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Unlicensed Operation in the TV Broadcast Bands	)	ET Docket No. 04-186
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To: The Commission

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SUMMARY

The TV White Space

Although broadcasting will occupy 17 fewer TV channels than it does today after the transition to digital television (DTV), substantial unused but useful radio spectrum will remain in the TV bands. This spectrum, known as white space, resembles Swiss cheese—it is a large block of spectrum with "holes" where the TV signals must be protected from interference.

Policy Choice

The FCC can choose among three different approaches to managing this white space: (1) allow the white space to continue to lie idle, (2) permit unlicensed use of the white space, or (2) auction off flexible, tradable rights, or licenses, to the use of the white space. Unfortunately, much of the debate to date has focused on the possibility and details of unlicensed use; licensed use has remained the unexamined alternative.

Commendably, the Commission has now formally expanded its proceeding to include consideration of a licensed approach to use of the white space (Option 3). The purpose of our analysis is to better define this third option and to evaluate its benefits relative to those of an unlicensed approach (we discard Option 1 as wasteful).

Extent of White Space

- Under interference-protection rules appropriate to a licensed regime, 97% of the population lives in locations at which there will be at least 24 MHz of spectrum available in the white space following the DTV transition.

- There is dramatically less (about half as much) spectrum available in the white space under interference-protection rules that correspond to those the FCC is most likely to impose in an unlicensed regime.

Drawbacks to Unlicensed Use of the White Space (Near Term)

- For short-range data transfer, unlicensed TV spectrum would be inferior to the existing unlicensed bands at 2.4 GHz and 5 GHz. A combination of limited data rates, network externalities, and added costs to avoid interference with incumbents will impede adoption of this band for the market needs served by today's wireless local area networks (LANs).

- Similar factors fatally impaired the unlicensed PCS (UPCS) band. Although unlicensed white space (unlike UPCS) would attract users, the likely short-range applications would not add significant value beyond those found in existing unlicensed bands today.

- Investment in long-range applications would be impeded for a different reason—the threat of interference, including that from short-range wireless LAN operations in the white space. The FCC's ongoing 3.65 GHz proceeding supports the view that lack of exclusive rights discourages investment in long-range infrastructure.

- In addition to offering limited incremental benefits, an unlicensed regime would impose a large opportunity cost by precluding licensed use of the white space. This is a key difference between the white space and the oft-cited 2.4 GHz band, and something that unlicensed advocates have systematically ignored.

- As one source of this opportunity cost, the white space is "overqualified" for the low-power, short-range wireless networks that unlicensed advocates envision; it would amount to using land in downtown Tokyo to grow rice.

Advantages of Licensed Use of the White Space (Near Term)

- Licensed access creates the incentive and opportunity for white-space licensees and broadcasters to engage in negotiations to expand licensed service. Such Coasian bargaining could produce variances beyond the FCC interference standards—standards that themselves would be less protective in a licensed regime.

- Those two factors (bargaining plus less protective standards) should result in substantially more white space being used than in an unlicensed regime. (Our calculation of available white space captures only the latter.)

- By controlling interference, licensed access provides better incentives for the provision of long-range services, such as wireless Internet access, for which this spectrum is particularly well-suited. Thus, a licensed approach is far more likely to produce the large investments in long-range infrastructure that rural broadband requires.

Long-Term Impact of Unlicensed versus Licensed

- Whatever its short-run contribution, unlicensed access would impede the long-term transition of the TV band to higher value uses by creating a constituency of spectrum "squatters" and their suppliers. In this way, an unlicensed regime would perpetuate the current regulatory system's tendency to encourage rent-seeking and discourage entrepreneurial innovation.

- In principle, one could use technology to moderate the effects of the squatter's rights problem. But it would require political will to impose a technological solution—an unlikely scenario.

- By contrast, a licensed approach would facilitate the evolution of the TV band. If broadcasters were given flexible use rights, over time, broadcasters and white-space licensees would reengineer the broadcast system, freeing up most of the spectrum for higher value uses.

Feasibility of a Licensed Approach

- To the limited extent that they have acknowledged the licensed alternative to white-space access, unlicensed advocates have dismissed it as infeasible on the grounds that the transaction costs of dealing with spectrum "Swiss cheese" would be prohibitive.

- But transaction costs are an issue only because licensed operations would make more extensive and efficient use of the white space through frequency coordination and interference negotiation. A white-space licensee could always eliminate transaction costs by using the white space in the same, limited way that unlicensed advocates propose.

- Moreover, contrary to the claims of unlicensed advocates, those coordination activities need not be prohibitively complex or costly. The FCC typically structures overlay licenses with an eye to limiting coordination costs, and structuring licenses for the white space would not be fundamentally different.

Potential Auction Revenues

- The revenues from the auction of white-space spectrum could be substantial. Using two different market comparables, we estimate that white-space auctions would yield between $3.7 billion and $6 billion.

I. INTRODUCTION

Television broadcasters occupy a large band of spectrum that is considered highly desirable largely because of its superior propagation characteristics. Although broadcasters will relinquish 17 UHF channels (channels 52-69) as part of the digital television (DTV) transition, the post-transition TV band (channels 2-36 and 38-51) will still represent a large swath (294 MHz) of choice spectrum.

