pay and the expected revenue to the auctioneer. Therefore, depending on the auction design, the auctioneer can emphasize revenue, efficiency, or balance the two.

(120) That trade-off in my model is depicted in Figure 15. (See Appendix E for the details underlying this illustration.) Expected auctioneer revenue is on the vertical axis, and the expected number of units reallocated or traded is represented on the horizontal access, where a larger number of units reallocated implies that the auction is more efficient. The curves in Figure 15 are downward sloping, which indicates that auction designs that produce greater expected revenue also produce a lower expected number of trades.

(121) The blue line in Figure 15 shows the combinations of average revenue and numbers of trades that are feasible without exclusion. That is, without exclusion, if the auction is designed to maximize revenue, the auctioneer can expect to earn nearly $2 with an average of 4 units changing hands. If instead the auction is designed to maximize efficiency, the auctioneer will expect to earn less than $0.50 with an average of approximately 7.5 units changing hands. The blue curve between these two extremes represents all of the intermediate combinations of expected revenue and number of trades that are achievable depending on the auction design parameters chosen.[60] Similarly, the green curve depicts the combinations that are achievable if two of the five identical buyers are excluded.

Figure 15 Expected number of trades and auction revenues in a simple two-sided auction



Source: Calculations.

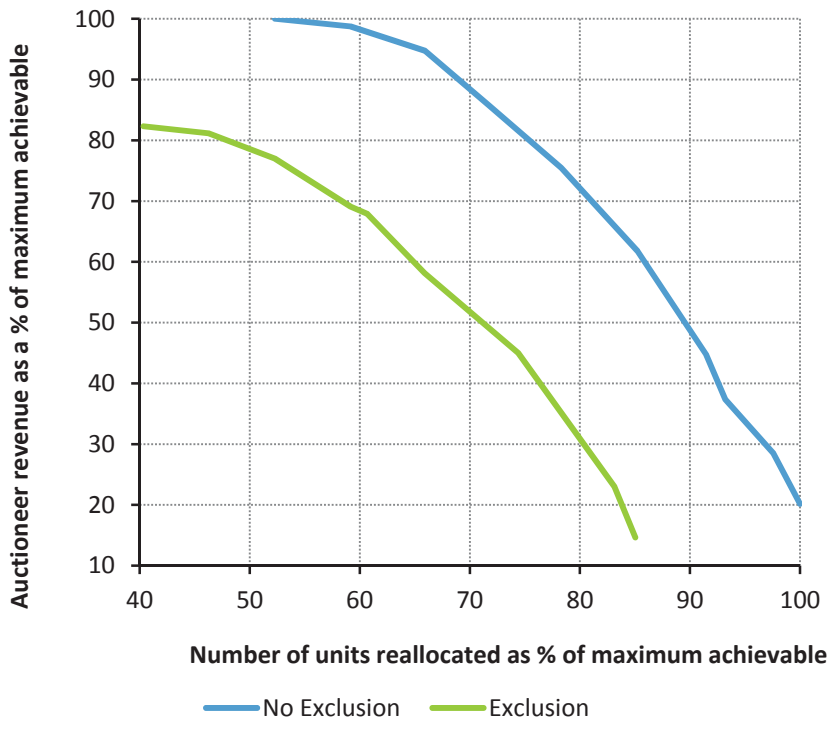
VII.B.1. Exclusion of bidders in a two-sided mechanism worsens the choices available to an auctioneer

(122) In my illustrative model, the number of units traded are not calibrated to real-world values, so I redraw Figure 15 to express the *shift inward of the auction outcomes under exclusion* as a percentage

[60] These combinations of revenue and numbers of trades are achievable in an expected sense. The values of the buyers and sellers are random in the model. Therefore, for a given reserve price the number of trades and revenue will depend on the actual values drawn. The combinations of revenue and numbers of trades are the mean outcomes when values are redrawn and auction rerun many times.

of the maximum number of trades achievable under no exclusion—the point representing approximately 7.5 units in Figure 15 corresponds to 100 units in Figure 16 below. Similarly, because auction revenues in the model are not calibrated to real-world values, I redraw the figure so that approximately $2.00 in auctioneer revenues in Figure 15 corresponds to 100 in Figure 16.

Figure 16 Impact of exclusion in a simple two-sided auction (max trades under no exclusion=100; max auctioneer revenue under no exclusion=100)



Source: Calculations.

(123) As shown in Figure 16, exclusion reduces the maximum auctioneer revenue by just under 20%. (You can see this in the figure by noting that the maximum revenue value for the green line is just over 80.) Exclusion also reduces the efficiency-maximizing number of trades by approximately 15%. (The maximum number of trades for the green line is approximately 85.) An auctioneer aiming to find a compromise solution between these two conflicting targets stands to lose more than 20% on auction revenue and more than 15% on efficiency from exclusion. (The green line is more than 20% below the blue line, except close to the point of maximum revenue where it is slightly less than 20% below, and the green line is more than 15% to the left of the blue line.)

(124) The set of revenue levels and numbers of transactions that can be achieved in a two-sided mechanism shifts down and to the left (towards lower revenue levels and fewer trades) when buyers are excluded. Bidding restrictions mean that the maximum possible revenue is reduced and the maximum number

of transactions that can be achieved is reduced. Furthermore, the feasible set of revenue levels and numbers of transactions is worsened from the perspective of the auctioneer.

VII.B.2. Exclusion of bidders in a two-sided mechanism can cause revenue and transaction goals to be unattainable

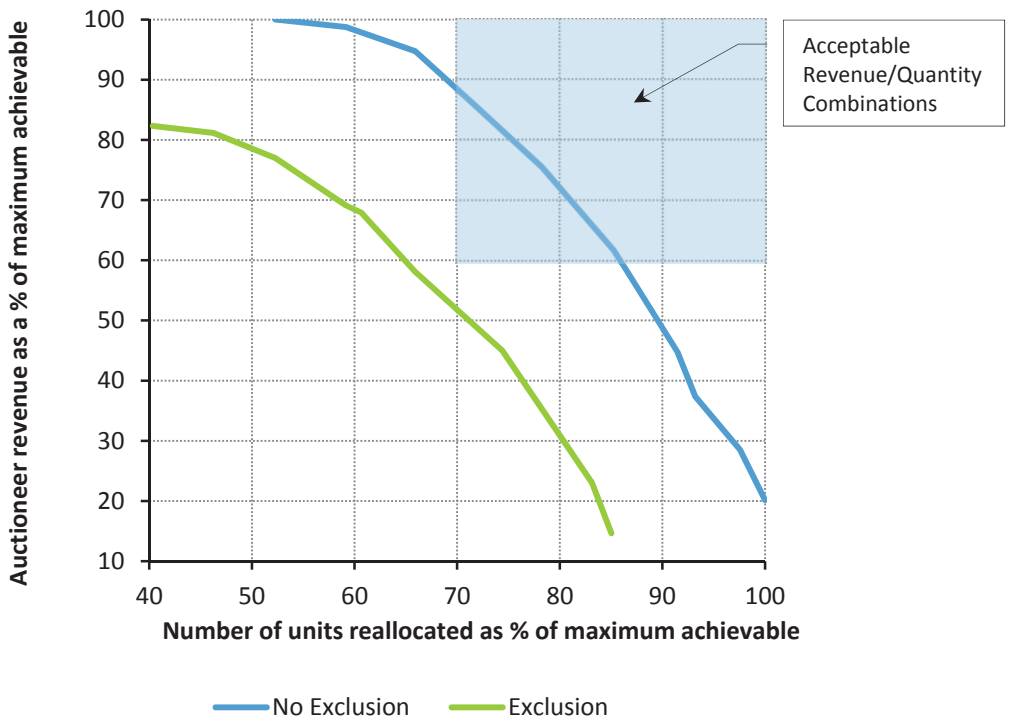
(125) As described above (see para. (20)), the Incentive Auction must raise a minimum level of revenue in order to succeed in reallocating licenses from broadcast TV to mobile wireless services. In addition, although not required by the authorizing legislation, it is clear that the Incentive Auction is being relied upon to fund the First Responder Network Authority (FirstNet) (see fn. 7).

