Taking Stock of Spectrum Sharing

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Executive Summary

Shared access to airwaves dates back to the dawn of radio. Yet, recent spectrum policy in the United States has articulated the idea of "spectrum sharing" as a distinct form of radio regulation. In this paper we take stock of spectrum sharing as a public policy, with a focus on four questions.

1. What does it mean to have a spectrum sharing "policy"?

We consider different ways of looking at spectrum sharing, including as a form of traditional radio coexistence and as a set of new technologies. We observe:

- Sharing technologies can be grouped according to a simple framework, based on whether they use coordinating, sensing, or informing techniques and whether the implementation is centralized or decentralized.
- Spectrum sharing as a public policy is not the same as spectrum sharing technology. Spectrum sharing as public policy is necessary when different categories of spectrum users are governed by overlapping, heterogeneous regulatory models.

2. What have we learned from recent spectrum sharing policy approaches?

We consider several different spectrum sharing initiatives from recent years, including coordinated sharing in the licensed AWS-3 Band, automated sharing in the UHF, 5 GHz, and 6 GHz Bands (Television White Space, Dynamic Frequency Selection, and Automated Frequency Coordination, respectively), and multi-tiered sharing in the 3.5 GHz Band (the Citizens Broadband Radio Service). Key takeaways include the following:

- White House leadership is critical when federal spectrum interests are at stake. Convening stakeholders in an organized forum to align expectations and share information is also essential.
- Sharing scenarios that involve both unlicensed operators and more traditional licensed users generally require an automated sharing technology to operate at scale. This automation can take the different technological forms described above. Enforcement is an important function that can be facilitated through centralized systems.
- Multi-tier sharing can be complex but has been shown to work, with over 150,000 network nodes deployed in CBRS and no reported cases of interference. The CBRS rules promote sharing among a wide and heterogeneous range of users and use cases, including public and private networks, mobile and fixed wireless access, and consumer and industrial applications. Rule changes after the original order prevented experiential learning from some of the more innovative aspects of the CBRS regime and limited access to the Priority Access License tier in major markets to large network service providers.

3. What principles should guide future spectrum sharing policies?

From these past experiences we distill several principles that are essential to a successful spectrum sharing policy:

- *Develop interference expectations.* Sharing regimes should be informed by reasonable interference expectations, developed using modern analytics, rather than worst-case analysis.
- *Encourage standards and technologies that facilitate sharing.* Sharing can be facilitated through private sector development of cross-industry "meta standards," designed to be agnostic as to the underlying radio technologies used for transmission.
- *Promote sharing by design*, particularly in bands in which there are no incumbents.
- *Avoid artificial scarcity*. Spectrum "scarcity" is often a byproduct of regulation. Wherever possible, the default should be rules that promote the abundance of spectrum through spectrum re-use.
- *Avoid "Trojan Horses" for market power.* No single private entity should hold the key to enabling a centralized shared spectrum policy.
- *Build in enforcement mechanisms*. Enforcement is necessary to ensure various stakeholders trust the sharing mechanism.

4. What spectrum sharing policies might the current Administration pursue?

We see two main opportunities for spectrum sharing policy in the near term:

- *3 GHz Band*. The 3 GHz Band has evolved into a patchwork of different exclusive and shared regimes. We see an opportunity to consolidate "like" types of spectrum access in different parts of the band, reserving the upper 3 GHz for more traditional cellular licensing and extending the multi-tier CBRS framework farther into the lower portion of the band to facilitate sharing with federal systems.
- *Lower 37 GHz Band*. This band is currently allocated for both federal government and commercial use, with little or no incumbent use. It presents a unique opportunity to develop "two-way" sharing from the ground up.

There is no magic formula for spectrum sharing policy. A dynamic landscape of heterogeneous spectrum uses, multiple spectrum authorities, technology advances, and evolving national objectives requires case-by-case assessments. However, such assessments should be informed by the experiences and principles described above.

Introduction

It is, by now, a telecom policy cliché to say that radio spectrum is the lifeblood of wireless communications. Yet, like most cliches, this one has some truth. Spectrum—or, more accurately, the ability for radio technologies to transmit and receive on specific frequency bands—is an essential input into wireless communications, including now-ubiquitous Wi-Fi and cellular networks and their ongoing evolution to next-generation standards. But wireless broadband—important as it is to our everyday lives, our economy, and society in general—is just one "consumer" of radio spectrum among many others. Radars, satellites, military warcraft, automobiles, space telescopes, and countless other technologies rely on radio transmissions and therefore need access to spectrum. As we have described elsewhere,[1] the question of how to accommodate this ever-changing menu of users and uses is the central challenge of radio spectrum management, necessitating changes in institutions and policies to keep pace.

The U.S. spectrum authorities, the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA), have increasingly turned to "spectrum sharing" to address this policy challenge. It has been nearly a decade since the President's Council of Advisors on Science and Technology (PCAST) issued an influential report that boldly declared that "the norm for spectrum use should be sharing, not exclusivity"[2] and, further, that "spectrum should be managed not by fragmenting it into ever more finely divided exclusive frequency assignments, but by specifying large frequency bands that can accommodate a wide variety of compatible uses and new technologies that are more efficient with larger blocks of spectrum."[3] The United States Government took this approach to heart in constructing the shared Citizens Broadband Radio Service in the 3.5 GHz Band, but its ethos has extended to an even wider range of "shared" spectrum bands.

In this paper we take stock of spectrum sharing as public policy, with a focus on four questions. First, what does "spectrum sharing" mean, really, and when is it most applicable as a policy tool? Second, what have we learned from several notable, but also notably different, spectrum sharing regimes established over the past decade or so? Third, what key principles should define the next generation of spectrum sharing policies? And fourth, what are some opportunities for the current Administration to begin to apply these principles in the near term? Our purview here is *terrestrial* spectrum sharing, although sharing with and among satellite and other non-terrestrial systems is an interesting and evolving topic in its own right.

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[1] Leibovitz, J. and Milkman, R., Modernizing Radio Spectrum Management, (Jan. 23, 2020) Day One Project, available at: https://www.dayoneproject.org/post/modernizing-radio-spectrum-management

[2] President's Council of Advisors on Science and Technology, Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth (2012) (PCAST Report) at vi, available at http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf

[3] PCAST Report at vii.

1. What do we mean by "spectrum sharing"?

Like many regulatory terms of art, "spectrum sharing" is a semantic shapeshifter, having different meanings in different contexts. Often, "spectrum sharing" is held in contradistinction to now-familiar policies, like "exclusive," "unlicensed," or "coordinated" spectrum use. Are these distinctions correct? If not, what exactly do we mean when we refer to "spectrum sharing"? And, because our ultimate concern is with policy implementation—not language games—what *should* it mean in a public policy context? What features or attributes characterize a meaningful and principled spectrum sharing policy?

A. Sharing as non-interference

Spectrum sharing is not a new concept. The spectrum has always been shared among different users and uses. After all (and contrary to many a PowerPoint slide) the radio spectrum is not a naturally ordered set of "things" to be parceled out. Rather, "spectrum" is a social and legal construct representing the range of frequencies across which a radio device, which sends or receives electrical signals through a medium with the aid of various common components (amplifiers, antennas, etc.), can operate. For regulatory purposes this range currently stops at 300 GHz, but the limit has shifted upward over the years.

From the first days of radio, we have always had a system of "reusing" the airwaves across the now familiar dimensions of *frequency*, *space*, and *time*. Early users learned to tune their equipment to different channels to avoid interference. They also discovered that depending on a number of technical parameters they could operate these channels in different locations or by pointing focused radio beams in different directions. Further, they recognized that for intermittent radio operations, sharing in time was an option.[4]

Another dimension of radio coexistence applies in the *signal* domain. Some radio systems, such as those using spread-spectrum technology, encode their transmissions in a way that makes it unlikely to cause or receive interference with other radio systems.[5] Code Division Multiple Access (CDMA) provides a paradigmatic example. A high density of users on a CDMA cellular network can share the same channel in the same area at the same time. This technology was also envisioned to allow sharing between "unlike" users. For example, a cellular CDMA system and a narrowband point-to-point microwave link could share a channel without causing or receiving interference.[6]

Our modern system of spectrum allocation, licensing, and assignment generally represents a set of regulations that keep users separated in one or more of the basic dimensions of spectrum access to prevent interference. In this sense, the Table of Frequency Allocations familiar to every radio regulator represents a spectrum sharing methodology, albeit a fairly primitive one. For the most part, regulatory separations are understood to be static. Disparate

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[4] The Radio Act of 1912, passed in the wake of the Titanic calamity, specified a "Division of Time" whereby non-governmental radio stations that were located near governmental stations and caused interference to the government stations were required not to transmit during the first fifteen minutes of each hour. See Radio Act of 1912, Sections 12 and 13, 37 Stat. 302 (Pub. Law 62-264) (1912). (We thank Peter Tenhula for calling our attention to this provision.)

[5] For an influential and comprehensive review see Scales, W., Potential Use of Spread Spectrum Techniques in Non-Government Applications, MITRE Corp, (1980) available at: http://www.mitre.org/sites/default/files/pdf/MTR80W335.pdf (We thank Michael Marcus for making us aware of this study.)