In some geographic areas, substantial blocks of the TV band are essentially vacant—*i.e.*, not encumbered by existing licensees—and that pattern will persist following the DTV transition. However, estimates vary as to how much of this vacant TV spectrum ("white space") there is now in different locations, and how much will be left following the DTV transition.

Although white space was traditionally considered unusable, developments in digital technology mean that this valuable spectrum can now be put to productive use. There are three basic options for managing the TV white space in a post-DTV environment. Option 1 is to leave it fallow. Option 2 is to make the white space available for non-interfering, low-power devices on an unlicensed, or commons, basis. Option 3 is to make it available under a flexible and tradable license that would protect incumbent license-holders (primarily broadcasters) from interference.

Remarkably, the debate over TV white space has until recently been limited to the first two options: leave the white space idle (*i.e.*, status quo) versus allow unlicensed access. Proponents of the second option have argued that unlicensed devices could identify the vacant spectrum and use it to provide valuable new wireless applications that would generate substantial consumer benefits. Broadcasters, asserting that such devices would interfere with their over-the-air signals, have staunchly defended the status quo policy on white space (no access). The debate over these two choices has focused largely on technical issues related to whether unlicensed devices would in fact create harmful interference.

Commendably, the Commission has now formally expanded its proceeding to include consideration of a licensed approach to use of the white space (Option 3). The purpose of our analysis is to better define this third option and to evaluate its benefits relative to those of an unlicensed approach (we discard Option 1 as wasteful).

We focus on the relative economic benefits of licensed versus unlicensed access to the white space, in the belief that spectrum allocation is, ultimately, an economic policy choice. We ignore the technical question of whether an unlicensed approach would create harmful interference, on the assumption that the FCC could find a way to implement such an approach that would control interference. (A licensed approach, by definition, would control interference.) That said, we do take into account the fact that the choice of approach—licensed versus unlicensed—would affect the amount of TV white space available for use (and, in fact, we quantify that effect).

Our report is organized as follows. In Section II, by way of background, we summarize the broader debate over the appropriate mix of spectrum management models—command and control, property rights and unlicensed commons. In Section III, we present the results of our own analysis of a threshold, technical question: How much white space will be available in the

TV band following the DTV transition under different scenarios? In Section IV, we critique the case for unlicensed access to the TV white space and examine key effects of such an approach. In Section V, we make the affirmative case for licensed access; among other things, we estimate the potential revenue that an FCC auction of white-space spectrum rights would generate.

II. ORIGINS OF THE WHITE SPACE DEBATE

The FCC's traditional, highly regulatory approach to limiting spectrum interference—a legacy of the technologies and communications needs of the 1920s and 1930s—is a source of significant waste and inefficiency in our digital age. The litany is familiar: Restrictions on the use and transferability of licenses keep valuable bandwidth locked into the provision of low-value services and encourage hoarding of spectrum. Over time, these restrictions depress the incentives for innovation and delay the introduction of valuable new technologies. An innovator who wants to bring a new technology to market often has to wait years or even decades for the FCC to make the necessary changes in the spectrum rules and allocations, and in the process reveal proprietary business ideas to potential competitors. Although the Commission has reformed key elements of this obsolete regime, much spectrum remains tightly regulated.

The same forces that discourage innovation promote rent-seeking. Firms spend large resources on lawyers and lobbyists in an effort to influence the market-shaping decisions of regulators and their congressional overseers. And the playing field is not level. As with other Depression-era "public interest" regulatory regimes, spectrum regulation has often protected incumbents and other special interests from competition. Among other things, often broadcasters "play the interference card" to oppose the entry of potential rivals and others seeking to use adjacent spectrum.[1]

A. Property Rights versus Unlicensed Commons

Although there is a broad consensus that the command-and-control regulatory regime should give way to a more flexible, decentralized approach to spectrum governance, there is less agreement on what that approach should be. The debate has revolved around two competing, but not necessarily mutually exclusive, visions—a market approach that treats licensed access to the spectrum as private property, and a commons approach that eschews licensing altogether.

Economists, who have long been skeptical about the ability of government agencies to "pick winners," have preponderantly favored a market approach to the allocation of resources, generally, and spectrum, in particular.[2] As early as 1959, Ronald Coase wrote that spectrum was a fixed factor of production, like land or labor, and should be treated in the same way, with its use determined by the pricing system and awarded to the highest bidder. In an analysis of FCC regulation that led directly to his Nobel-winning essay the following year, Coase concluded

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[1] Jonathan E. Neuchterlein and Philip J. Weiser, *Digital Crossroads: American Telecommunications Policy in the Internet Age* (MIT Press, 2005), p. 240. Broadcaster concerns with interference are often legitimate. However, under FCC rules, broadcasters cannot sell or lease adjacent spectrum or negotiate over its use; thus, their incentive is to take the most conservative possible stance regarding the threat of interference.

[2] William J. Baumol and Dorothy Robyn, *Toward an Evolutionary Regime for Spectrum Governance: Licensing or Unrestricted Entry?* (Brookings Institution Press, 2006), pp. 9-14.

that the assignment of well-defined property rights in spectrum use that such an allocation would entail would be sufficient to prevent inefficient broadcast interference.[3]

The market-based approach to spectrum governance has two important advantages over traditional licensing. The first is *efficiency in use*. Economists believe that the profit motive will deliver spectrum, like any other valuable resource, to those who can put it to the uses most desired by the public. Over time, the inexorable pressure to make efficient use of a scarce resource, such as spectrum, leads to increased investment and innovation; this *dynamic efficiency* is a second important advantage that markets provide relative to administrative licensing.