(126) Furthermore, the National Broadband Plan calls for the FCC to take steps to reallocate 120 MHz from the broadcast TV bands as part of the goal of making an additional 300 megahertz between 225 MHz and 3.7 GHz available for mobile use by 2015. As described in the National Broadband Plan, "Incentive auctions can be especially useful where fragmentation of spectrum licenses makes it difficult for private parties to aggregate spectrum in marketable quantities."[61]

[61] National Broadband Plan, Section 5.3, http://www.broadband.gov/.

(127) If minimum thresholds of revenue and quantity transacted are required for the auction to succeed, then the elimination of two buyers can make achieving those thresholds impossible, causing the auction to fail. This case is illustrated in Figure 17, which assumes that auction success requires at least 70% of the maximum number of trades and 60% of the maximum revenue achievable under unrestricted competition. The blue-shaded box represents the range of outcomes that satisfy both requirements for auction success. As Figure 17 shows, exclusion results in failure to satisfy either requirement.

Figure 17 Exclusion may cause the illustrative two-sided auction to fail



Source: Calculations.

(128) My understanding is that there are substantial technical challenges associated with configuring a band plan that makes a reasonable amount of paired spectrum available to wireless operators. Specifically, I understand that no party has presented a band plan designed to repurpose paired spectrum if the amount of cleared spectrum is less than 72 MHz in numerous markets because that is the minimum amount needed to configure a 25x25 MHz band plan. Given the potentially drastic result of an outcome where that minimum clearing threshold is not met, imposing restrictions that would materially suppress the quantity of spectrum repurposed would present a particularly acute risk of outright auction failure.

(129) Therefore, bidding restrictions on buyers at the Incentive Auction have the potential to create an environment in which the goals for the Incentive Auction of revenue generation and spectrum reallocation cannot be achieved. In this sense, bidding restrictions can cause the Incentive Auction to fail.

VII.C. Proposals for a contingent auction would distort the auction process and potentially contribute to auction failure

(130) T-Mobile recently proposed that the FCC apply strict bidding restrictions to Verizon and AT&T, but if certain revenue goals are not met, then the restrictions would be relaxed and the auction rerun, and so on, relaxing the restrictions repeatedly until revenue goals are met.[62] That proposal would increase the complexity of an already complex Incentive Auction and would increase the risk of auction failure. Rerunning auctions can cause a number of problems from increased risk of coordinated bidding to distorted bidding incentives in an effort to game the system, which in complicated auctions can be difficult to predict and therefore avoid. In addition, even if such a mechanism theoretically allows the auction to achieve a revenue target, bidding restrictions will still decrease the amount of reallocated spectrum. Perhaps the most fundamental problem with the T-Mobile proposal is that it subverts the benefits of a two-sided auction as a means of determining the efficient allocation. The proposal would use a revenue target determined outside of the auction context to determine the amount of spectrum to be reallocated, but there is no way such a revenue target can reasonably be expected to achieve an efficient reallocation. If the auction were to meet the arbitrary set of revenue targets with restrictions on Verizon and AT&T, it is likely that the auction would have reallocated additional spectrum and/or raised more revenue had there been no restrictions.

(131) It has been shown in the economics literature that contingent re-auctions are generally neither efficient nor optimal for the seller.[63] Strategic bidding in the 700 MHz auction as a result of the contingent re-auction format has been documented in the economics literature.[64] In order to avoid incentives for strategic bidding in the proposed auction format, detailed and potentially complex and restrictive activity rules would have to be put in place. However, such complicated restrictions would likely reduce the efficiency of the auction and would themselves create additional harmful effects.

(132) One such harmful effect is illustrated by T-Mobile's attempt to address potential strategic bidding incentives by imposing an "activity rule" under which restrictions would be relaxed *only* in markets where the restricted bidders are actively bidding. That rule creates an exposure risk because it may

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[62] See http://apps.fcc.gov/ecfs/document/view?id=7520934888.

[63] Sandro Brusco, Giuseppe Lopomo, and Leslie M. Marx (2011), "The Economics of Contingent Re-Auctions," *American Economic Journal: Microeconomics* 3(2), 165-193.

[64] Sandro Brusco, Giuseppe Lopomo, and Leslie M. Marx (2009), "The 'Google Effect' in the FCC's 700 MHz Auction," *Information Economics and Policy* 21, 101–114.

require restricted bidders to bid on licenses that in and of themselves are of little value in order to retain and expand their eligibility to bid on the licenses they actually want. Take the example of a restricted bidder whose business plan calls for a 10x10 MHz license in a particular market and who places little value on a single 5x5 license. If the bidder only has "headroom" under the cap to bid on a single 5x5 MHz licenses, under T-Mobile's proposal it would need to bid on a license that has little value by itself in order to have a chance of acquiring the license it does want. A firm in that position may choose not to bid on the smaller license because of the risk that it wins it without the ability also to acquire the complementary licenses that are needed for its business plan. That exposure problem is further complicated and exacerbated by the fact that, under the cap, firms will have different levels of headroom in different markets, which introduces an additional layer of complexity for firms interested in acquiring footprint-wide licenses of particular sizes.

(133) T-Mobile's proposal would also compromise the ability of restricted bidders to move their demand between geographic markets based on price feedback received during the auction. Consider a firm that is interested in acquiring a license in either Milwaukee or Kansas City, but not in both markets. Under a normal auction, that bidder could first seek to acquire a license in Kansas City and see how the bidding proceeds there, and then it may choose to shift its demand to Milwaukee if the Kansas City license becomes too expensive. Auction designs that support the ability of bidders to move demand between markets have been promoted by the FCC. But under the proposal, that strategy would be prohibited because the firm would lose its ability to bid in Milwaukee if it has not been actively bidding there starting in round one. The result is that a rational firm may not acquire *any* license even though it would have acquired a license in an unrestricted auction.

(134) The exposure risks and strategic bidding incentives created by the proposal would not be limited to the restricted bidders. For example, the risk that the proposal leaves money on the table is heightened by the fact that non-restricted bidders would have the incentive to bid strategically to ensure that the revenue is target is met, but not exceeded, in order to avoid letting the restricted bidders have the opportunity to bid on more spectrum, which would increase overall bidding.

(135) In sum, my prediction on the auction outcome under T-Mobile's proposal is that Sprint and T-Mobile would raise their bids just enough to meet the revenue target and win the licenses at depressed prices. They and/or other winners at the auction would then have the ability to sell that spectrum on the secondary market to Verizon and AT&T at higher prices.

VIII. Conclusion

(136) I have analyzed proposals to restrict the participation of Verizon and AT&T in the Incentive Auction in order to prevent the anticompetitive foreclosure of smaller rivals. The evidence does not support assertions that anticompetitive foreclosure is likely. (1) I have reviewed the outcomes of previous

auctions and find no evidence of foreclosure. (2) The evidence from secondary market transactions and previous auctions suggests that Sprint and T-Mobile failed to take advantage of numerous opportunities to purchase low-frequency spectrum. (3) A review of the pricing plans offered by Verizon, AT&T, Sprint, and T-Mobile is consistent with the conclusion that the networks of Verizon and AT&T are capacity constrained relative to Sprint and T-Mobile, implying that little would be gained from foreclosing Sprint and T-Mobile. (4) As both Verizon and AT&T would supposedly benefit from foreclosure of Sprint and T-Mobile, incentives to free ride on the other's efforts would further reduce any gains from foreclosure. (5) Successful foreclosure is complicated and made more costly by the fact that, in the Incentive Auction, an increase in bid amounts to deny Sprint and T-Mobile spectrum will tend to increase the amount of spectrum supplied to the market. (6) Finally, the market for wireless services does not appear to be sufficiently concentrated to make foreclosure profitable.