[6] See, e.g., D. L. Schilling, R. L. Pickholtz and L. B. Milstein, "Spread spectrum goes commercial," IEEE Spectrum, vol. 27, no. 8, pp. 40-41, (1990) available at: https://ieeexplore.ieee.org/document/58433. We will return to this point when we consider the recent example of sharing in the 6 GHz Band.

radio systems can operate and co-exist most or all the time, although there are some cases where system operators are required to coordinate to use frequencies at different times. The general approach has been to conduct studies, usually involving a set of incumbent licensees and a newcomer technology that wishes to gain access to some frequency, to define technical parameters that largely prevent "harmful interference" from occurring. These technical rules often favor incumbents and tend to err on the side of caution/conservatism as far as the technical abilities of newcomers. In some cases, the newcomers become the incumbents as uses and technologies evolve over time and the cycle repeats.

B. Sharing as technology

Engineers have, over the years, devised automated technologies with the singular purpose of allowing disparate radio systems to share spectrum in automated or dynamic ways. These techniques often facilitate time sharing of spectrum but also may enforce rules about geographical separations, channel assignments, power levels, or other technical parameters to enable sharing. We have attempted to synthesize the various approaches in a simple framework, which we discuss below. The framework encompasses three basic approaches: *coordinating*, *informing*, and *sensing*. Each approach can be implemented through *centralized* (i.e., network resident) or *decentralized* (edge device resident) functionality. It is likely this list is incomplete. We are beginning to see the emergence of new approaches as technology marches on, for example, through the application of artificial intelligence.

Coordinated sharing involves the use of known parameters about two or more radio systems to ensure they can operate without an unacceptable level of interference. In the *centralized* version, a database contains operational parameters of the different systems and potentially the environment (e.g., terrain), basic coexistence criteria, and a set of rules or models to apply these criteria to the different systems. The database analysis may be relatively static (as with the TV White Space in the UHF Band and the Automated Frequency Coordination system in the 6 GHz Band) or operate on a real-time basis (as with the Spectrum Access System in the CBRS Band). *Decentralized* coordinated sharing is a novel area exemplified by some of the Cooperative Intelligent Radio Networks (CIRNs) developed as part of the recent Spectrum Collaboration Challenge sponsored by DARPA (the Defense Advanced Research Projects Agency). According to DARPA, this approach represents "a new, more efficient wireless paradigm in which radio networks autonomously collaborate to dynamically determine how the spectrum can be used most efficiently moment to moment…taking advantage of recent advances in artificial intelligence (AI) and machine learning, and the expanding sophistication of software-defined radios."[7] (The winners of the DARPA challenge did not rely on decentralized coordination, however, which suggests more work remains to be done in this area.)

Sharing through *sensing* puts the onus on one radio system to detect and "back off" when another radio system is transmitting. The Environmental Sensing Capability (ESC) employed by CBRS in the 3.5 GHz Band provides an example of *centralized* sensing. A sensor infrastructure along the U.S. coasts works in conjunction with the Spectrum Access System (SAS) databases to ensure that incumbent Navy radars do not receive harmful interference. One very common example of a *decentralized* approach to sensing is the listen-before-talk (LBT) etiquette used in Wi-Fi to prevent interference with other users of the unlicensed bands. Another example

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[7] See Defense Advanced Research Projects Agency, Spectrum Collaboration Challenge (Archived), October 23, 2019 Presentation at Mobile World Congress Americas, available at https://www.darpa.mil/news-events/spectrum-collaboration-challenge-sc2

is the Dynamic Frequency Selection (DFS) system used in the 5 GHz Band requiring networks to listen for the presence (or rather the absence) of incumbent weather radar systems before transmitting.

Sharing through *informing* is a less widespread approach that holds great promise. An informing approach puts the onus on a transmitter or receiver to inform other systems when it is in operation so that the other systems can take evasive action. In a *centralized* implementation this information would be sent to a database to be disseminated to all users. One notable concept along these lines is the *Incumbent Informing Capability* proposed by NTIA staff as a means to facilitate sharing in various Federal bands.[8] In the proposed system, Federal operators inform non-Federal users, via a secure channel, that a system is "turning on" in a given place and time. The affected non-Federal users would turn off or retune their systems for the duration to avoid interference. (The success of such a system obviously depends on stakeholder confidence that its activation and deactivation would follow a well-specified, non-arbitrary decision process.) *Decentralized* informing systems are also possible, for example, through "beaconing." A radio system can transmit a beacon signal on a known channel that automatically informs other systems in the vicinity of the basic fact that it is operating and also provide certain technical parameters that may facilitate sharing. The disparate systems need only interoperate in their ability to decipher the beacon signals; the systems can otherwise use incompatible or encoded signals for underlying data transmissions.

Figure 1 summarizes our basic framework with examples for each type of system.

	Centralized	Decentralized
Coordinating	TVWS, AFC, SAS	Some CIRN systems
Sensing	ESC	LBT, DFS
Informing	IIC	Beaconing

Figure 1: Spectrum Sharing System Framework

C. Sharing as public policy

So, when is "spectrum sharing" a *public policy*? And how is such a policy different from the ordinary systems of licensing and assignment? Or from technologies that allow for granular and dynamic spectrum sharing but which can operate within many different regulatory structures?

Viewed broadly, any public policy that facilitates coexistence among disparate radio users could be considered "spectrum sharing." From our standpoint, having followed the spectrum sharing policy record over more than a decade, this definition is so broad as to be essentially meaningless, for it would sweep in the entire rulebook of radio regulation. Regulations that provide for coexistence with a common set of rules or procedures and apply *uniformly* to *all*

[8] DiFrancisco, M., Drocella, E., Ransom, P., & Cooper, C., Incumbent Informing Capability (IIC) for Time-Based Spectrum Sharing, NTIA (2021) available at: https://www.ntia.doc.gov/report/2021/ntia-report-incumbent-informing-capability-iic-time-based-spectrum-sharing

users within a band and geography may in fact promote sharing of spectrum among a wide variety of users and uses. One might therefore describe the traditional tools of geographic licensing, frequency coordination, and unlicensed access as "sharing" policies. However, this is not what we mean by "spectrum sharing policy" for purposes of this paper.

Instead, we posit a narrower definition, rooted in the idea of overlapping modes of regulatory authorization for spectrum use. We define spectrum sharing *policy*—from a regulatory perspective, not a physical or technological perspective—as a framework that expressly accommodates multiple, overlapping types of spectrum use authorizations in a single frequency band and geography.[9] Viewed through this more narrow frame, spectrum sharing *policy* is one solution to the problem of regulatory heterogeneity in spectrum access.

We acknowledge that "spectrum sharing" can occur under many types of spectrum use authorizations. A cellular network operating under a flexible use licensing scheme arguably enables the spectrum to be shared among millions of users, with the network operator providing a kind of "private commons." The unlicensed rules permit millions of Wi-Fi, Bluetooth, and other devices to share spectrum in a "public commons," and traditional frequency coordination rules can also allow many different uses to coexist without harmful interference. Yet we concern ourselves here with sharing *across* these different kinds of spectrum authorization regimes.

We emphasize that such heterogeneity is a product of regulatory decisions, typically made over the course of many years or decades. Were the entire radio spectrum to be allocated under a common framework of rights, or through a common administrative agency, or with a common set of procedures for accommodating multiple user interests (whether these procedures involve frequency coordination, market transactions, or automated technologies), there would be no need for "spectrum sharing policy" as we define it here.

Of course, we do not live in that simpler world. In the United States we have two separate spectrum authorities (the FCC and NTIA) with their own statutory authority and rule books. And each regime itself contains many different forms of spectrum regulation applied differently in bands where different user interests and needs have historically held sway. Although one can offer compelling theoretical reasons to collapse all spectrum authorization into a single paradigm, consensus on which one to use seems like a tall order.[10] As commercial wireless technologies consume ever more bandwidth even as legacy systems continue to serve important and expanding purposes, the "heterogeneity problem" only seems to be getting more challenging. So, for the foreseeable future, it seems that spectrum sharing *as public policy* is only likely to grow in relevance for regulators in coming years.

Several practical questions frame any spectrum sharing policy:

- *Who* are the users: past, present, and future? What incumbents must be protected and to what degree? What existing rules or regulations govern their use? What new uses and users are anticipated to be enabled through a new spectrum sharing policy?

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[9] The geographical dimension is important – it is quite common to allocate spectrum to different uses, with different authorization types, in different regions through the Table of Allocations. The National Radio Quiet Zone is one example. We don't consider the existence of the Quiet Zone to be a "spectrum sharing" policy even though it requires all radio users to "share," in principle, with radio astronomy telescopes located in West Virginia.