Although the FCC has traditionally allowed some role for the market in spectrum management (*e.g.*, radio licenses have long been bought and sold), that role expanded markedly in 1993, when Congress authorized the use of auctions to award (some) spectrum licenses—an approach that every American president since the 1970s had advocated. The FCC has auctioned off most new exclusive spectrum licenses since then, and it recently took steps to promote a secondary market in spectrum rights. Although these changes represent a big improvement on administrative licensing, only a fraction of the most valuable spectrum is subject to market-based management.

At the same time that market-based reforms to spectrum regulation were gaining wider acceptance, some legal scholars and a handful of firms (*e.g.*, Apple Computer) were urging the FCC to eschew licensing altogether and treat the spectrum, or large blocks of it, as a common resource, or commons.[4] The Commission had traditionally allowed certain bands to be used by anyone who transmitted with equipment that met certain specifications; as of 1996, about 200 MHz of spectrum was designated for such unlicensed use.[5] Since then, the FCC has set aside a significant amount of additional spectrum for unlicensed use, and several of these unlicensed bands have generated widespread use. The most prominent use of unlicensed spectrum is wireless computer networking—specifically, wireless local area networks (WLANs, or LANs), including Wi-Fi and Bluetooth devices. The popularity of these applications has generated broader support for a commons (or unlicensed) approach to spectrum governance.

Proponents of a commons approach base their case primarily on recent and anticipated developments in technology. They note that the "amount" of spectrum that many new uses require is minimal and newer receivers can adapt to the presence of interference at levels that

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[3] Ronald H. Coase, "The Federal Communications Commission," *Journal of Law & Economics* 2 (1959).

[4] Commons proponents are as critical of administrative licensing of spectrum as are economists, but for a different reason: whereas economists oppose the use of *regulation* to assign the licenses and restrict their use, commons proponents oppose *licensing*—i.e., the *exclusive assignment of frequencies*. From their perspective, moreover, a market approach to licensing represents little if any improvement on administrative licensing.

[5] FCC staff proposed such flexible bands as early as the late 1970s. In the mid-1980s, the FCC adopted liberal rules permitting the use of spread spectrum radio systems on an unlicensed basis at 902-928, 2400-2483.5 and 5725-5850 MHz. Over time, the rules governing these and other unlicensed bands have been relaxed to permit the use of any digital modulation, not just spread spectrum, subject to limits on power and power density. The FCC's current, more relaxed rules are similar to what FCC analysts proposed three decades ago. See C. Jackson, "The Allocation of the Radio Spectrum," *Scientific American*, Vol. 242, No. 2 (February 1980).

would have caused traditional technologies to fail. Thus, there is said to be little or no need for the imposition of exclusivity to prevent serious interference. As important, licensing is said to be impractical because the transaction costs of arranging to get the necessary spectrum rights for this newer technology would exceed the benefits. For example, the spectrum used by a keyless automobile door lock control would be worth only a few hundredths of a cent.

Although the proponents of a commons regime reject the exclusive assignment of spectrum rights that is essential to the market approach, they maintain that a commons approach would nevertheless harness market forces by facilitating the operation of a market for end-user equipment. According to this argument, it would be in the interests of manufacturers of unlicensed spectrum-using equipment to invest in designs that performed robustly in the presence of interference as a way to expand their volume of business. They argue that this would lead to efficient spectrum use in many circumstances (*i.e.*, no tragedy of the commons). Even more controversially, commons advocates maintain that equipment manufacturers would be as powerful an engine for innovation in a commons regime as licensees and their suppliers are in a market regime.

Criticism of the Unlicensed Commons Approach

Support for the unlicensed approach to spectrum governance appears to be concentrated in the computer science community and the information technology (IT) industry; the IT industry benefits directly from the sale of computer networking equipment and indirectly from having such equipment more broadly available as a complement to its other products. Much of the intellectual leadership has come from some prominent legal scholars who see in unlicensed access a fundamental reform of radio law.[6] Their detailed treatises have attracted a larger following of individuals who favor unlicensed spectrum as an "ideal of freedom." [7]

This movement has generated strong criticism as well—primarily (but not exclusively) from economists. Critics maintain that the commons approach lacks the essential advantage that property rights provide—namely, economic incentives that will ensure efficient use of the spectrum and promote investment in innovation. For example, the Progress and Freedom Foundation (PFF) recently released a report on spectrum policy by a prominent panel of experts that includes three former FCC chief economists and the agency's former chief technologist.[8] Although the panel acknowledges that "there is considerable disagreement (even within this

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[6] See, for example, Larry Lessig, *The Future of Ideas: The Fate of the Commons in a Connected World* (Random House, 2001); and Yochai Benkler, "Overcoming Agoraphobia: Building the Commons of the Digitally Networked Environment," *Harvard Journal of Law & Technology* 11: 287 (1997). For a recent response to the Benkler and Lessig, see, "Spread Spectrum is Good, But it Does Not Obsolete N.B.C. v. U.S.!," by Charles Jackson, Raymond Pickholtz, and Dale Hatfield, *Federal Communications Bar Journal*, Vol. 58, No. 2 (April 2006).

[7] See http://www.volweb.cz/horvitz/os-info/whatis-OS.html for example.