(137) While not addressing a real problem, proposals to restrict the bidding of Verizon and AT&T conflict with the goals of the Incentive Auction: reallocation of spectrum to higher valued uses and revenue generation. In order to assess the impact of bidding restrictions, I have simulated their impact on Auction 66 (AWS) and Auction 73 (700 MHz) and found that restrictions would have significantly reduced the revenue generated in those auctions. In addition, I have simulated the exclusion of two bidders in an illustrative example of a two-sided market similar in structure to the Incentive Auction. The results illustrate the trade-off faced by an auctioneer in a two-sided setting between revenue generation and efficiency. Excluding bidders reduces both the amount of spectrum reallocated and the potential revenue generated.

(138) The Incentive Auction represents a unique opportunity to reallocate underutilized spectrum to higher valued uses. It would be particularly unwise to artificially reduce demand in the Incentive Auction through restrictions on the bidding of Verizon and AT&T. Bidding restrictions conflict with the goals of the Incentive Auction by reducing both the amount of spectrum reallocated and the revenue potential of the auction. Such restrictions risk a complete failure of the auction by making the achievement of minimum revenue and spectrum reallocation thresholds impossible to achieve. Despite the evidence I have presented, if the FCC believes that foreclosure by Verizon and AT&T of smaller rivals is a real problem, I urge the FCC to consider other less distortionary policies to address the potential problem, such as build-out requirements and anonymous bidding. Complicated bidding procedures and bidding restrictions on top of an already complicated two-sided auction put at risk the goals of the Incentive Auction. I find such proposals both unnecessary and counterproductive.

Appendix A. Curriculum vitae of Leslie M. Marx, PhD

A.1. Education

- PhD, Economics, Northwestern University
- MA, Economics, Northwestern University
- BS, Mathematics, Duke University

A.2. Professional experience

- Fuqua School of Business, Duke University, Robert A. Bandeen Professor of Economics, 2013–present
- Fuqua School of Business, Duke University, William and Sue Gross Research Fellow and Professor of Economics, 2012–2013
- Fuqua School of Business and Department of Economics, Duke University, Professor of Economics, 2008–2013
- Associate Professor of Economics, Fuqua School of Business, Duke University, 2002–2008
- Chief Economist, U.S. Federal Communications Commission, August 2005–August 2006
- Associate Professor of Economics and Management, W.E. Simon Graduate School of Business Administration, University of Rochester, 2000–2002
- Visiting Associate in Economics, California Institute of Technology, January 2000–June 2000
- Associate Professor of Economics and Management, W.E. Simon Graduate School of Business Administration, University of Rochester, 1999–2000
- Assistant Professor of Economics and Management, W.E. Simon Graduate School of Business Administration, University of Rochester, 1994–1999

A.3. Teaching

- MBA: Managerial Decision Analysis, Managerial Game Theory, Environmental Economics
- Executive MBA: Managerial Economics, Managerial Decision Analysis, Managerial Game Theory
- PhD: Game Theory, Industrial Organization

A.4. Publications

- "Tacit Collusion in Oligopoly" (with Edward Green and Robert C. Marshall). In *Oxford Handbook of International Antitrust Economics*, eds. Roger D. Blair and D. Daniel Sokol. Oxford University Press, forthcoming.
- "Economics and the Efficient Allocation of Spectrum Licenses" (with Simon Loertscher). In *Mechanisms and Games for Dynamic Spectrum Access*, eds. Tansu Alpcan, Holger Boche, Michael L. Honig, and H. Vincent Poor. Cambridge University Press, forthcoming.
- "The Economics of Auctions and Bidder Collusion" (with Robert C. Marshall and Michael J. Meurer). In *Game Theory and Business Applications*, 2nd ed., eds. Kalyan Chatterjee and William F. Samuelson. New York: Kluwer Academic Publishers, forthcoming.
- *The Economics of Collusion: Cartels and Bidding Rings* (with Robert C. Marshall). Cambridge: MIT Press, 2012.
- "Plus Factors and Agreement in Antitrust Law" (with William E. Kovacic, Robert C. Marshall, and Halbert L. White). *Michigan Law Review* 110, no. 3 (2011): 393–436. Winner of the Tenth Annual Jerry S. Cohen Memorial Fund Writing Award given for the best antitrust writing during the prior year.
- "Bidder Collusion at First-Price Auctions" (with Giuseppe Lopomo and Peng Sun). *Review of Economic Design* 15, no. 3 (2011): 177–211.
- "Carbon Allowance Auction Design: An Assessment of Options for the U.S." (with Giuseppe Lopomo, David McAdams, and Brian Murray). *Review of Environmental Economics and Policy* 5, no. 1 (2011): 25–43.
- "Coordinated Effects in the 2010 Horizontal Merger Guidelines" (with Wayne-Roy Gayle, Robert C. Marshall, and Jean-Francois Richard). *Review of Industrial Organization* 39, no. 1 (2011): 39–56.
- "The Economics of Contingent Re-Auctions" (with Sandro Brusco and Giuseppe Lopomo). *American Economic Journal: Microeconomics* 3, no. 2 (2011): 165–93.
- "Break-Up Fees and Bargaining Power in Sequential Contracting" (with Greg Shaffer). *International Journal of Industrial Organization* 28, 451–463 (2010).
- "Slotting Allowances and Scarce Shelf Space" (with Greg Shaffer). *Journal of Economics & Management Strategy* 19, no. 3 (2010): 575–603.
- "Cartels as Two-Stage Mechanisms: Implications for the Analysis of Dominant-Firm Conduct" (with Randall D. Heeb, William E. Kovacic, and Robert C. Marshall). *Chicago Journal of International Law* 10, no. 1 (2009): 213–31.

- "Individual Accountability in Teams" (with Francesco Squintani). *Journal of Economic Behavior & Organization* 72, no. 1 (2009): 260–73.
- "Quantitative Analysis of Coordinated Effects" (with William E. Kovacic, Robert C. Marshall, and Steven P. Schulenberg). *Antitrust Law Journal* 76, no. 2 (2009): 397–430.
- "The 'Google Effect' in the FCC's 700 MHz Auction" (with Sandro Brusco and Giuseppe Lopomo). *Information Economics and Policy* 21 (2009): 101–14.
- "The Vulnerability of Auctions to Bidder Collusion" (with Robert C. Marshall). *Quarterly Journal of Economic*s 124, no. 2 (2009): 883–910.
- "Cartel Price Announcements: The Vitamins Industry" (with Robert C. Marshall and Matthew E. Raiff). *International Journal of Industrial Organization* 26 (2008): 762–802. Awarded the 2009 Paul Geroski Best Article Prize for one of the best two articles published in the *International Journal of Industrial Organization* in 2008.
- "Bidder Collusion" (with Robert C. Marshall). *Journal of Economic Theory* 133 (2007): 374–402.
- "Coordinated Effects in Merger Review: Quantifying the Payoffs from Collusion" (with William E. Kovacic, Robert C. Marshall, and Steven P. Schulenberg). In *Annual Proceedings of the Fordham Competition Law Institute: International Antitrust Law & Policy*, ed. Barry E. Hawk, 271–85 (Huntington, NY: Juris Publishing, Inc., 2007).
- "Exploring Relations Between Decision Analysis and Game Theory" (with Jules van Binsbergen). *Decision Analysis* 4 (2007): 32–40.
- "Lessons for Competition Policy from the Vitamins Cartel" (with William E. Kovacic, Robert C. Marshall, and Matthew E. Raiff). In *The Political Economy of Antitrust*, vol. 282, eds. Vivek Ghosal and Johan Stennek, 149–176 (New York: Elsevier, 2007).
- "Rent Shifting and the Order of Negotiations" (with Greg Shaffer). *International Journal of Industrial Organization* 25 (2007): 1109–25.
- "Upfront Payments and Exclusion in Downstream Markets" (with Greg Shaffer). *RAND Journal of Economics* 38 (2007): 823–43.
- "Bidding Rings and the Design of Anti-Collusion Measures for Auctions and Procurements" (with William E. Kovacic, Robert C. Marshall, and Matthew E. Raiff). In *Handbook of Procurement*, eds. Nicola Dimitri, Gustavo Piga, and Giancarlo Spagnolo, 381–411 (Cambridge: Cambridge University Press, 2006).
- "Economics at the Federal Communications Commission." *Review of Industrial Organization* 29 (2006): 349–68.