[10] Leibovitz, J., The Great Spectrum Debate, 6 Yale J.L. & Tech. 390 (2004) available at: https://yjolt.org/great-spectrum-debate-commentary-fcc-spectrum-policy-task-forces-report-spectrum-rights-and

- *What* are the relevant physical characteristics of the band, such as signal propagation? It is worth considering any trade-offs between technical properties and sharing? For example, does sharing require reducing power levels and how does that affect the usability of the spectrum for different applications?
- *Where* will sharing occur? Is sharing likely to happen on a nationwide or regional basis? Within any shared region are there places (such as indoor spaces) that are effectively isolated from the broader radio environment?
- *When* will sharing occur? Is it a temporary activity to facilitate a transition of different radio systems in a band? Or is sharing likely to be permanent?
- *How* will sharing be authorized? Who authorizes legacy and new spectrum uses? Does the envisioned sharing span federal spectrum allocations (regulated by NTIA) and non-federal spectrum allocations (regulated by the FCC)? What controlling statutes apply?[11] Should the process be manual or automated?

All of these questions can inform the basic analysis of whether the benefits of a new spectrum sharing policy exceed its costs. In some cases, where it is possible to clear spectrum of incumbent users through incentives (e.g., monetary payments, compensated system upgrades, expanded use of different spectrum), these approaches may be preferable to a sharing policy.[12] And it is important to recognize that the costs of a sharing policy may go beyond expenses related to implementation—they may also include *opportunity* costs if the spectrum sharing regime tends to "lock in" unproductive legacy uses that otherwise might face market pressure to exit a frequency band. Relocation costs may be non-linear, resulting in a lumpy (or stair-step) cost curve, so that the cost-benefit analysis changes depending on the amount of spectrum and/or the systems to be relocated. In many cases, especially where legacy uses involve expensive mission-critical systems that are not easily displaced, a sharing policy can be an effective way to expand access to the spectrum. By enabling a rich tapestry of new users and uses involving a heterogeneous mix of regulatory authorizations such a policy may also encourage more intensive and productive spectrum use than otherwise would be the case.

Moreover, the assessment of benefits and costs may encompass national objectives beyond spectrum policy. Two examples come readily to mind: the expansion of broadband and the desire to enhance U.S. manufacturing capabilities. At the time of this paper, Congress is considering broadband infrastructure legislation that may be favorable to fixed wireless operations in some geographies. Both the required minimum "build-to" standard (which might be 100 Mbps down and 20 Mbps up) and the definitions of unserved areas (which might limit the viability of new FTTP builds given their higher minimum geographic scale requirements) will be threshold questions for sizing how much broadband deployment funding will flow to fixed wireless. These determinations are not yet final as of the writing of the paper. But another

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[11] Federal spectrum sharing may be governed by the statutory framework of the Commercial Spectrum Enhancement Act (CSEA). See 47 U.S.C. §928 The CSEA authorized the Spectrum Relocation Fund (SRF). The SRF, which is funded by revenues from FCC auctions that involve spectrum reallocated from federal government use, provides a centralized mechanism through which federal agencies can recover the costs associated with relocating their radio communications systems or sharing the reallocated spectrum.

[12] Federal law provides that "In evaluating a band of frequencies for possible reallocation for exclusive non-Federal use or shared use, the NTIA shall give priority to options involving reallocation of the band for exclusive non-Federal use and shall choose options involving shared use only when it determines, in consultation with the Director of the Office of Management and Budget, that relocation of a Federal entity from the band is not feasible because of technical or cost constraints." 47 U.S.C. Section 923(j)(1). There is no similar statutory provision with respect to commercial sharing, but the FCC generally considers the feasibility of relocating incumbents. See, e.g., In the Matter of Expanding Flexible Use of the 3.7-4.2 GHz Band, GN Docket No. 18-122, Report and Order and Order of Proposed Modification (March 3, 2020).

requirement for fixed wireless is access to spectrum. It is easy to imagine that a spectrum sharing policy that makes additional spectrum available would be relevant to the ability of fixed wireless to compete widely for broadband funding. In addition, one may take the view that next-generation manufacturing and industrial competitiveness would be enhanced by access to spectrum. In that case, the accessibility of shared spectrum for important new uses is a benefit to be considered.

All of these factual and normative determinations vary greatly by spectrum band. There is no magic recipe for determining when spectrum sharing is the best policy and what kind of sharing is appropriate. Public policy approaches to spectrum sharing should reflect an analysis of a given set of circumstances at a given time. Nonetheless, we can extrapolate some useful lessons about what—and what not—to do from past experience.

2. Spectrum sharing policy exemplars

The FCC and NTIA have implemented a range of spectrum sharing regimes over the past 20 years which exemplify some of the concepts described above. We briefly review some of these sharing approaches to help illustrate the ways spectrum sharing policy has evolved to address different kinds of regulatory issues. For each example we offer some high-level observations as to the benefits and limitations of these policies.

A. Coordinated sharing: AWS-3

In January 2015, the FCC's auction of the AWS-3 band concluded with proceeds exceeding $40 billion—a record at the time. This result was far from preordained. A significant portion of the band, by megahertz-pops (a commonly used measure of spectrum occupancy), consisted of "overlay rights" in spectrum assigned mostly to the Departments of Defense and Justice (DOD and DOJ). Spectrum sharing was a key that helped unlock the door. This policy was predicated on a fairly traditional process of "manual" frequency coordination conducted by human beings and it was not the first example of this model of spectrum sharing. Indeed, the AWS-1 Band, auctioned in 2006, involved sharing of spectrally adjacent and equivalent commercial spectrum with Federal incumbents.[13] AWS-3 was novel because of the scope and scale of the application of these tools. It set a new state-of-the-art for coordinated sharing between commercial and Federal users. For this reason, a quick review of the sharing regime and the process that generated it is instructive.[14]

The AWS-3 sharing regime makes use of a toolkit that has been available to regulators for a long time. The FCC, in coordination with NTIA, updated the Table of Allocations to allow commercial mobile network deployments in the band. A new footnote to the Table specified a number of incumbent Federal systems that must be protected by commercial AWS-3 licensees.[15] The FCC also established service rules establishing "flexible use" geographical area licenses for non-Federal users.[16] Under authority provided by the Commercial Spectrum Enhancement Act (CSEA), auction proceeds could be directed to pay for costs incurred by Federal agencies

[13] See 47 CFR § 27.1134(a).
[14] For purposes of this discussion, we will focus on the 1755-1780 MHz sub-band.
[15] See Table of Allocations 47 CFR § 2.106, footnote US 91. See also § 27.1134(f).
[16] See, e.g., 47 CFR § 27.1(b)(12), § 27.5(h), and § 27.6(k).

in clearing out of some portions of the spectrum and for sharing the remainder.[17]

What set AWS-3 apart from previous Federal/non-Federal spectrum sharing rules were three factors. First, the AWS-3 rules contemplated an unprecedented level of spectrum sharing: dozens of Federal systems in hundreds of different service areas potentially affecting tens of millions of the U.S. population. Second, this large-scale effort necessitated a similarly unprecedented large-scale planning process, led by NTIA, involving multiple government agencies and industry representatives. All told, hundreds of people were involved in the planning process. Third, once the plans were complete, the DOD commenced its own process to share information about the systems that would remain in the band with enough granularity to inform would-be commercial licensees about what they might be buying at auction while protecting sensitive national security details.[18]

The AWS-3 experience provides several valuable lessons for spectrum sharing policy. The first lesson is that when Federal spectrum interests are involved, White House leadership truly matters. The Federal agencies involved in the AWS-3 process were motivated by two separate Presidential memoranda directing them to bring spectrum to market through a collaborative process that involved spectrum sharing as part of the solution.[19] (Issuance of these documents, of course, followed staff-level coordination across the U.S. Government.) Second, is the importance of convening all stakeholders in an organized forum. NTIA brought together government and commercial spectrum users through its Commerce Spectrum Management Advisory Committee (CSMAC). This intensive 15-month process proved essential to establishing a rigorous framework to analyze sharing among very different wireless systems (e.g., commercial cellular and airborne military systems). The CSMAC process surfaced challenging problems and resulted in creative solutions to increase the overall usability of the spectrum. It also fostered working relationships that proved crucial to finding common-ground. Third, is the importance of information sharing. The AWS-3 process led to development of an analytic product known as the "DOD Workbook," which provided census tract level spectrum sharing data to auction bidders. The Workbook proved important in allowing bidders to tailor their valuation of new spectrum licenses based on an understanding of how temporary and perpetual sharing arrangements might affect their own network deployments.

The CSMAC effort also surfaced some challenges. It was a costly, time-intensive process, which begged for more off-the-shelf tools and automated analysis. It also involved a *static* analysis, which meant that adjustments to the sharing arrangements would require further manual analysis and negotiation. For example, on the commercial side the analysis relied on a hypothetical "grid" that was actually an amalgam of several cellular operators' network deployments. Once the auction concluded, and the licensees were no longer hypothetical, the analysis lost some validity. A similar issue presented on the Federal side. Footnote US 91 in the Table of Frequency Allocations stipulates that Federal agencies may make "reasonable modifications" to 25 grandfathered satellite earth stations if approved by NTIA and successfully coordinated with AWS-3 licensees. Our understanding is that such modification requests have

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[17] See Commercial Spectrum Enhancement Act, Pub. L. 108-494, Title II (2004) and 47 U.S.C.§928. The complicated history of the CSEA and its various amendments is a topic worthy of further discussion, but which exceeds the scope of this paper.