[8] "Digital Age Communications Act: Report from the Working Group on New Spectrum Policy," Progress and Freedom Foundation (March 2006). The sections of the report quoted below appear on pp. 3-7.

working group) over what should replace [command-and-control regulation]," the group concludes that the commons approach cannot be the primary direction of spectrum reform.

The Working Group highlights two inherent problems with the commons approach. First, because it lacks property rights, "the large investments needed to use the available spectrum efficiently and create new wireless services are likely to be delayed and/or dampened, with adverse consequences for the U.S. economy."[9] The report acknowledges that the model might have some initial appeal for small, innovative providers, but concludes that it is "insufficiently specific about how efficient priorities will be established and … based on strong conjectures about future radio technology." Second, the group faults the absence of "market-determined prices as the mediating mechanism in spectrum usage decisions." The report concludes that, in this respect, the commons model retains a core (negative) attribute of command-and-control.

The Working Group also expresses concern that the commons model is more susceptible than a market approach to political pressures favoring inefficient outcomes—another weakness of the legacy regime:

> For example, even if technological developments lead to a situation in which moving millions of Wi-Fi users is efficient, it is difficult to see how there could be the political will to do so. Experience indicates that markets are much more likely to adjust continually to underlying conditions of tastes and technology than are political decisions.

Notably, the panel rejects the claim that *new technologies* such as Wi-Fi and cognitive radio either favor a commons regime or will not succeed in a property rights environment. In fact, higher-power versions of those technologies, such as WiMax, will tend to favor a licensed regime because channel contention will be greater as will the need for infrastructure investment, the report concludes. The group argues that even the lower power uses that are currently extolled as successful examples of unlicensed operations could be handled by a property rights regime: for example, an investor could license the use of a specific frequency to an equipment manufacturer, who would sell users the product (say, a Wi-Fi router) and the spectrum rights jointly. The panel notes that this approach would be more efficient than an unlicensed approach, in which the use of the product is under-priced, because users do not have to pay the opportunity cost of the spectrum.

The Working Group rejects on similar grounds the claim that the potentially large *transaction costs* associated with use of the new technologies provide a justification for the commons approach. The report asserts that "the market often finds clever ways of economizing on transactions costs when there are benefits from doing so," such as having manufacturers pay royalties to spectrum owners.

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[9] As the report explains, "We see the benefits of secure priority rights already in the operation of the PCS bands where providers with those rights have made, and continue to make, very large investments. Because there is no mechanism for securing top priority in the commons model, that model provides no comparable incentives for services requiring substantial investment."

The Working Group acknowledges that there is an economic argument for an unlicensed commons. Specifically, a commons is justified in those cases where the efficient price for spectrum use is zero—that is, where the use imposes no incremental congestion costs (and no opportunity cost)—*e.g.*, a garage door opener operating in a low-power band. But the report cautions that the number of such cases is likely to be small.

"Round 3"

Advocates of the property rights and commons approaches have engaged in a rich debate over the last decade, and that process, together with developments in industry and government, has produced a degree of convergence. Many commons advocates have retreated from the claim that new technology will bring an end to spectrum scarcity and abandoned calls for broad swaths of dedicated unlicensed spectrum. For their part, most property rights advocates have acknowledged the benefits from some of the FCC's unlicensed allocations and recognized the inevitability of a mixed regime.

That said, as the PFF report illustrates, leading property rights advocates have held to their position that there is only a limited justification for unlicensed commons. In part, that reflects their belief that a property rights regime, unlike a commons regime, would allow those subject to it to have their cake and eat it too—that is, that licensed spectrum can accommodate not just exclusive use but also the kinds of shared use now associated with unlicensed bands.[10]

Similarly, the tenor of the debate has gone from philosophical to results-oriented, as the conflict of ideas over spectrum management has entered what Professor Gerald Faulhaber calls "Round 3."[11] In particular, both sides have recognized the importance of key practical issues, including transaction costs, dispute resolution, and the need to provide for future flexibility.

In that spirit of pragmatism, there has been a growing recognition that the choice of governance regime for individual spectrum bands should reflect a clear understanding of the tradeoffs between alternative approaches—what economists call a marginal allocation problem. Several

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[10] The argument that a licensed band can accommodate unlicensed uses is correct in theory: any transmitter that can be operated in an unlicensed regime can be operated in a licensed regime. Nevertheless, there may be impediments to the implementation of a "private commons." A key issue is enforcement: If a microwave oven manufacturer were to buy the rights to a band for its customers to use on a shared basis, what would prevent customers of a competing manufacturer from trespassing? Although the first manufacturer could bring legal action, it would have to identify the trespassers—no easy feat, especially if the trespassing systems are low-power, located indoors and used infrequently. In addition, there are problems with any theory of trespass (*e.g.*, one could argue that the alleged trespassers caused no direct harm because they would not have interfered with or precluded use of the band by any of the manufacturer's customers; if so, the efficient levy of damages would be zero). Enforcement issues aside, with so much spectrum having been made available for unlicensed use, manufacturers of devices suited to such use may have little incentive to buy or lease their own spectrum. For a discussion of the enforcement problem, see Jon M. Peha, "Spectrum Management Policy Options," *IEEE Communications Surveys* (Fourth Quarter 1998), p. 3.