- "Inefficiency of Collusion at English Auctions" (with Giuseppe Lopomo and Robert C. Marshall). *Contributions in Theoretical Economics* 5, no. 1 (2005): article 4, http://www.bepress.com/bejte/contributions/vol5/iss1/art4.
- "Opportunism and Menus of Two-Part Tariffs" (with Greg Shaffer). *International Journal of Industrial Organization* 22 (2004): 1399–1414.
- "Opportunism in Multilateral Vertical Contracting: Nondiscrimination, Exclusivity, and Uniformity: Comment" (with Greg Shaffer). *American Economic Review* 94 (2004): 796–801.
- "The Joint Determination of Leverage and Maturity" (with Michael J. Barclay and Clifford W. Smith, Jr.). *Journal of Corporate Finance* 9 (2003): 149–67. Winner of Outstanding Paper in Corporate Finance at the 1997 Southern Finance Association Meetings.
- "Adverse Specialization" (with Glenn M. MacDonald). *Journal of Political Economy* 109 (2001): 864–99.
- "Insurer Ownership Structure and Executive Compensation as Complements" (with David Mayers and Clifford W. Smith, Jr.). *Journal of Risk and Insurance* 68 (2001): 449–63. Winner of Outstanding Paper in Financial Services at the 1998 Southern Finance Association Meetings.
- "Dynamic Voluntary Contribution to a Public Project" (with Steven A. Matthews). *Review of Economic Studies* 67 (2000): 327–58.
- "Adaptive Learning and Iterated Weak Dominance." *Games and Economic Behavior* 26 (1999): 253–78.
- "Odd-Eighth Avoidance as a Defense Against SOES Bandits" (with Eugene Kandel). *Journal of Financial Economics* 51 (1999): 85–102.
- "Payments for Order Flow on Nasdaq" (with Eugene Kandel). *Journal of Finance* 54 (1999): 35–66.
- "Predatory Accommodation: Below-Cost Pricing Without Exclusion in Intermediate Goods Markets" (with Greg Shaffer). *RAND Journal of Economics* 30 (1999): 22–43.
- "Process Variation as a Determinant of Bank Performance: Evidence from the Retail Banking Study" (with Frances Frei, Ravi Kalakota, and Andrew Leone). *Management Science* 45 (1999): 1210–20.
- "Efficient Venture Capital Financing Combining Debt and Equity." *Review of Economic Design* 3 (1998): 371–87; Winner of the Koç University Prize for the Best Paper of the Year in Review of Economic Design.
- "The Effects of Transaction Costs on Stock Prices and Trading Volume" (with Michael J. Barclay and Eugene Kandel). *Journal of Financial Intermediation* 7 (1998): 130–50.

- "Cost Effective Use of Muscle Relaxants: A Decision Analysis" (with Jeffrey S. Rubenstein, Wendy Colin, Darryl Jackson, Craig Lockwood, and Janice Molloy). *Pediatrics* 100 (1997): 451–52.
- "Nasdaq Market Structure and Spread Patterns" (with Eugene Kandel). *Journal of Financial Economics* 45 (1997): 35–60.
- "Order Independence for Iterated Weak Dominance" (with Jeroen M. Swinkels). *Games and Economic Behavior* 18 (1997): 219–45. "Corrigendum." GEB 31 (2000): 324–29.

A.5. Working papers

- "Antitrust Leniency with Multi-Product Colluders" (with Robert C. Marshall and Claudio Mezzetti), 2013.
- "A Long Way Coming: Designing Centralized Markets with Privately Informed Buyers and Sellers" (with Simon Loertscher and Tom Wilkening), 2013.
- "Monopolization Conduct by Cartels" (with Robert C. Marshall and Lily Samkharadze), 2013.
- "Buyer Resistance for Cartel versus Merger" (with Vikram Kumar, Robert C. Marshall, and Lily Samkharadze), 2013.
- "Buyer Power, Exclusion, and Inefficient Trade" (with Greg Shaffer), 2009.
- "Opportunism and Nondiscrimination Clauses" (with Greg Shaffer), 2002.

A.6. Grants

- National Science Foundation Grant #SES-0849349, Applied Mechanism Design, 2009–2011
- National Science Foundation Grant #SES-0001903, "Economic Analysis of Sequential Vertical Contracting Environments," 2000–2001
- Emerging Scholar Program Grant from the American Compensation Association, "Compensation and Control in Entrepreneurial Ventures," 1997

A.7. Selected honors and awards

- Honored as an FCC Woman Leader by The Minority Media and Telecommunications Council, April 2013
- Honored as one of the *Global Competition Review* Top 100 Women in Antitrust, March 2013
- Named *Financial Times* Business School Professor of the Week, July 2012

- Awarded the 2012 Tenth Annual Jerry S. Cohen Memorial Fund Writing Award, given to the best antitrust writing during the prior year (Awarded for "Plus Factors and Agreement in Antitrust Law," published in the *Michigan Law Review*)
- Awarded the 2009 Paul Geroski Best Article Prize for one of the best two articles published in the *International Journal of Industrial Organization* in 2008
- Simon School Teaching Honor Roll, 1999, 2001
- Koç University Prize for the Best Paper of the Year in Review of Economic Design, 1998
- Outstanding Paper in Financial Services at the Southern Finance Association Meetings, 1998
- Outstanding Paper in Corporate Finance at the Southern Finance Association Meetings, 1997
- Alfred P. Sloan Doctoral Dissertation Fellowship, 1993–1994
- National Science Foundation Graduate Fellowship, 1989–1992

A.8. Professional activities

- Council Member of Game Theory Society, 2013–present
- Editorial Board of *International Journal of Game Theory*, 12/2009-present
- Editorial Board of *Journal of Economic Literature*, 2010–2012
- Advisory Editor for *Games and Economic Behavior*, 2010–2012
- Editorial Board of *American Economic Journal: Microeconomics*, 2007–present
- Academic Affiliate of the Center for the Study of Auctions, Procurements and Competition Policy at Penn State University, 2007–present
- Associate Editor, *International Economic Review*, 2002–2005

Appendix B. Secondary market transactions, all bands

Figure 18 Number of transactions, all bands, January 2007–May 2013 (whole and partial licenses)

Counts of trades		Buyer					
		Verizon	ATT	T-Mobile	Sprint	Other	Total
Seller	Verizon		162	63	12	108	345
	ATT	15		85	8	29	137
	T-Mobile	127	36		28	43	234
	Sprint	15	16	17		28	76
	Other	1,010	1,350	121	33	1,847	4,361
	Total	1,167	1,564	286	81	2,055	5,153
	buy/sell ratio	*3.38*	*11.42*	*1.22*	*1.07*	*0.47*	

Source: Calculations based on FCC data and documentation.