[18] See AWS-3 Transition, NTIA, at https://www.ntia.doc.gov/category/aws-3-transition

[19] President Barack Obama, Unleashing the Wireless Broadband Revolution, Presidential Memorandum (2010) at https://obamawhitehouse.archives.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution and President Barack Obama, Expanding America's Leadership in Wireless Innovation, Presidential Memorandum (2013) at https://obamawhitehouse.archives.gov/the-press-office/2013/06/14/presidential-memorandum-expanding-americas-leader-ship-wireless-innovatio

since led to challenging negotiations between Federal and non-Federal users.

AWS-3 established an important template for a specific type of Federal/non-Federal spectrum sharing. This general approach has informed subsequent proceedings, most notably for the 3.45-3.55 GHz Auction scheduled to begin October 2021.

B. Automated Sharing: DFS, TVWS, and AFC

Intentional unlicensed use has been permitted since 1985 on a non-interference basis. Once the value of unlicensed consumer devices became clear, the question arose as to whether unlicensed use could be added to bands that had high value federal or licensed commercial incumbents such as weather radars or television broadcasters. In contrast to the AWS-3 approach, coordination would not be an effective sharing mechanism, because unlicensed use generally involves a wide array of devices and networks that operate independently of a centralized network operator. So new techniques needed to be developed to ensure that the consumer devices were operating on a non-interference basis with incumbent services and the new systems needed to be automated so that they could detect and avoid situations in which they would interfere.

Dynamic Frequency Selection (DFS) in the 5 GHz Band

DFS is an example of a decentralized *sensing* system, primarily designed to protect a single type of incumbent system (i.e., weather radars). The technology enables a "detect-and-avoid" approach to spectrum sharing. In 2003, the FCC enabled unlicensed use in additional parts of the 5 GHz band but required devices to be able to monitor available spectrum and detect radar signals. If a radar signal is detected, the channel associated with the radar signal was off limits for unlicensed use. The DFS feature dynamically instructs a transmitter to switch to another channel whenever a particular condition is met.[20]

The FCC was particularly interested in adding unlicensed use to additional parts of the 5 GHz band because these frequencies were used globally for radio local area networks (RLANs). The incumbent operations of concern were federal government radar operations, primarily Federal Aviation Administration (FAA) Terminal Doppler Weather Radar (TDWR) used on and near airports to detect wind shear and other weather conditions. The DFS approach was adopted as a means of enabling additional unlicensed use while protecting incumbents.

There have been some hitches along the way, including interference to weather radars at multiple locations, as well as interference to radars at rocket test and launch ranges.[21] A NTIA report on the topic states that causes of interference included unauthorized modification of certified U-NII devices, resulting in non-response to radar, as well as insufficient data on radar characteristics, such as pulse repetition frequency, used to develop DFS. The FCC subsequently implemented changes to its technical requirements to address these issues.[22] However, the parts of the 5 GHz band in which DFS is required may not be as heavily used as other parts of the 5 GHz band, because of the effect on consumer Wi-Fi.[23] One might say

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[20] Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) devices in the 5 GHz band, Report and Order, FCC, 18 FCC Rcd 24484 (32) (2003).

[21] Lessons Learned from the Development and Deployment of 5 GHz Unlicensed National Information Infrastructure (U-NII) Dynamic Frequency Selection (DFS) Devices, NTIA, (2019) (NTIA Report) available at https://www.ntia.doc.gov/report/2019/lessons-learned-development-and-deployment-5-ghz-unlicensed-national-information

[22] NTIA Report, Executive Summary at xii-xvi.

[23] See, for example, WiFi DFS May Be Great For You If You Live In An Apartment or Condo , White Paper, Motorola available at https://motorolacable.com/whitepapers/Wi-Fi-dfs, (states that DFS is disabled by default in consumer Wi-Fi cable modems and routers because during the process of checking for radars, the router will lose wireless connectivity for a minute or so).

this approach was not an unqualified success—at least initially—but did enable additional unlicensed use in globally harmonized bands, with interference concerns addressed over time. The DFS interference episodes certainly highlighted the challenge of enforcing sharing rules, especially those involving a decentralized system with many different users.

Television White Space in the UHF Band

TVWS is a simple database-oriented system protecting several incumbents (TV, Wireless Medical Telemetry Service (WMTS), and wireless microphones) in the UHF band. Historically, the licensing of analog television stations required significant geographic and frequency separation and therefore created "white spaces" between stations and channels. At the same time, UHF has excellent propagation characteristics—signals travel much farther compared to the higher bands used for unlicensed operations, such as 2.4 GHz and 5 GHz. In addition to television broadcasters, the UHF band contains WMTS incumbents and radio astronomy in certain geographic areas, both in Channel 37. Licensed and unlicensed wireless microphones also operate in the UHF band.

The TVWS regime, as noted above, is a version of a *centralized coordinating system*. Two novel concepts enabled unlicensed use in the television bands: (1) the creation of a database, operated by multiple, competing administrators, in which protected uses could be registered; and (2) the requirement that TVWS devices have geo-location capabilities and query the database periodically and shut down or switch to a different channel if the database indicated incumbent use. The implementation of this effort was years in the making, and the details continue to evolve.

The usefulness of the band for unlicensed devices was somewhat reduced by the broadcast incentive auction proceeding, which repurposed some of the broadcast television spectrum for commercial wireless use, and repacked the broadcasters closer together, thereby reducing the amount of white space available. Nevertheless, the FCC did preserve some channels for unlicensed use,[24] and there are unlicensed operations in the UHF band, sharing with protected operations. In addition to the white spaces between television stations, devices are permitted to operate in the duplex gap between the uplink and downlink for wireless services, in the guard bands between wireless, in channel 37, and in the 600 MHz wireless frequencies where wireless operators have not yet built out.

The commercial success (or lack thereof) of television white space devices continues to be a matter of some debate, involving other factors such as the prolonged regulatory uncertainty and lack of an unlicensed equipment ecosystem in the target bands. For purposes of this paper, we simply note that the implementation of the concept of geo-location combined with a database that can identify vacant channels available for use was a significant advance in enabling sharing, which was subsequently applied in other bands including CBRS and 6 GHz.

Automated Frequency Coordination in the 6 GHz Band

The latest FCC framework for automated sharing is the *6 GHz Proceeding*, another example of a *centralized coordinating system*.[25] In the *6 GHz Order*, the FCC authorized standard power access

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[24] Amendment of Part 15 of the Commission's Rules for Unlicensed Operations in the Television Bands, Repurposed 600 MHz Band, 600 MHz Guard Bands and Duplex Gap, and Channel 37, and Amendment of Part 74 of the Commission's Rules for Low Power Auxiliary Stations in the Repurposed 600 MHz Band and 600 MHz Duplex Gap; Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, Report and Order, FCC, 30 FCC Rcd 9551 (12) (2015).

[25] Unlicensed Use of the 6 GHz Band; Expanding Flexible Use in the Mid-Band Spectrum Between 3.7 and 24 GHz , Report and Order and Notice of Proposed Rulemaking, FCC, 35 FCC Rcd 3852 (5) (2020) (6 GHz Order).

points in two sub-bands of the 6 GHz band, using an Automated Frequency Coordination (AFC) system. The FCC also authorized indoor low-power access points across the entire 6 GHz band and did not require them to use the AFC.

The incumbents in the relevant sub-bands (U-NII-5 and U-NII-7) are fixed microwave licensees. These are point-to-point wireless links that support services provided by utilities, commercial and private entities, and public safety agencies, as well as backhaul for commercial wireless providers.[26] The AFC relies on the Commission's Universal Licensing System (ULS) for microwave link data. All standard-power access points are required to have geo-location capability and to re-check their authorized frequencies daily.[27]

There will be multiple AFC administrators, similar to the situation in the TV white spaces and CBRS. The FCC's Office of Engineering and Technology (OET) has not yet authorized any AFCs, but the Wi-Fi Alliance has recently released the first draft specification for AFC function.[28] and the Wireless Innovation Forum (WInnForum) also has various projects underway to support AFC implementation with their outputs expected in the September 2021 timeframe.[29]

Because the 6 GHz AFC system is not yet in place, it is too early to draw conclusions about this proceeding, other than to note that the FCC has taken advantage of its experience with previous centralized coordinating systems to establish a system for sharing between licensed fixed microwave links and unlicensed operations.

C. Multi-Tier Sharing: CBRS

The FCC created the Citizens Broadband Radio Service in response to NTIA's 2010 decision to make the 3550-3650 MHz band available for commercial sharing with shipborne and other radars operated by the DOD.[30] Through several stages of rulemaking, the FCC decided to adopt PCAST's 2012 recommendation to use a novel three-tiered sharing framework in the band.[31] In 2015 and 2016, the FCC issued a complete set of CBRS rules encompassing an expanded band from 3550-3700 MHz.[32] These rules represented a comprehensive implementation (and extension) of the PCAST vision. In 2018, the FCC revised some of the more innovative aspects of the CBRS rules.[33] In January 2020, the FCC certified several SAS providers for full scale commercial deployment in the band[34] and later that year conducted an auction for the second tier "priority access licenses."[35]

The CBRS Framework

CBRS consists of three tiers of spectrum access allowing preemption of lower-tier users

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[26] 6 GHz Order at para. 7.