[11] Gerald R. Faulhaber, "The Question of Spectrum: Technology, Management, and Regime Change," *Journal on Telecommunications and High Technology Law*, Volume 4, Issue 1 (2005).

proposals—including Democratic presidential nominee John Kerry's proposed set-aside of 30 MHz of the 700 MHz band for dedicated unlicensed use, and the FCC's current proceeding on the 3650 MHz band—have generated relatively thoughtful, balanced discussions of the benefits and opportunity costs of markets versus spectrum commons. By contrast, as we will discuss below, the white space debate has been wholly one-sided.

B. TV White Space

The history of efforts to exploit vacant TV channels for non-broadcast use is long and complex. Much of the pre-1996 history involves land mobile radio; we need not recite it here, except to make two points. First, licensed allocation of TV white space is longstanding practice, not just theory. For example, in 1971, the FCC authorized the use of 12 MHz of unused TV spectrum for land mobile services in each of several major metropolitan areas. Second, opposition by the incumbent broadcasters has impeded more such reallocation. Most prominently, in the mid-1980s, the National Association of Broadcasters blocked a proposed reallocation of vacant TV frequencies to land mobile on the rationale that its members would need the spectrum in order to convert to high definition TV technology when it became available.[12]

Pressler Plan

Ten years later, a proposal by Senate Commerce Committee Chairman Larry Pressler to license *all* unoccupied spectrum in the TV band encountered similar resistance. The proposal was part of an ambitious plan to liberalize spectrum, generally, and to facilitate the use of (some) broadcast spectrum for higher value wireless applications, specifically. The Pressler plan directed the FCC to allocate all spectrum in the TV band to overlay licenses that would be assigned via auction. Winning bidders would have the right to use any spectrum not encumbered by existing analog TV stations or future digital TV stations (*i.e.*, the white space). In addition, the plan exempted from auction the licenses that, under the just-passed 1996 Telecommunications Act, were to be given to broadcasters for the provision of digital TV during the analog-to-digital transition (the Pressler plan did require licensees to pay a deposit that would be refunded when they turned in their analog license), and allowed broadcasters to provide non-TV services in addition to, or in place of, broadcasting.[13]

Sen. Pressler withdrew his draft plan in a matter of days in the face of intense opposition—primarily from broadcasters, who objected to the licensing of unoccupied TV spectrum. The plan drew criticism from the other side as well, echoing earlier objections by commentators and

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[12] Thomas W. Hazlett and Matthew L. Spitzer, "Digital Television and the Quid Pro Quo," *Business and Politics*, Vol. 2: No. 2 (2000), p. 124.

[13] Thomas W. Hazlett, "The Wireless Craze, the Unlimited Bandwidth Myth, The Spectrum Auction Faux Pas, and the Punchline to Ronald Coase's 'Big Joke': An Essay on Airwave Allocation Policy," *Harvard Journal of Law & Technology* 14: 337-469 (2001), p. 442.

Members of Congress to the proposed "giveaway" of digital TV licenses as well as to proposals that would allow digital TV licensees to provide non-broadcast services.[14]

Despite the overwhelming political objections it generated, the Pressler plan reflected the view of many experts that a shift of broadcast spectrum to non-broadcast services could produce large efficiency gains.[15] The shorthand expression for this widely held view is "Negroponte's Switch," referring to the observation by MIT computer scientist Nicholas Negroponte that people increasingly get their TV over wires and their telephone service over the air—just the reverse of the traditional pattern.

The creation of overlay rights to the TV spectrum (white space) was also seen by many as a practical way to allow for the productive use of that valuable spectrum in the short term—one that, in combination with a grant of technical flexibility to broadcasters, would facilitate the Negroponte switch over the longer term. The regions in which television signals are protected from interference are roughly circular regions with a radius of about 60 to 100 miles. There are necessarily gaps between these regions—that is, areas defined by TV channel and geographic location in which the spectrum does not contain a TV signal that is protected from interference. Although these gaps are too small to permit operation of a TV station, digital technology makes it possible for them to be used for other purposes without interfering with TV reception.

Recent Debate—The Sound of One Hand Clapping

In recent years, commons advocates have pursued Sen. Pressler's goal of allowing access to the TV white space, albeit on an unlicensed basis—a significant difference. The broad coalition supporting these proposals includes self-styled consumer and public interest groups as well as information technology firms such as Intel and Microsoft.

Unlicensed advocates maintain that the white space could easily be detected and utilized by (unlicensed) cognitive radios for a variety of valuable new wireless applications, providing substantial consumer benefits. The unlicensed applications they cite include accelerated deployment of wireless broadband service to rural areas; new, cutting-edge consumer applications that take advantage of the superior reliability and range of signals in this spectrum (*e.g.*, home automation and power monitoring, home security with robust low power wireless video feeds, and data and video distribution within the home); and auxiliary services to augment public safety communications on licensed networks (*e.g.*, placement of remote video cameras at a disaster site to relay images to a command center, and use of portable "helmet cams" to provide real-time, point-of-view command/control information).

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[14] For a discussion of the "giveaway" controversy prior to and during the debate over the 1996 Act, see Hazlett and Spitzer, *op cit.*, pp. 130-131.

[15] Support for that view came from a 1995 FCC estimate that the spectrum covered by the digital TV licenses was worth between $11 billion and $70 billion, based in part on the revenues from the most recent FCC auction of PCS licenses. Unfortunately, the estimate served largely to embolden "giveaway" critics by quantifying the magnitude of the perceived windfall to broadcasters.