Appendix C. Band plans for spectrum auctioned in the AWS and 700 MHz auctions

(139) The figures in this appendix provide background information on the band plans used in the AWS and 700 MHz Auctions.

Figure 19 Auction 66 (AWS-1) band plan, reserve price, and minimum opening bids

Block	Frequencies	Pairing	Bandwidth	Area	Licenses	Total of Minimum Opening Bid Amounts
A	1710-1720 and 2110-2120 MHz	2 x 10 MHz	20 MHz	CMA	734	$259,332,500
B	1720-1730 and 2120-2130 MHz	2 x 10 MHz	20 MHz	EA	176	$259,342,000
C	1730-1735 and 2130-2135 MHz	2 x 5 MHz	10 MHz	EA	176	$129,678,000
D	1735-1740 and 2135-2140 MHz	2 x 5 MHz	10 MHz	REAG	12	$129,672,000
E	1740-1745 and 2140-2145 MHz	2 x 5 MHz	10 MHz	REAG	12	$129,672,000
F	1745-1755 and 2145-2155 MHz	2 x 10 MHz	20 MHz	REAG	12	$259,341,000
Totals					1,122	$1,167,037,500

Source: FCC documentation.
Note: As for the reserve price, the FCC ruled as follows: “the winning bids (net of bidding credits) in the auction must total at least approximately $2.06 billion in order for the Commission to conclude the auction and award the licenses.” (FCC 06-47, April 12, 2006)

Figure 20 Auction 73 (700 MHz) band plan, reserve prices, and winning bids

Block	Frequencies	Pairing	Bandwidth	Area	Licenses	Reserve Price ($ millions)	Actual Net Winning Bids ($ millions)	Net Bids with outright exclusion ($ millions)
A	698-704, 728-734	2 x 6 MHz	12 MHz	EA	176	1,807	3,876	2,279
B	704-710, 734-740	2 x 6 MHz	12 MHz	CMA	734	1,374	9,068	2,704
C	746-757, 776-787	2 x 11 MHz	22 MHz	REAG	12	4,638	4,747	4,717
D	758-763, 788-793	2 x 5 MHz	10 MHz	Nationwide	1	1,330	Unsold	Unsold
E	722-728	unpaired	6 MHz	EA	176	904	1,267	1,241
Total			62 MHz		1,099	10,053	18,958	10,942

Source: FCC documentation.

Appendix D. Results assuming CMA-only licenses

(140) In Auction 66, AWS licenses were defined over 734 small Cellular Market Areas (CMA), over 176 larger Economic Areas (EA), and over 12 large Regional Economic Area Groups (REAG). Under the 33% share exclusion rule, if the weighted average MHz market share of low-band spectrum for a large REAG were below 33%, AT&T and Verizon would be allowed to bid for such a license. However, if the proposed Incentive Auction is conducted at the CMA level, AT&T and Verizon would be excluded from many CMA markets within the REAG. Alternatively, AT&T or Verizon could be excluded from a particular REAG as a result of the 33% share exclusion rule, but would have been allowed to bid in many of the CMA markets within the REAG. Therefore, basing exclusion on shares in larger geographic regions may distort the degree of exclusion from the 33% share exclusion rule. As a robustness check, we rescale the AWS spectrum auction so that all licenses are over a CMA. I find that my results are generally consistent with my simulation results without this rescaling.

(141) In order to account for the circumstances described above, I use the Auction 66 results to create a new set of auction results. For each EA and REAG license, I create a set of artificial licenses associated with each CMA within an EA or REAG. In order to simulate bidding on these artificial CMAs, I assume that the bidders on the artificial CMA licenses are the same as the bidders for the associated EA or REAG, and I allocate the bids on the EA or REAG to the artificial CMA licenses proportionally to the population of the CMA. By creating these artificial CMA licenses, I create an auction in which each CMA has 6 licenses associated with it, one from Block A, which was the original CMA license, and others from Blocks B, C, D, E, and F, represented by the artificial licenses with scaled-down bids.[65] In this way, I can demonstrate how simulation results change if the 33% share cap is applied at the CMA level instead of at the EA or REAG level.

(142) The results based on the artificial auction with CMA-only licenses do not differ much from the original simulation results. The auction revenue would fall significantly in all scenarios: from 16% in the outright exclusion scenario to 8% in the scenario in which AT&T and Verizon are excluded from the CMA markets where their post-auction spectrum share would have been above 33% had they purchased 10 MHz of spectrum. When exclusion is made at the CMA-level, the degree of exclusion (and associated revenue reduction) based on post-auction shares after 10 MHz purchase in the auction is much higher than the exclusion with the actual set of AWS spectrum licenses (see footnote 52).

[65] Counties from one CMA can be included in several EAs or REAGs. In such cases, I allocate all of a CMA's counties to an EA or a REAG that accounts for the highest population share in this CMA.

(143) Figure 21 and Figure 22 report simulation results of exclusion in an artificial AWS auction with CMA-only licenses. Auction revenue would fall nearly 16% in an outright scenario, and 10-14% in share capped exclusion scenarios.

Figure 21 Simulated auction revenue change with artificial CMA-only AWS spectrum auction licenses in different scenarios of Verizon and AT&T exclusion

Simulation scenarios	Verizon	AT&T	T-Mobile	SpectrumCo (Sprint)	Other	Total
Excluded outright	-100.0%	-100.0%	33.8%	16.4%	5.2%	-15.9%
Excluded if pre-auction share is greater than 33%	-93.6%	-79.1%	30.9%	14.2%	4.1%	-14.1%
Excluded if post-auction share after 20 MHZ purchase is greater than 33%	-55.1%	-79.0%	17.4%	14.3%	4.0%	-10.3%

Source: Calculations based on the FCC data and documentation.

(144) The results based on the auction with CMA-only licenses show that Verizon and AT&T, even under capped exclusion, lose the bulk of their MHz*POPs. These MHz*POPs are captured by T-Mobile and SpectrumCo.

Figure 22 Simulated percent change in the MHz*POP with CMA-only AWS spectrum auction licenses in different scenarios of Verizon and AT&T exclusion

Simulation scenarios	Verizon	AT&T	T-Mobile	SpectrumCo (Sprint)	Other
Excluded outright	-100.0%	-100.0%	64.3%	23.3%	10.5%
Excluded if current share is greater than 33%	-91.4%	-72.1%	57.1%	18.4%	6.8%
Excluded if share after 20 MHZ is greater than 33%	-48.5%	-72.0%	33.3%	18.3%	6.1%

Source: Calculations based on the FCC data and documentation.

Appendix E. Modeling details for the simulated incentive auction

(145) In this appendix, I provide an overview of the Vickrey mechanism as applied to the sale of multiple units, where buyers potentially desire more than one unit. I refer to this as the multi-unit Vickrey mechanism. I begin by discussing this mechanism in an environment where the auctioneer owns the items for sale. This is the "one-sided" setting. Then I discuss the mechanism in an environment like the Incentive Auction where the auctioneer must provide incentives for sellers to participate. This is the "two-sided" setting.

(146) Let me first illustrate the multi-unit Vickrey mechanism in a *one-sided setting*—that is, where the auctioneer *owns the items to sell* (so the auctioneer does not have to induce sellers to reveal their willingness to pay). In a single-unit case, the auctioneer will open the sealed envelopes and award the item to the highest bidder (provided her bid exceeds the reserve price), but, using the Vickrey mechanism, the auctioneer will charge the winner the amount offered by the second-highest bidder.