[27] 6 GHz Order at paras. 8, 40.

[28] Hetting, C., Wi-Fi Alliance preps outdoor 6 GHz Wi-Fi with first AFC specification, blog post, Wi-Fi NOW (Jan. 2021) available at: https://wifinowglobal.com/news-and-blog/wi-fi-alliance-preps-outdoor-6-ghz-wi-fi-with-first-afc-specification/

[29] Wireless Innovation Forum 6 GHz Committee at https://6ghz.wirelessinnovation.org/

[30] An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, 4200-4220 MHz, and 4380-4400 MHz Bands, Report NTIA,(2010) available at: https://www.ntia.doc.gov/report/2010/assessment-near-term-viability-accommodating-wireless-broadband-systems-1675-1710-mhz-17.

[31] PCAST Report at xi, 15, 22-24

[32] Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band , Report and Order and Further Notice of Proposed Rulemaking, FCC, 30 FCC Rcd 3959 (5) (2015) (CBRS Report & Order); Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, Order on Reconsideration and Second Report & Order, FCC, 31 FCC Rcd 5011 (6) (2016) (CBRS Second Report and Order).

[33] Promoting Investment in the 3550-3700 MHz Band, Report & Order, FCC, 33 FCC Rcd 10598 (16) (2018).

[34] WTB And OET Approve Four Spectrum Access System Administrators For Full Scale Commercial Deployment In The 3.5 GHz Band And Emphasize Licensee Compliance Obligations In The 3650-3700 MHz Band Under Part 96, Public Notice, FCC, 35 FCC Rcd 117 (1) (2020).

[35] Auction 105: 3.5 GHz Band, FCC, at https://www.fcc.gov/auction/105

by higher-tier users, with all sharing mediated by a centralized coordinating function—the Spectrum Access System (SAS). The *Incumbent Access* tier consists of military systems in the bottom 100 megahertz of the band and legacy satellite operations in the top 50 megahertz. The middle, *Priority Access*, must not cause interference with the Incumbent Access tier. Likewise, users in the bottom tier, *General Authorized Access* (GAA), operate at sufferance to the two higher tiers. CBRS involves a hybrid of the *centralized coordination* and *sensing* sharing approaches.

All Citizens Broadband Service Devices (CBSDs) must register location and other technical attributes with an FCC-authorized SAS. The SAS itself connects to a network of spectrum monitoring stations called an Environmental Sensing Capability (ESC). The ESC "listens" for incumbent-tier military radar operations and informs the SAS if any are detected. Upon receiving this information, the SAS instructs affected CBSDs in the relevant frequencies and locations to cease transmission or move to a different channel. (The channel is reauthorized when the radar operations stop.) The SAS also enforces coordination zones around incumbent-tier satellite earth stations. The SAS and ESC providers are private entities. The FCC has authorized multiple providers and requires them to interoperate in order to ensure a competitive marketplace for these services. Interoperability is also encouraged due to standardization of the protocol interface between the CBSDs and SASs by WInnForum. (An accompanying certification program from the OnGo Alliance ensures compliance and efficient sharing among 4G/5G cellular networks.)

Priority Access Licenses (PALs), issued for as much as 70 of the available 150 megahertz in CBRS, have the next highest claim to the band after incumbent users. Under the "use or share" rule, the SAS will give precedence to a Priority Access licensee on its assigned channel over GAA users but allow GAA use in places where this channel is left vacant by the Priority Access licensee. GAA users, which are licensed by rule, enjoy equal rights to access any of the remaining spectrum in the band. Both Priority Access and General Authorized Access users are required to operate at power levels lower than traditional cellular bands (but higher than unlicensed bands), which facilitates spatial reuse of the spectrum by many different types of users.

In designing the CBRS rules, the FCC opted to focus on functional requirements ("what" different actors need to do) rather than technical standards ("how" they do it). As anticipated by the FCC, multi-stakeholder groups, most notably the Wireless Innovation Forum and a new group called the CBRS Alliance (now known as the OnGo Alliance), wrote detailed technical specifications to allow for automated implementation under a range of scenarios. The multi-stakeholder groups have continued to evolve these specifications in response to real-world experiences and marketplace needs.

Breaking Down Spectrum Silos

The CBRS Second Report and Order establishing CBRS began with a concise statement of an ambitious policy agenda:

> The Citizens Broadband Radio Service takes advantage of advances in technology and spectrum policy to dissolve age-old regulatory divisions between commercial and federal users, exclusive and non-exclusive authorizations, and private and carrier networks.[36]

[36] CBRS Second Report & Order at Para 2.

The SAS and ESC addresses the first "age-old regulatory division," enabling dynamic sharing between Federal incumbents and commercial CBRS users. In place of a static system of manual frequency allocation (exemplified by the AWS-3 approach) the FCC called for an automated system that adapts, in near-real time, to authorize or deauthorize shared use based on database information, sensor inputs, and interference calculations. There is no doubt this automated framework is more complex than a more traditional manual coordination or sharing policy, but the result has been deployment of spectrum sharing on a very wide scale. Though over nearly 150,000 CBRS network nodes have now been deployed,[37] no instance of commercial interference into the incumbent military systems has yet been reported. The system seems to be working.

The novel design of Priority Access Licenses addressed the second "age-old regulatory division," between exclusive and non-exclusive spectrum authorizations. We have discussed, at a high level, the "use-or-share" interplay between the Priority Access and the General Authorized Access tiers. The original, 2015 CBRS rules established that the PALs themselves would be temporary 3-year grants of priority access in census-tract level areas on up to seven 10 megahertz channels. The FCC explained:

> Ultimately, we adopt a hybrid framework that selects, automatically, the best approach based on local supply and demand. Where competitive rivalry for spectrum access is low, the GAA tier provides a low-cost entry point to the band, similar to unlicensed access. Where rivalry is high, an auction resolves mutually exclusive applications in specific geographic areas for PALs. Finite-term licensing facilitates evolution of the band and an ever-changing mix of GAA and Priority Access bandwidth over time.[38]

The FCC essentially created a system of paid prioritization of spectrum access. The PALs were intended to be more dynamic than conventional spectrum licenses, providing exclusionary rights in a geographically granular and time-limited way. The Priority Access and GAA tiers were not envisioned as dichotomous "licensed" and "unlicensed" regimes, awkwardly crammed together in a common band. Rather, they were seen as two points in a continuous function in which spectrum exclusivity was a product of scarcity at a particular place and time. This unorthodox approach was made possible by the same technology, the SAS, devised for sharing spectrum with the Federal incumbents.

The passage above alludes to a third distinction: between carrier and private networks. The FCC saw a unique opportunity in CBRS to accommodate a diverse array of use cases:

> This regulatory adaptability should make the 3.5 GHz Band hospitable to a wide variety of users, deployment models, and business cases, including some solutions to market needs not adequately served by our conventional licensed or unlicensed rules. Carriers can avail themselves of "success-based" license acquisition, deploying small cells on a GAA basis where they need additional capacity and paying for the surety of license protection only in targeted locations where they find a demonstrable need for more interference protection. Real estate owners can deploy neutral host systems in high-traffic venues,

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[37] Hardesty, L. (2021, January 11). CBRS Alliance broadens spectrum-sharing scope. FierceWireless. https://www.fiercewireless.com/private-wireless/cbrs-alliance-broadens-spectrum-sharing-scope

[38] CBRS Report & Order at para 5. As noted above the GAA tier is licensed under the FCC's Part 95 Citizen Band Radio rules, so it is not exactly the same as unlicensed use under Part 15.

> allowing for cost-effective network sharing among multiple wireless providers and their customers. Manufacturers, utilities, and other large industries can construct private wireless broadband networks to automate processes that require some measure of interference protection and yet are not appropriately outsourced to a commercial cellular network. Smart grid, rural broadband, small cell backhaul, and other point-to-multipoint networks can potentially access three times more bandwidth than was available under our previous 3650-3700 MHz band rules. All of these applications could share common wireless technologies, providing economies of scale and facilitating intensive use of the spectrum.[39]

Enabling a wide range of users in a sizable spectrum band would mean that they could all make use of the same, standardized wireless technologies. Moreover, they could use the flexible licensing to acquire interference protection only where needed. The CBRS power limits are an important aspect of this policy goal. The FCC actually increased the power limits between the 2015 CBRS Report and Order and the 2016 CBRS Second Report & Order, though not to the same level as conventional cellular bands. It noted that while higher power levels provide greater operational flexibility for any one user, "lower power limits may lead to greater spatial reuse of the band, reduced coexistence challenges, and increased aggregate network capacity."[40] In other words, similar to the experience in unlicensed bands, lower power limits facilitate sharing among the kinds of heterogeneous users described in the passage above.

2018 Changes

The start of a new Administration in 2017 would bring changes to CBRS, particularly with respect to license terms and geographic areas. Under the banner of "winning the race to 5G," the PAL licenses were given longer terms with an expectation of renewal, effectively making them permanent licenses.[41] The geographical license size was increased from census tracts to counties, which, while smaller than traditional cellular licenses, still put the PALs out of reach for most non-telecom providers in populated areas.