The coalition found broad support among Members of the Senate Commerce Committee, which approved legislation last year to facilitate unlicensed access to the TV white space. The FCC's 2004 proceeding adopted a similar goal. Broadcasters have strongly opposed these efforts on the grounds that unlicensed access to the TV band would create harmful interference.

Remarkably, prior to the FCC's October 2006 Further Notice of Proposed Rulemaking, these deliberations excluded virtually any mention much less consideration of a licensed approach. Unlicensed advocates argued for open access to the white space as if it were the only alternative to the status quo. And they devoted their analysis almost exclusively to refuting broadcaster claims that unlicensed devices would harm TV reception.

Similarly, the Senate Commerce Committee, whose chairman had in the past supported spectrum auctions, did not appear to consider the possibility of an auction of licensed rights to the white space. For example, at the Senate Commerce Committee's March 2006 hearing on spectrum reform, several witnesses testified in favor of the Committee's draft legislation to authorize unlicensed use of the white space, and the broadcasters testified against it; as usual, the two sides focused on technical disagreements over interference.[16] Another witness—the economist who co-chaired the Progress and Freedom Foundation's Working Group on spectrum policy—presented the group's recently released recommendations on the economic benefits of spectrum "propertization" and the economic costs of a commons approach (he did not mention the white-space issue, specifically). Not a single Member acknowledged the direct contradiction between the Working Group's recommendations and the Committee's white-space legislation.

As the hearing illustrated, the white-space debate has marked a departure from the constructive trend described earlier, in which both sides treat the choice of regime in an individual band as a marginal allocation problem. Instead of a rich discussion of the tradeoffs between a market-based approach and an unlicensed commons, the white-space debate has been an argument regarding the pros and cons of permitting unlicensed uses. Analytically, it has amounted to the sound of one hand clapping.

The argument over unlicensed access to the white space has been a limited one, at that. Dominated by engineers, it has focused almost exclusively on technical questions about interference. This clash of technical experts has diverted attention from fundamental economic questions: Will unlicensed access to the TV white space work as a commercial matter? Will it really produce the policy benefits that its advocates claim? Will it help or hinder the long term transition of the TV band to higher value applications?

Ultimately, what matters is whether the benefits from an unlicensed approach to the TV white space will exceed those from a licensed approach—one that more nearly approximates a market. That is an economic policy question, not a technical question, although technical considerations

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[16] Intel's testimony included only one page on consumer benefits and more than three pages on why interference would not harm broadcasters. Testimony of Kevin Kahn, Intel Corp., before the Senate Committee on Commerce, Science and Transportation, Hearing on "Wireless Issues/Spectrum Reform" (March 14, 2006).

are critical to be sure. To answer the economic question, policymakers must look at, among other things, the practical issues, including transaction costs, dispute resolution and future flexibility. In short, the process should generate the sound of two hands clapping.

III. HOW MUCH WHITE SPACE WILL THERE BE?

In theory, the choice of governance regime should not turn on how much white space will be available following the DTV transition: either approach (licensed or unlicensed) is feasible regardless of the amount of white space. In practice, however, both the amount and geographic distribution of white space could make a difference in the relative appeal of one approach or the other. For example, if many urban areas have less than 6 MHz of white space, that could limit the appeal of a licensed regime by precluding nationwide service. Conversely, the availability of a large amount of white space would increase the appeal of a licensed regime.

In their narrow debate over the merits of unlicensed access, both the unlicensed advocates and the broadcasters have generated white space estimates, and their results are far apart. On the unlicensed side, most prominently, Free Press and New America Foundation (FP/NAF) looked at 22 TV markets and found that all of them will have a significant number of vacant channels after the DTV transition, ranging from 15 (Trenton, NJ) to 41 (Fargo, ND).[17] On the other side, the Association of Maximum Service Television (MSTV) concluded that there would be almost no locations in the Northeast (among other places) where an unlicensed device could operate without causing interference to DTV reception.[18]

However, both studies have limitations, particularly for regulators trying to choose between the licensed and unlicensed options. The MSTV study is based on a massive and sophisticated computation that incorporates detailed measures of topography, but it defines white space using an interference protection rule that would be excessive if the white space were licensed. Stated differently, MSTV's results underestimate the amount of white space that would be available in a licensed regime. The FP/NAF study is more fundamentally flawed. It treats each channel in a given market as either occupied (no white space) or vacant (100 percent white space), depending on whether a station operates on that channel. That binary approach both underestimates and overestimates the actual amount of white space.[19] It also ignores population, which is key: 6 MHz of white space should count for more if it is located in a densely populated region than in a sparsely populated one.

Because of the limitations of the existing studies, we developed our own estimate of how much white space there will be following the DTV transition. We used a more sophisticated, disaggregated approach than that of FP/NAF to calculate white space, so as to avoid the flaws in

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[17] Free Press and New America Foundation, "Measuring TV 'White Space' Available for Unlicensed Wireless Broadband," January 5, 2006.

[18] See Attachment A of "Joint Reply Comments of the Association for Maximum Service Television, Inc. and the National Association of Broadcasters, ET Docket 04-186, January 31, 2005.