(147) In the case of multiple units for sale, buyers submit bids consisting of multiple amounts: a bid for the 1st unit, a bid for the 2nd unit, a bid for the 3rd unit, and a bid for the 4th unit. If there are, say, 4 units for sale, the auctioneer awards the items to the bidder(s) who have placed the 4 highest bids (this could be a single buyer whose bids placed in the top four spots in the ranking). The identification of the winners is thus an easy extension of the single-item set-up—the highest bids win.

(148) The determination of the amount each winning bidder must pay for each unit she won is slightly more complex when more than one unit is being sold, but still follows quite straightforwardly from the single-unit set-up. In the single-unit set-up, the auctioneer can be thought of saying to the winner: "If you had not participated, I would have given the item to the second-highest bidder. Because she was willing to pay the amount she wrote in her envelope, I am now asking for that amount from you (unless the second-highest bid is below the reserve price, in which case you owe me the reserve price)."

(149) In the multi-item set-up, consider for example a bidder who placed 2 of the top 4 highest bids. The auctioneer would say: "If you had not participated, two lower bids that did not make the top-4 list would have now made the top-4 to replace your bids. As a consequence, I am now charging you those two amounts for the two units you actually won (unless those lower bids that would replace your two bids are below the reserve price, in which case you owe me the reserve price)."

(150) Vickrey's mechanism induces the bidders to truthfully bid their valuations because it gives a bidder no incentive to lie about her valuation: by under-reporting her willingness to pay, a potential buyer only hurts her chances to be named the winner (her bid is less likely to make it to the top of the list),

but it does not reduce the amount she pays if she wins because that amount does not depend on her bid at all. It depends only on the nonwinning bids of other buyers.

(151) Because my illustrative model pertains to a two-sided auction rather than a one-sided multi-unit Vickrey auction, the auctioneer will proceed as follows (see Loertscher and Mezzetti, 2013).

(152) First, the auctioneer will call out a reserve price and ask buyers and sellers to bid, that is, to report their willingness to pay or to accept in exchange for the license (which they have an incentive to do). Once both sides have submitted their bids, the auctioneer will count how many sellers have submitted a bid below the reserve price: these are the units available for sale at that reserve price. Similarly, the auctioneer will determine how many units the buyers demand at the reserve price.

(153) When the units offered at the reserve price are fewer than the units demanded (suppliers are on the "short side"), the auctioneer will pay each willing seller the reserve price; the auctioneer will then run a one-sided Vickrey auction to select the winning buyers and determine the price they will pay.

(154) Each winning buyer (who could win one or more units) pays a "personalized" price for each unit won—as described above, the highest bid(s) that would have made the winning circle in her absence, or the reserve price, whichever is highest.

(155) Conversely, when the units offered at the reserve price are more than the units demanded, the buy-side is the short side that determines how many units are traded. The auctioneer will collect the reserve price from each of them. The auctioneer will then run a one-sided Vickrey auction among the sellers to select the winners (those asking for the lowest payments), and pay them "personalized" prices — the next-highest request in a winner's absence, or the reserve price, whichever is the lowest.

(156) For each possible reserve price that the auctioneer could set between $0.05 and $0.95 (in increments of 5 cents), I have computed the average number of trades and corresponding average auction revenues the auctioneer can expect to realize.[66] These results are illustrated in Figure 15.

(157) For the purposes of Figure 15, I have assumed that buyers demand up to 20 units while suppliers will offer only up to 10 units. Moreover, I have assumed that buyers are expected, on average, to be willing to pay more for any given unit, $0.75, than the sellers are asking to give it up, $0.50. Under these assumptions, an efficiency-driven auctioneer wishing to maximize the number of efficient transactions will use a reserve price well above $0.50 (about $0.80), inducing all but the extremely high valuing sellers to give up their units. Then the auctioneer will take advantage of high demand (at that reserve price, sellers will still be more likely than not on the short-side, i.e., demand at a price of $0.80 likely exceeds supply) to assign those units to buyers valuing them more than the reserve price via the Vickrey mechanism among buyers.

[66] This is based on 5,000 random draws for the sellers' and the buyers' valuations.

(158) An auctioneer can increase expected auction revenue at the expense of efficiency by using a lower reserve price. The lower reserve price reduces the number of trades, but allows the auctioneer to collect higher prices from the buyers, who on average will be on the long-side competing for those fewer sales in most or all of the random draws. In my simulation, the highest expected revenue (the top-left point on the blue curve) that can be achieved occurs when the auctioneer uses a reserve price of approximately $0.40. While only 4 units are sold on average in this case, the "personalized" prices that the auctioneer can extract from each buyer—the expected 5th highest valuation, the first unit that does not make the top 4—is about $0.90, yielding a $0.50 = $0.90 - $0.40 unit margin per sale and $2.00 in auction revenues. By using a high reserve price, the auctioneer acts like a profit-maximizing monopolist that restricts the quantity traded in order to collect high margins.

ATTACHMENT 12

Letter from Tamara Preiss (Verizon) to
Marlene H. Dortch (FCC)
September 27, 2013

Tamara Preiss
Vice President
Federal Regulatory Affairs

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September 27, 2013

Ex Parte

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: Expanding the Economic and Innovation Opportunities of Spectrum through Incentive Auctions, GN Docket No. 12-268

On September 25, Charla Rath, Avery Gardiner, Christopher Oatway, and Tamara Preiss, from Verizon, and Dr. Leslie Marx, from Duke University, met with the following FCC staff: Gary Epstein and Edward Smith of the Incentive Auction Task Force; Jim Schlichting, Joel Taubenblatt, Susan Singer, Martha Stancill, Margaret Weiner, Weiren Wang, Paroma Sanyal, Catherine Matraves, Heidi Kroll, and Eliot Maenner of the Wireless Telecommunications Bureau; and Steve Wildman, Paul LaFontaine, Evan Kwerel, and Omar Nayeem of the Office of Strategic Planning & Policy Analysis. Also participating by telephone were Paul Milgrom, Jon Levin, and Ilya Segal of Auctionomics.

Dr. Marx discussed her study, "Economic Analysis of Proposals that Would Restrict Participation in the Incentive Auction," which demonstrates the lack of empirical evidence that some carriers are at risk of foreclosure from access to spectrum unless the Commission restricts Verizon's and AT&T's participation in the upcoming Incentive Auction.[1] She also explained the auction simulations she conducted, which establish that bidding restrictions on AT&T and Verizon will likely result in material reductions in auction revenues and the amount of spectrum re-purposed, if not outright auction failure. The attached slides were used during the meeting.

This letter is being filed pursuant to Section 1.1206 of the Commission's Rules. Should you have any questions, please contact the undersigned.

Sincerely,

Attachment

cc: (via e-mail)

Gary Epstein	Margaret Weiner	Steve Wildman
Edward Smith	Weiren Wang	Paul LaFontaine
Jim Schlichting	Paroma Sanyal	Evan Kwerel
Joel Taubenblatt	Catherine Matraves	Omar Nayeem
Susan Singer	Heidi Kroll	
Martha Stancill	Eliot Maenner	

[1] *See* "Economic Analysis of Proposals that Would Restrict Participation in the Incentive Auction," attached to Letter from Tamara Preiss, Verizon, to Ruth Milkman, Gary Epstein, and William Lake, FCC, GN Docket No. 12-268 (filed Sept. 18, 2013).

The Consumer and Revenue Benefits of Open Eligibility in the Incentive Auction

Leslie M. Marx

Robert A. Bandeen Professor of Economics, Duke University

September 25, 2013

Open Auctions → Efficient Spectrum Allocation

Auctions that allow maximum participation

- Most efficient means of assigning spectrum licenses
- Ensure that licenses are awarded to bidders that value the spectrum most highly and can put it to its highest and best use

Incentive auction that maximizes participation

- Maximizes the combination of revenues for taxpayers and quantity of spectrum repurposed for mobile broadband

Restricted Auctions → Less Revenue, Less Spectrum

Restricted auction that limits participation:

- Complicates auction
- Not needed to prevent foreclosure (spectrum warehousing)
- Suppresses revenues
- Distorts bidding and allows for strategic manipulations
- Reduces amount of spectrum repurposed for mobile broadband
- Allows some participants to acquire spectrum at below market rates
- Risks auction failure

Conclusion: Given the significant drawbacks, auction restrictions should only be implemented if there is a strong likelihood of competitive harm without restrictions.