Unfortunately, we may never know how the original PAL specifications would have played out in practice because the rules were changed before any real-world effects could be observed. Meanwhile, the FCC released nearly 400 megahertz of 5G-suitable mid-band spectrum in the 3.7 and 3.45 GHz Bands, on top of nearly 200 megahertz already available in the 2.5 GHz Band, for a total of nearly 600 megahertz—dwarfing the 70 megahertz of PAL spectrum in CBRS. Indeed, the only major cellular carrier currently using PALs has earmarked them for 4G operation, not 5G.[42] It appears that the 2018 changes to the PAL rules had little to no impact on the launch of 5G networks in the United States, which so far have taken root in other mid-band spectrum.

Non-Traditional Licensees

One of the main promises of 5G is to bring wireless technology to use cases other than mobile devices. The idea is that large swaths of the economy, in areas such as manufacturing and healthcare, will migrate onto new 5G wireless networks. Many industry experts believe that such a transformation, sometimes referred to as "Industry 4.0," will require the ability of

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[39] CBRS Report & Order at para 6.

[40] CBRS Second Report & Order at para 76.

[41] For a discussion of why the FCC originally adopted time-limited licenses, see CBRS Report & Order para 108 et seq..

[42] Dano, M.,(2021, March 11) Amid 5G push, Verizon supercharges 4G network, LightReading. https://www.lightreading.com/5g/amid-5g-push-verizon-supercharges-4g-network/d/d-id/768004

industrial players to deploy their own "private" 5G networks—built to their exacting operational specifications—inside their facilities. Some other nations, including Germany, France, and the United Kingdom, are now assigning valuable mid-band spectrum to industrial users exactly for this purpose.[43] Indeed, the ability of private networks to access standardized, interference-protected spectrum was an important design goal of the original CBRS rules. But largely because of changes in the geographic areas for licenses, with a few exceptions,[44] the CBRS auction generally failed to assign PALs to industrial licensees in the top markets where much industrial activity occurs.[45] County-sized license areas made these locations unobtainable at auction for most companies. The top five auction winners, all of which were wireless or cable companies, acquired over 85% of the PAL spectrum (measured by "megahertz-pops") in the top 500 counties, where 75% of the U.S. population resides. Despite a novel "light touch leasing" rule embedded in the CBRS framework,[46] a highly anticipated secondary market in hyper-local PAL fragments has yet to emerge.

Taking Stock of CBRS

CBRS remains the most significant spectrum sharing policy enacted by the FCC to date. Its significance stems from the comprehensive way in which the FCC sought to leverage automated CBRS sharing infrastructure to create a "universal" spectrum band that could accommodate unprecedented heterogeneity of regulatory authorizations and spectrum use cases. In many ways, CBRS is a success story, with some important qualifications.

The sharing regime has successfully increased access to the 3.5 GHz Band without causing interference to incumbent operations. Could the system be improved? While the SAS and ESC have done their job with respect to interference prevention, the fact that no single case of interference has been reported raises questions of whether the systems are *over*protecting incumbents. Additionally, the ESC has demonstrated the viability of uncoordinated sharing between the incumbent government users and lower tiers. However, the need to protect the ESC from interference may itself be restricting some commercial spectrum access, particularly along the coasts.[47] Could the system benefit from a transition to an incumbent informing capability to replace the ESC? This is a topic worthy of further discussion among various stakeholders, especially including the DOD and the SAS/ESC community.

Is CBRS living up to its promise as a multi-purpose, do-everything band? Verizon has deployed thousands of base stations using CBRS to add speed and capacity to its network in high-traffic areas. WISPs use the band to provide rural broadband service. And others are pursuing CBRS for a wide range of use cases—some envisioned by the FCC but many not—ranging from "green" buildings to automated seaports to smart factories. The OnGo Alliance, for example, now includes about 200 member organizations representing an unusually "big tent" of spectrum users, from large telcos to WISPs to industrial users to startups. On the other hand, as discussed above, most of these "non-traditional" users have little recourse to interference-protected PALs in the most populated areas, though industrial uses do seem to be emerging

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[43] 5G private licences spectrum in Europe, 5G Observatory at https://5gobservatory.eu/5g-private-licences-spectrum-in-europe/

[44] Con Edison in California, John Deere in Illinois, and Alabama Power in Alabama were awarded PAL licenses.

[45] The move to county-sized licenses (as opposed to even larger licenses typical of other FCC auctions) did allow some non-telco licensees, such as WISPs, utilities, and John Deere, to acquire PALs in more rural areas.

[46] 47 CFR § 1.9046

[47] See Google Comments filed in FCC Proceeding Facilitating Shared Use in the 3100-3550 MHz Band 3.5 GHz SAS and ESC Applications (2020) at p 11. (Google CBRS Comments) Available at https://ecfsapi.fcc.gov/file/112122603914/FINAL%202020-11-20%20Google%20Comments%20on%20the%203100-3550%20MHz%20Band%20(WT%2019-348%2C%20GN%2015-319).pdf

in the GAA tier. Whether the absence of licensed interference protections will deter industrial investment in the band remains to be seen.

All of which is to say: old habits die hard in spectrum policy. If one of the main purposes of CBRS was to bring widely different usage scenarios into a common regulatory frame, a reversion to traditional categories and concepts may have the opposite effect. It is not difficult to imagine CBRS splitting into two sub-bands: one "licensed" and the other effectively "unlicensed," contrary to the original concept and to the detriment of spectrum policy overall. For this reason, we believe the FCC should tread carefully in evaluating whether to increase power limits in the band.[48] We return to CBRS—and highlight some opportunities to reverse this trend—when we discuss the Lower 3 GHz below.

3. Sharing policy principles

The goal of spectrum sharing is to yield additional productive use or social value – it is not sharing for sharing's sake. Potential advantages of sharing include more use of spectrum, but also increased ability of federal users to take advantage of commercial-off-the-shelf (COTS) technologies and the ability for non-traditional players to access spectrum. For many years, the FCC has promoted secondary markets as a means of enabling non-carrier players to access spectrum for their private needs, but the secondary markets policy has generally not fulfilled this purpose. Use-or-share rules such as those in the CBRS band, may help non-traditional entities to gain access to spectrum where it otherwise lays fallow. In this section, we outline some design principles that should apply to any successful spectrum sharing policy.

Develop interference expectations. Sharing regimes should be informed by reasonable interference expectations, developed using modern analytics, rather than worst-case analysis. Statistical methods such as Monte Carlo analysis[49] can be used to assess the probability of interference. The standard cannot be 0% chance of interference. Effectively it is not 0% today, though we sometimes pretend that it is. In addition, it should be possible to make assumptions about the capability of radio systems to reject interference through resilient engineering. "Victim" radio operators can assess whether it is lower cost to accept the possibility of some interference, to design the receivers in a way to avoid interference, or to build in redundancy such that interference with one receiver does not impair operation of the overall system.

Encourage standards and technologies that facilitate sharing. Sharing can be facilitated through private sector development of cross-industry "meta standards," such as the ones developed by the Wireless Innovation Forum for the CBRS band.[50] These standards may be designed to be agnostic as to the underlying radio technologies used for transmission. In this way, a Wi-Fi system based on 802.11 standards could share spectrum with a cellular system based on 3GPP standards, at least in principle.

Promote sharing by design, particularly in bands in which there are no incumbents. In the

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[48] Dish Network Corporation's March 5, 2021, ex parte filing in the FCC's CBRS proceeding at pp 2-6 and Attachment 1 available at: https://ecfsapi.fcc.gov/file/1030580594111/2021-03-05%20DISH%20Network%20Ex%20Parte%203.45%20GHz%20Band.pdf

[49] See Monte Carlo Simulation, IBM Cloud Education (2020) available at: https://www.ibm.com/cloud/learn/monte-carlo-simulation

[50] See Enhancements to CBRS Baseline Standards (Release 2), CBRS WInnForum Standards, available at: https://cbrs.wirelessinnovation.org/enhancements-to-baseline-specifications

lower 37 GHz band, as well as higher bands that are allocated for both federal and commercial use but have little or no use today, both the regulatory framework and the systems of users should be built from the ground up with sharing in mind. For example, a regulatory framework that provides for symmetry of rights among users, whenever possible, will facilitate the users working things out via negotiation or commercial arrangements rather than by regulatory fiat. Where intermittent but mission-critical government operations are anticipated, a purpose-built sharing system can allow priority preemption by government users when needed but preserve use for non-governmental users most of the time. The design of regulations and systems should also preserve flexibility to alter uses over time, even in a shared environment.

Avoid artificial scarcity. Spectrum "scarcity" is often a byproduct of regulation. Wherever possible, particularly in the higher bands where propagation is highly directed and contained, the default should be rules that promote the abundance of spectrum through spectrum re-use. "Enclosing" the spectrum through very large licenses for bands where transmissions are inherently localized and mostly non-interfering is a recipe for spectrum underuse. Transaction costs and institutional incentives have historically limited the theoretical potential of market forces to naturally disaggregate such licenses into smaller units suitable for non-interfering uses. (This principle in particular has not been applied consistently by the FCC.)