[19] The FP/NAF study implicitly assumes that a broadcast station occupies an entire channel—i.e., that it encumbers the entire metropolitan market ("market" is defined as the relevant Nielsen designated marketing area, or DMA). In fact, even high-power stations may not cover an entire DMA, and low-power channels usually cover far less. In that respect, the FP/NAF study undercounts white space. It overcounts white space by only partially accounting for out-of-market signals (signals from one market that spill over into another). (The FP/NAF study also ignores the possible need to protect adjacent channels, although it is easy enough to adjust the results taking that into account.)

their study. To address the limitation of the MSTV study, we did those calculations under different scenarios—*i.e.*, using alternative assumptions about the appropriate level of interference protection, as described below.[20]

Our Basic Approach

Briefly summarized, our methodology involved three steps: First, we defined white space as those locations—in frequency and geography—where broadcast signals do not need protection. We used the B contour—the FCC-designated coverage area—as the measure of what needs protection, and we calculated that coverage contour for each DTV antenna, based on its channel, power and height. We included more than 10,000 antennas, including more than 2,700 DTV stations and nearly 8,000 class A TV stations, TV translators and land mobile systems.

Second, we calculated the population within each B coverage contour. To do that, we summed the population in every census tract block group within an individual contour. A census tract block group is the smallest geographic unit for which the U.S. Census publishes population data; individual census tract block groups, on average, are 16 square miles in area and include about 1,300 people. There are more than 200,000 census tract block groups in the United States.

Third, for each of the 49 channels (2-36 and 38-51), we calculated the total U.S. population that is covered by antennas operating on that channel anywhere in the country. Through simple subtraction, we then calculated the U.S. population that is not covered by that channel (total U.S. population minus the number of people covered by a particular channel equals the number of people not covered by that channel). That non-covered population represents the white space—that is, if 50 percent of the total U.S. population is not covered by channel 2, then, on average, we can regard half of channel 2 (3 MHz) as white space on a national basis.

Specific Measures

Using these results, we aggregated the amount of white space across all 49 channels and subsets thereof. We also used our basic approach to calculate results at a regional level. Specifically, we used the 52 Major Trading Areas, or MTAs, each of which contains a major metropolitan area and surrounding rural areas. For each MTA, we calculated the *average* amount of white space (averaged across census block groups). In addition, and to provide a more meaningful measure of capacity, we calculated the *minimum* amount of white space—measured in 6 MHz increments—representing the smallest amount of white space available to any census tract block group within the MTA (an MTA contains thousands of census tract block groups).[21]

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[20] MSTV calculated interference effects using data on actual terrain along the propagation path. As a shortcut, we used average height above terrain as listed in the FCC records. In that key respect, our analysis is less sophisticated and rigorous than that of MSTV.

[21] For example, under one scenario (Scenario X), New York has 140 MHz of white space, on average, and a minimum of 78 MHz, or 13 channels. Note that this does not mean that the same 13 channels are vacant throughout New York. Rather, it means that 13 channels are vacant at any point in the MTA; the identity of those channels may (and likely will) vary from point to point.

Using national data, we calculated a cumulative distribution chart of white space. Such a chart shows the minimum amount of white space (measured in 6 MHz increments) that is available to any given fraction of the population. In addition to the "basic" chart, which includes all 49 channels (2-51), we calculated cumulative distribution charts for smaller subsets of channels.[22] The cumulative distribution chart is perhaps the single most important measure of white space, because it speaks to the commercial feasibility of nationwide service: a licensee would probably need to have at least 6 MHz of white space in enough geographic locations to reach most (say, 90 percent) of the population in order to offer such service.

We also calculated certain results at the level of the basic trading area (BTA), which are smaller than MTAs. (There are a total of 493 BTAs.) Specifically, for each BTA, we identified the number of channels that are entirely vacant (*i.e.*, 100 percent white space at every point in the BTA). This is a complement to our measures, described above, of the minimum amount of white space available across census tract block groups. It is relevant because the availability of one or more BTA-wide vacant channels could reduce the amount of engineering needed to provide service in the white space. (Although we discuss the results below, we do not include the BTA-level charts in the Appendix.)

Scenarios

We ran these calculations for four different scenarios:

- Scenario X: All DTV and Class A stations and land systems; no adjacent channel protection
- Scenario Y: Same as Scenario X but with adjacent channel protection[23]
- Scenario Z: Same as Scenario Y plus TV translators
- Scenario UL-1: Same as Scenario Y but with a geographic buffer in the co-channel and the adjacent channel[24]
- Scenario UL-2: Same as Scenario UL-1 but with channels 2-4 and 14-20 excluded

Scenarios X, Y and Z correspond to interference rules that we view as appropriate to a licensed regime, where it would be possible to engineer white-space operations in close to the contour using directional antennas and low-power transmitters. (We view Scenarios Y and Z as the most

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[22] Throughout our analysis, we excluded channel 37, which is set aside for use by radio astronomers and is not considered part of the TV band.

[23] For those scenarios (Y, Z and UL-1 and UL-2) that provide adjacent channel protection, we followed the basic approach described above, but we treated each DTV facility as if it operated at three channels—its own channel and the channels directly below and above.