No Economic Evidence of Foreclosure Risk

- Foreclosure of low-band spectrum is not possible if the spectrum is available in the market
- Sprint and T-Mobile had many opportunities to buy low-band spectrum at auction and in secondary market but did not.
  - In 2008, they did not buy spectrum in the 700 MHz auction
  - Since 2007, there have been more than 2,000 transactions of low-frequency spectrum.
    T-Mobile bought one license. Sprint bought none.
- Sprint and T-Mobile's unlimited usage plans indicate they are not capacity-constrained

Auction Design Will Deter Foreclosure

Attempt to Foreclose Rivals: Costly, Difficult, Unlikely

The auction design discourages foreclosure because:

- **Higher bids** produce more available spectrum, increasing costs of foreclosure
- **Blind bidding:** Verizon and AT&T can't target rivals if they don't know the identity of other bidders. They might end up bidding against each other.
- **"Free rider" issues:** Verizon and AT&T would each prefer that the other spend the money needed to foreclose rivals.
- **Insufficient concentration** in wireless market

Head-to-head competition between Verizon and AT&T proves there is no foreclosure strategy

- 700 MHz auction in 2008: Verizon and AT&T competed against each other to bid **$4.2 billion more** than would have been necessary if their intent was to foreclose competitors.

If Foreclosure, Rectify Post-Auction

Foreclosure can be addressed through:

- Build-out requirements
- FCC and Department of Justice post-auction review

These are effective policy measures that:

- Avoid unnecessary distortions and risk of auction failure
- Are targeted to address any evidence of anti-competitive behavior

Bidding Restrictions Depress Revenues

- **Simulations of past auctions using *actual* bid data show that:**
  - **If Verizon and AT&T were excluded, revenue would have been:**
    - **45% lower** in the 700 MHz auction in 2008
    - **16% lower** in the AWS auction in 2006; T-Mobile would have paid less for its licenses
      (see chart on slide 11)
  - **If Verizon and AT&T faced restrictions short of outright exclusion:**
    - Any material reduction in their demand would risk a substantial reduction in revenue and could lead to auction failure
- **Simulations of two-sided auctions show that bidding restrictions:**
    - Reduce maximum possible revenue
    - Reduce maximum possible quantity of repurposed spectrum
      (see chart on slide 12)

Robust Auction Participation

There is no evidence that the unrestricted presence of Verizon and AT&T will scare away bidders:

- **AWS Auction**
  - Verizon, AT&T, and T-Mobile participated without restrictions
  - 168 qualified bidders; 104 license winners
- **700 MHz Auction**
  - Verizon and AT&T participated without restrictions
  - 214 qualified bidders; 101 license winners
- **Sprint and T-Mobile do not claim that they would be deterred from participating and competing for spectrum**
  - T-Mobile participated in the AWS auction and spent more money and won more spectrum than either Verizon or AT&T
- **Sprint and T-Mobile do not explain why their own presence would not deter smaller rivals from participating**

The Dynamic Market Rule Risks Auction Failure

T-Mobile's Restriction Proposal Risks Auction Failure by:

- Increasing auction complexity
- Decreasing amount of repurposed spectrum
- Decreasing potential revenues
- Creating incentives for strategic bidding
- Creating exposure risk for bidders
- Enabling Sprint and T-Mobile to win licenses at depressed prices

Empirical evidence demonstrates that:

- Restrictions on participation are not needed to deter foreclosure
- Any attempt at foreclosure would be both difficult and costly.
- Limiting participation in the incentive auction by carriers that place a high value on spectrum will increase the risk of auction failure by:
  - Suppressing revenues
  - Reducing the amount of spectrum repurposed for mobile broadband

AWS Auction Simulation

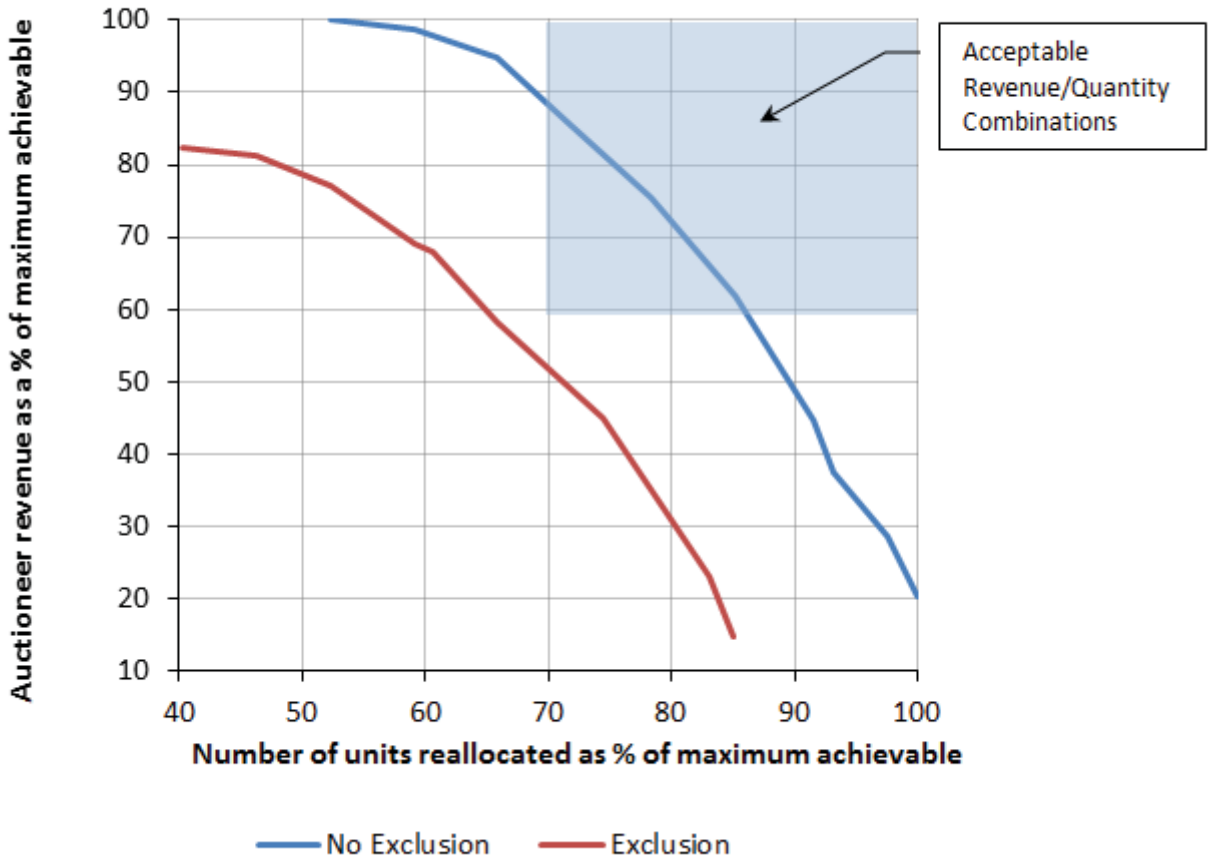
Figure 11 AWS spectrum auction simulation example (license AW-REA001-F)

		Actual Bids		"As Bid" simulation	
Round	Bidder	Bid ($ millions)	Random number	Bid ($ millions)	Random number
9	Verizon	248	0.16		
	Denali	248	0.65	248	0.65
	Dolan	273	0.40	273	0.40
	SpectrumCo (Sprint)	**447**	**0.87**	**447**	**0.87**
	Wireless DBS LLC	248	0.56	248	0.56
10	Verizon	537	0.21		
	Dolan	**537**	**0.32**	**537**	**0.32**
12	Verizon	**644**	**0.66**		
	T-Mobile	644	0.15	**644**	**0.15**
13	T-Mobile	**773**	**0.27**	**773**	**0.27**
14	Verizon	**927**	**0.12**		
15	T-Mobile	**1,113**	**0.74**	**1,113**	**0.74**
16	Verizon	**1,335**	**0.68**		

Source: FCC documentation.
Note: The provisional winning bids for each round are in bold. The original win is highlighted in yellow and the simulated win is in green.