Avoid "Trojan Horses" for market power. No single private entity should hold the key to enabling a centralized shared spectrum policy. Of course, private entities enable spectrum sharing all the time, but they do so on the basis of obtaining a spectrum license, often acquired at auction. Sharing rules should not enable a *de facto* licensee that is able to obtain this privilege without all of the usual obligations and processes associated with licensing. It is imperative to have multiple, competing administrators of TVWS databases, SASs in the CBRS bands, and AFC systems in the 6 GHz band. Future sharing frameworks should operate similarly.

Build in enforcement mechanisms. One of the common objections to sharing, from federal and commercial incumbents, is the concern that interference limits will not be enforced. The DFS 5 GHz example is often cited. In order to enable enforcement, the framework requires: (1) clear interference standards that include transmitter rules but also a responsibility to design receiver systems in a way that does not make them vulnerable to interference; (2) resources for enforcement at both the FCC and NTIA; and (3) a willingness to adjust the rules if needed. The database-oriented systems, such as the SAS and AFC, can provide an important enforcement tool by providing (4) a mechanism to deauthorize radios that break the rules.

4. New opportunities for the new administration

With a new Administration comes new opportunities. The previous four years saw very large tranches of spectrum released into the marketplace to address well-established interests in licensed and unlicensed use of spectrum. The time seems ripe to reset a sharing agenda that builds upon the original vision of CBRS to expand the toolbox for a wide panoply of wireless users. Below we offer a few suggestions on where to start. These ideas focus on spectrum sharing as we have defined it above and by no means encompass the full range of spectrum policy opportunities that lie ahead.[51]

[51] For example, in the 95-300 GHz Band. See Leibovitz & Milkman Day One Project Paper pp. 7-8.

A. Lower 3 GHz Band

In its recent 3.45 GHz Second Report and Order the FCC recognized "there may be potential opportunities in the future to consider steps we might take, in cooperation with NTIA and other federal partners, to effect an overall rationalization of the non-federal services in the 3 GHz band."[52] Below we discuss what such a rationalization might entail as well as some of the potential benefits.

Over the past decade the U.S. Government has undertaken an effort to make DOD-allocated spectrum in the 3 GHz Band, primarily used for various airborne, shipborne, and ground-based radar systems, available for shared commercial use. CBRS spectrum from 3.55-3.65 GHz represented the first installment of this project. A 2018 law, the MOBILE NOW Act, required various Federal agencies to study the "feasibility of allowing commercial wireless services, licensed or unlicensed, to share use of the frequencies between 3100 megahertz and 3550 megahertz."[53] One result of this process was that the FCC removed secondary non-Federal allocations for Amateur and Radiolocation services from the 3.3-3.5 GHz range, to lay the groundwork for expanded commercial wireless use.[54] The Federal agencies' analysis of potential sharing opportunities focused on the 3.45-3.55 GHz band and produced the forthcoming auction.[55] Frequencies below 3.45 GHz, especially in the 3.3-3.45 GHz range, are presumably still under study by the Federal agencies. Indeed, Congress is presently considering a mandate to auction a portion of this band as part of the Infrastructure Investment and Jobs Act. The fact that these bands were not made commercially available in the first instance likely reflects a combination of factors, including "compressing" DOD systems into less occupied bandwidth (at least temporarily) to facilitate use of 3450-3550 MHz.

At the same time, various different approaches to repurposing spectrum across the 3 GHz Band over the past decade have left a patchwork of commercial authorization approaches. The "C-Band" spectrum at 3.7-3.98 GHz is authorized under an exclusive use model, with higher power cellular operations permitted. Just below this, the CBRS Band at 3.55-3.7 GHz allows lower power transmissions and uses the three-tiered SAS/ESC-based framework described above. The forthcoming 3.45-3.55 GHz Band permits high powered operation at the same levels as the C-Band but uses a more conventional AWS-3-like coordination approach to share with Federal incumbents.

The different rules create inconsistencies and challenges for commercial users. Numerous commenters to the C-Band and 3.45 GHz Band proceedings pointed out that the mismatch of power levels at both the upper and lower CBRS band edges can potentially lead to challenging interference scenarios.[56] The FCC largely sidestepped the issue in the C-Band Report & Order and adopted a vague coordination obligation along with an unconventional emissions mask in the 3.45 GHz Band rules.[57] Commenters also noted the inconsistencies in sharing approaches

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[52] Facilitating Shared Use in the 3100-3550 MHz Band, Second Report and Order, Order on Reconsideration, and Order of Proposed Modification, FCC, 36 FCC Rcd 5987 (9) (2021) at para 136 (stating there are potential opportunities to coordinate with NTIA to create an "overall rationalization of the non-federal services in the 3 GHz band" citing 47 U.S.C. §316).

[53] MOBILE NOW Act contained in Title 6 of the Consolidated Appropriations Act of 2018, Pub.L. 115–141 (2018).

[54] C Facilitating Shared Use in the 3100-3550 MHz Band, Report and Order and Further Notice of Proposed Rulemaking, FCC, 35 FCC Rcd 11078 (13) (2020) (3.45 GHz Band Report and Order).

[55] See Drocella, E., Sole, R., & LaSorte, N., Technical Feasibility of Sharing Federal Spectrum with Future Commercial Operations in the 3450-3550 MHz Band, Technical Report, NTIA (2020) available at: .https://www.ntia.gov/report/2020/technical-feasibility-sharing-federal-spectrum-future-commercial-operations-3450-3550 and 3.45 GHz Band Report and Order.

[56] See e.g. Nokia Comments on the FCC's 3.45 GHz Proceeding (Nov. 20, 2020) available at: https://ecfsapi.fcc.gov/file/1120194964929/Nokia%20Comments%20on%203%20GHz%2011-20%20FINAL.pdf

[57] 3.45 GHz Second Report and Order at para 79-85.

between the 3.45 GHz and CBRS Bands. Some SAS operators, for example, have noted that if DOD is planning to introduce an Incumbent Informing Capability in 3.45 GHz, this same approach could substitute for the ESC in CBRS.[58]

We do not take a position on these specific concerns here. However, we do note that as a general rule in spectrum policy, it is beneficial to minimize "border issues" by designating "like next to like" when feasible. We cannot help but observe that the patchwork nature of the commercial 3 GHz band reflects largely siloed regulatory processes directed by different administrations over the past decade. In an ideal world, the 3 GHz Band would be rationalized so as to reduce band-edge interference conflicts and streamline the Federal/non-Federal sharing regime. Were such an initiative to coincide with an effort to look at sharing below 3.45 GHz, it could produce "win-win" outcomes for all parties involved. We offer the following strawman proposal to instigate discussion around the broader 3 GHz opportunity.

The crux of our hypothesis is that the 3.45 GHz Band service could be swapped with the top 100 megahertz of CBRS. At the same time, Priority Access Licenses could be moved from the bottom end of the (relocated) CBRS band to the top portion. The result of these maneuvers would be the following band plan:

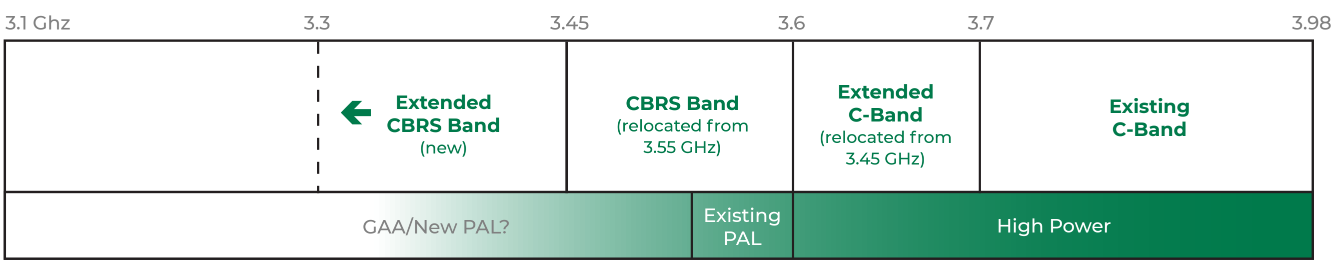

Figure 2. Rationalization of 3 GHz Band

As one can see from the diagram, the new band plan would consolidate all the higher-power licenses at the top end of the band. CBRS PAL licenses would similarly be moved adjacent to the high-power uses. The existing 80 megahertz "GAA floor" in CBRS would be consolidated at the bottom. Any new bandwidth enabled for commercial sharing below 3.45 GHz would be authorized as an extension of the CBRS Band. We expect sharing discussions would begin with the 3.3-3.45 GHz Band segment but potentially could encompass the full range down to 3.1 GHz.

The rationalization would result in 450 megahertz of contiguous area-licensed spectrum at the top end of the band (including 70 megahertz of PALs) and earmark the lower portion of the band for a more dynamic CBRS model. The existing PALs might or might not be converted to high-powered licenses as some have suggested. Similarly, the Extended CBRS Band might forego PALs entirely or, alternatively, might utilize a different model for PAL licensing similar to the localized, facilities-based model being used in Europe (and considered under the moniker "Contained Access Facility" in the original CBRS proceeding[59]).