Two-Sided Auction Simulation

Figure 17 Exclusion may cause the illustrative two-sided auction to fail



ATTACHMENT 13

Letter from Leora Hochstein (Verizon) to
Marlene H. Dortch (FCC)
January 27, 2014

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January 27, 2014

Ex Parte

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: ***Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, Docket No. 12-268**

Dear Ms. Dortch:

On January 23, Charla Rath, Christopher Oatway, and Leora Hochstein of Verizon met separately with Renee Gregory, Legal Advisor to Chairman Wheeler, and with Erin McGrath, Legal Advisor to Commissioner O'Rielly, to discuss issues in the above-referenced rulemaking proceeding.

First, the Verizon participants explained that in order to meet our customers' ever increasing demand for mobile broadband and to provide them with the highest quality service, Verizon will need additional spectrum and should be free to participate in the Incentive Auction on the same terms as any other bidder and without restrictions.

The Commission's goals in the auction include: relieving the spectrum crunch by repurposing broadcast TV spectrum for mobile broadband use; raising revenues for FirstNet and deficit reduction; and promoting wireless competition. The FCC can achieve these objectives through an open auction in which licenses are awarded to bidders that value the spectrum most highly and can put it to its highest and best use. Bidding restrictions would undermine these statutory and policy objectives. In this unique, two-sided incentive auction where demand for spectrum affects supply, restrictions on a particular carrier's ability to bid will reduce the quantity of spectrum ultimately repurposed from broadcast use for mobile broadband. Strong demand for spectrum by wireless carriers will be necessary to entice broadcasters to give up their spectrum in the reverse auction. On the other hand, reduced demand as a result of bidding restrictions will reduce the amount of spectrum made available to meet consumers' needs and create a corresponding reduction in service quality to consumers over the long term. If the Commission restricts carriers from bidding on broadcast spectrum, it will miss an historic opportunity to use a market-based mechanism to provide the spectrum consumers demand for mobile broadband.

The spectrum aggregation caps being proposed would restrict only Verizon and AT&T and would allow their competitors such as Sprint and T-Mobile to obtain licenses without having to compete with Verizon and AT&T at auction. Limiting the number of licenses on which Verizon and AT&T may bid would not create more competition in what is already a fiercely competitive market, but would merely shield certain carriers from competition in the auction, allowing them to buy licenses at below market rates. In addition to reducing the amount of spectrum that is made available for auction (as noted above), if the Commission does not receive the full market value for the spectrum it sells and, instead, receives less money than the spectrum is actually worth – by allowing the favored bidders to acquire spectrum at a cut-rate price – it will raise less revenue to fund FirstNet and deficit reduction. Shortchanging taxpayers in the form of a subsidy to certain large incumbents would not be good public policy.

Parties advocating restrictions have failed to support their assertions with evidence. They provide no evidence they would be unable to acquire 600 MHz spectrum in the absence of such restrictions. On the contrary, both Sprint and T-Mobile are backed by large multinational owners with ample ability to make the investment needed to compete at auction if they choose to do so. Nor do the proponents of restrictions assert that they have been unable to acquire the spectrum they need in auctions or in the secondary market. Similarly, proponents of restrictions do not provide evidence supporting the assertion that allowing Verizon and AT&T to participate fully in the auction might discourage other companies from bidding. In fact, unrestricted auctions in the United States have consistently attracted large numbers of smaller bidders that are undeterred by the presence of larger bidders, and those auctions have resulted in licenses being assigned to a wide variety of winning bidders. There is therefore no basis to conclude that imposing restrictions is necessary to achieve any competition objective.

Second, Verizon discussed the broad consensus that has emerged on the band plan the Commission should adopt. Numerous device manufacturers, as well as all four of the nationwide wireless operators, agree that the Commission should adopt a "Down from 51" FDD band plan that maximizes paired spectrum above Channel 37 and that protects against harmful interference from broadcasters. There is also a broad consensus among wireless operators that if enough spectrum is cleared in enough markets, the band plan should feature 35x35 MHz of paired spectrum.[1] For lower clearing scenarios (78 MHz or less in most markets), a 25x25 MHz band plan is advisable.[2]

As required by statute, the consensus band plans discussed above have guard bands and duplex gaps that are technically reasonable. Verizon supports authorizing low-powered unlicensed operations that do not cause interference with licensed operations, but the

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[1] For an illustration of the 35x35 MHz plan supported by all four nationwide wireless operators, Verizon referred to Ex Parte Letter of Kathleen Ham of T-Mobile and Kathleen Grillo of Verizon to Ruth Milkman, Chief of Wireless Telecommunications Bureau, and Gary Epstein, Chief of Incentive Auction Task Force, Docket No. 12-268 (filed Sept. 16, 2013) ("Joint Ex Parte Letter").

[2] For an illustration of the 25x25 MHz band plan, Verizon referred to Comments of Verizon and Verizon Wireless, Docket No. 12-268 (filed June 14, 2013), Ex. B.

Commission may not enlarge those duplex gaps or guard bands in order merely to increase the amount of unlicensed spectrum.[3]

The band plan proposal that Verizon and T-Mobile jointly filed on September 16, 2013, was designed to facilitate a single 3GPP band class to provide interoperability across all paired blocks in the 600 MHz band. Verizon and T-Mobile have stated that they intend to support adoption of a single band class through the 3GPP standards development organization.[4] Given that the Commission can establish a band plan that promotes interoperability – and that avoids the sorts of impairments that gave rise to the interoperability issues experienced in the Lower 700 MHz band – there is no basis for the Commission to abandon its long-standing policy of avoiding prescriptive mandates and leaving technical interoperability issues to industry standard-setting organizations.

Finally, we discussed Verizon's support for package bidding and for Economic Area (EA) license sizes. While the best approach is to auction the 600 MHz band using EAs and package bidding, if the Commission were to adopt smaller license areas such as PEAs, package bidding would be imperative because national and regional wireless providers need to be able to efficiently serve key economically integrated population centers.[5] Without package bidding, operators would face an "exposure" risk in that they could be unable to acquire markets that are essential to their business plan. In the event of smaller license sizes, Verizon would urge a package of the top 100 PEAs based on population, as suggested by AT&T, which would still leave 190 individual PEAs across the country available exclusively for individual bids. While that approach would be less administratively and economically efficient than adopting EAs with package bidding, it would at least ensure that operators can achieve economies of scale serving the largest metropolitan areas in the country. Verizon continues to work with other stakeholders on this issue.

***

This letter is being filed pursuant to Section 1.1206 of the Commission's rules. Should you have any questions, please contact the undersigned.

Sincerely,

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[3] Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, § 6407(b), 126 Stat. 156 (2012).

[4] *See* Joint Ex Parte Letter at 2.

[5] *See* Comments of Verizon and Verizon Wireless, Docket Nos. 12-268 & 13-185 (filed Jan. 9, 2014).