[58] See Google CBRS Comments

[59] CBRS Report and Order, para. 164 et seq.

We see several benefits from this reorganization:

- *Enhanced Federal Sharing*. The "hairy" Federal sharing at the bottom end of the band would involve low-powered CBRS operations rather than high-powered carrier operations. This should improve the prospects for sharing, which could potentially also make use of new techniques such as the Informed Incumbent Capability.
- *Minimized Band-Edge Interference*. In this approach there is only one high-power/low-power boundary, which reduces potential interference into CBRS.
- *Consolidated Carrier-Grade Spectrum*. Deployment costs would be reduced because base station equipment can operate across one large swath of bandwidth, potentially using a single radio.
- *More CBRS Spectrum*. The proposal earmarks new spectrum below 3.45 GHz to CBRS. As noted above, it also provides opportunities for additional commercial licensing innovation in this band segment.

Such a large-scale transformation would undoubtedly involve some dislocation and discomfort among existing CBRS users. Transition in the CBRS Band is not a new topic, however.[60] In some ways, the SAS-based architecture of CBRS can make transition easier. We note that bandwidth from 3.3 to 4.2 GHz is already standardized within a single 3GPP Band, n77, which should facilitate even greater equipment availability and interoperability than the current Band 48. The payoff for CBRS users would be access to twice as much bandwidth (or even more) over time. We would not expect such a transition to occur overnight; it would require staged equipment upgrades for some existing users. It would be best to establish such a plan before the new 3.45 GHz licensees commit to equipment purchases using the spectrum. The FCC clearly has ample authority to modify various licenses to effectuate such a transition, provided, of course, that NTIA and the Federal Agencies agree that it would preserve (or perhaps even promote) Federal capabilities in the spectrum. NTIA might consider pro-actively working with federal agencies to determine whether such a transition could benefit incumbent federal uses by, for example, reducing (or removing) the need to relocate some federal systems.

B. Lower 37 GHz Band

The lower 37 GHz band (37.0-37.6 GHz) was identified as a shared band for both federal and non-federal in the 2016 Spectrum Frontiers Order.[61] This band is unusual in that it is a shared band, allocated for both government and commercial use, with little or no incumbent use. Therefore, it is an opportunity to explore new approaches to sharing, without having to accommodate existing users.

The 2016 Spectrum Frontiers Order incorporated a high-level decision to have the lower 37 GHz be a shared band but deferred almost all implementation issues to a further notice, and

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[60] See 47 CFR §90.1338 (detailing protection and transition for existing fixed and base stations).

[61] Use of Spectrum Bands Above 24 GHz for Mobile Radio Services; Establishing a More Flexible Framework to Facilitate Satellite Operations in the 27.5-28.35 GHz and 37.5-40 GHz Bands; Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band; Amendment of Parts 1, 22, 24, 27, 74, 80, 90, 95 and 101 To Establish Uniform License Renewal, Discontinuance of Operation, and Geographic Partitioning and Spectrum Disaggregation Rules and Policies for Certain Wireless Radio Services; Allocation and Designation of Spectrum for Fixed-Satellite Services in the 37.5-38.5 GHz, 40.5-41.5 GHz and 48.2-50.2 GHz Frequency Bands; Allocation of Spectrum in the 46.9-47.0 GHz Frequency Band for Wireless Services; and Allocation of Spectrum in the 37.0-38.0 GHz and 40.0-40.5 GHz for Government Operations, , Report and Order and Further Notice of Proposed Rulemaking, FCC, 31 FCC Rcd 8014 (10) (2016) (2016 Spectrum Frontiers Order and NPRM)

five years later, there is no plan for licensing (whether by auction or by rule) and little use of the band. The upper 37 GHz band (37.6-38.6 GHz), however, was auctioned together with the 39 GHz (38.6-40 GHz) band, which is relevant because the FCC requires that equipment must be operable across the full 37 and 39 GHz band (37-40 GHz), including the shared band from 37.0-37.6.[62] This operability requirement should enable federal users to obtain commercial, off-the-shelf (COTS) equipment and component parts that can help in the development of new systems. The operability requirement can also help smaller companies obtain equipment across the bands.

The 2016 NPRM that accompanies the Spectrum Frontiers Order seeks comment on coordination mechanisms between federal and non-federal uses for the lower 37 GHz band, including manual approaches or the use of a SAS, or something in between. The NPRM also asks whether additional interference mitigation or enforcement mechanisms might be required. In 2018, the FCC issued a further NPRM on the coordination mechanism for the lower 37 GHz, and said that it "will work in partnership with NTIA, DoD, and other Federal agencies to develop a sharing approach that allows for robust Federal and non-Federal use in this band."[63] The FCC noted that it had received few comments on the coordination approach and sought additional comment on a first-come, first-served approach. More recently, Qualcomm has put a proposal in the record for shared use among commercial users, though it does not appear to propose anything with respect to federal users.[64]

The Qualcomm proposal is an example of more sophisticated sharing approaches that could be developed in the band. It seeks to take advantage of the technical characteristics of the band, namely that the signals are highly directional and do not travel long distances. Qualcomm's proposal contemplates a two-tiered scheme in which primary users are licensed and have priority, and other users must refrain from transmitting during a coordinated silence period, in which the non-primary base stations listen for nearby receivers, and refrain from transmitting on frequencies if needed.[65] This approach is geared to facilitate mobile use in the band, but as noted, Qualcomm does not propose a mechanism for federal sharing.

The greenfield nature of the Lower 37 GHz Band presents a rare opportunity to integrate true "bidirectional" spectrum sharing between federal and non-federal users into the rules from the ground up, in greenfield spectrum. DOD has supported the concept of bidirectional sharing for several years.[66] The key to success is a collaborative, cross-agency, public/private process that establishes a shared understanding of the technological underpinnings of such a sharing regime. It might involve the same technologies proposed by Qualcomm for sharing among commercial users or additional technologies (e.g., a well-designed IIC) that address special needs of federal operators (e.g., a desire to conceal military transmissions). It is imperative that such a process move toward a rapid conclusion, through strong White

[62] 2016 Spectrum Frontiers Order and NPRM at para 323.

[63] In the Matter of Use of Spectrum Bands Above 24 GHz For Mobile Radio Services; Amendment of Parts 1, 22, 24, 27, 74, 80, 90, 95 and 101 To Establish Uniform License Renewal, Discontinuance of Operation, and Geographic Partitioning and Spectrum Disaggregation Rules and Policies for Certain Wireless Radio Services, Third Report and Order, Memorandum Opinion and Order, and Third Further Notice of Proposed Rulemaking, FCC, 33 FCC Rcd 5576 (9) (2018) at para. 62.

[64] Qualcomm Ex Parte Filings in the FCC Spectrum Frontier Proceeding. July 1, 2021 filing available at: https://ecfsapi.fcc.gov/file/10701223752305/07-01-2021%20Qualcomm%20Lower%2037GHz%20ExParte.pdf; May 5, 2021 filing available at: https://ecfsapi.fcc.gov/file/1050518968838/05-05-2021%20Qualcomm%20Ex%20Parte.pdf

[65] See Qualcomm May 5, 2021 ex parte filing.

[66] See e.g., Electromagnetic Spectrum Superiority, DOD, (2020) at p 6 available at: https://media.defense.gov/2020/Oct/29/2002525927/-1/-1/0/ELECTROMAGNETIC_SPECTRUM_SUPERIORITY_STRATEGY.PDF

House and inter-Agency leadership. The next step would be to issue rules that encourage development of technical standards to emerge, in an appropriate forum, to enable widespread commercialization of the technology.

The lower 37 GHz presents a near-term opportunity to advance sharing in 600 MHz of spectrum with a robust technology ecosystem available to both commercial and military users (although for very different missions). Issues to resolve will be: (1) working out a solution that enables bidirectional federal and non-federal use; (2) considering whether it is advisable to build on some of the components of the CBRS regime, including multiple tiers, with a multi-stakeholder group taking on much of implementation, including mitigation and enforcement; (3) considering whether, because of the propagation characteristics of 37 GHz, e.g., building loss, it may also be possible to have different rules for indoor and outdoor use; and (4) facilitating uses beyond carrier-offered 5G, given the amount of other millimeter spectrum that is already available for 5G. In considering appropriate resolution of these and other issues, it will be desirable to avoid unnecessary complexity. Federal agencies could benefit from early engagement by NTIA to develop an approach that enables federal users to take advantage of standardized, commercially available equipment. In addition, an FCC-NTIA solution in the lower 37 GHz that opens additional spectrum to both federal and commercial use could establish a model for future bidirectional sharing in other bands.

Conclusion

Over the past two decades, the FCC and NTIA have shown that sharing between commercial and federal users can be successful. The FCC has also created robust models of sharing in commercial bands. These sharing approaches represent a significant advance in spectrum policy, by enabling additional use and users of spectrum. This Administration has an opportunity to expand the use of sharing techniques still further, both by replicating (with modifications as needed) established sharing mechanisms and by developing creative new approaches.