[24] For Scenarios UL-1 and UL-2, we followed the basic approach described above, but instead of measuring white space as everything outside the B contour, as we did for Scenarios X, Y and Z, we allowed for a significant buffer: the co-channel buffer is 46, 30 and 17 miles for low VHF, high VHF, and UHF, respectively; the adjacent channel buffer is 5 miles.

likely, because of the high probability that the FCC would require adjacent channel protection even in a licensed regime.) By contrast, Scenarios UL-1 and UL-2, with the additional geographic buffer, correspond to interference rules that would be appropriate to—and which the FCC would be likely to impose on—mobile or nomadic devices in an unlicensed regime. Scenario UL-2, which excludes channels 2-4 and 14-20, closely mirrors the FCC's latest proposals for an unlicensed regime.[25]

Results

Our methodology and results are presented in detail in Appendix A. Table 1 provides a summary of our results. Four points are key:

- Scenario X, which does not provide for adjacent channel protection, has significantly more white space than Scenarios Y and Z, which do. Adjacent channel protection reduces the amount of white space available by about half, generally speaking.
- However, even under Scenarios Y and Z, there is a critical mass of white space available nearly everywhere. Most significant, 95 percent of the population will have access to at least 24 MHz of white space (all channels included). As noted above, these two scenarios correspond to the level of protection that the FCC is most likely to demand under a licensed regime.
- The additional buffer protection provided in Scenario UL-1 reduces the availability of white space significantly relative to Scenarios Y and Z—by one-quarter to one-half, depending on how it is measured. Because Scenario UL corresponds to the higher level of interference protection that we believe the FCC would demand in an unlicensed regime, that reduction in white space can be thought of as the "loss" associated with using an unlicensed as opposed to a licensed approach. However, because Scenario UL-1 includes all 49 channels, it probably understates that "loss."
- Scenario UL-2 corresponds most closely to the level of interference protection that we believe the FCC would be likely to demand in an unlicensed regime. This scenario shows a noticeable reduction in white space even compared to Scenario UL-1, and only about half as much white space as Scenarios Y and Z.

Figures 1-4 show selected results for Scenarios Z and UL-2, which are the scenarios that we consider to be most representative of the kind of interference rules that the FCC would adopt in a licensed and unlicensed regime, respectively.

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[25] The FCC has proposed to exclude mobile devices from channels 14-20, and it has requested comments on whether to exclude fixed devices. Channels 2-4 would be off limits for fixed and mobile devices under the FCC's proposal.

Specifically, for Scenario Z, Figure 1 shows the minimum amount of white space available by MTA. Only one MTA (San Francisco/Oakland/San Jose) has less than 6 MHz of white space. Every other MTA has a minimum of 12 MHz of white space available, and most MTAs have significantly more—*e.g.*, New York and Chicago have 18 MHz, Detroit and Cleveland have 24 MHz, Boston has 42 MHz, and Phoenix has 84 MHz. Figure 2 shows the cumulative distribution of white space for all 49 channels under Scenario Z. For example, 99 percent of the U.S. population has access to at least 18 MHz of white space; 97 percent has access to at least 24 MHz; and 91 percent has access to at least 30 MHz. Our BTA-level analysis, which is not shown graphically, reveals that under Scenario Z, 90.5 percent of all BTAs have at least two fully vacant channels. These BTAs account for 62 percent of the U.S. population.

The parallel results for Scenario UL-2 are strikingly different. Figure 3 shows that fully seven MTAs have less than 6 MHz of white space and another six MTAs have only 6 MHz. Similarly, Figure 4 shows that only 92 percent of the population has access to 6 MHz of white space. The BTA-level analysis (not shown graphically) reveals that only 73.2 percent of BTAs have at least two fully vacant channels; those BTAs account for only 41 percent of the population.

Conclusion

Our results should be viewed as approximate rather than exact: we believe that the nationwide results (*e.g.*, the cumulative distribution charts) are reasonably accurate, but our results for any individual MTA will exhibit greater variability around the actual figures. Two key factors limit our ability to estimate the amount and location of white space with greater accuracy. First, our approach to calculating the necessary interference protection is more approximate than the one used by MSTV, which required months of continuous computer processing. Second, the list of post-transition licensees (both broadcast stations and translators) is still somewhat in flux. (Note that we included even stations that did not appear to have submitted a DTV application; for purposes of our analysis, we assumed that they would ultimately operate a DTV station at their analog channel.) Uncertainty about the FCC's interference rules is another limiting factor, although we have addressed that issue by estimating white space under alternative interference-rule scenarios.

Despite these caveats, one result comes through clearly (and it accounts for much of the difference between the results obtained by MSTV versus FP/NAF): the amount of white space differs dramatically depending on the (assumed) interference rules. Moreover, the interference rules that are most appropriate to an unlicensed spectrum model result in substantially less white space than even the most conservative rules that in our view are appropriate to a licensed model. Stated simply, there is far more white space in a licensed environment than in an unlicensed environment, because the FCC interference rules do not need to be as protective. (In Section V, we will discuss another fundamental reason that licensing would result in more white space—namely, the parties would have the incentive and the ability to negotiate variances from the FCC interference standards.)

Table 1
Measures of White Space under Alternative Interference-Protection Scenarios

	Included Facilities	Co-Channel Protection	Adjacent-Channel Protection	*Total MHz-Pops in White Space (Millions)*			*Percent of MHz-Pops in White Space*			*White Space Bandwidth Covering 100% of Total Population*			*White Space Bandwidth Covering 95%+ of Total Population*			*Average White Space Bandwidth Available Nationwide*		
				2-51	5-51	14-51	2-51	5-51	14-51	2-51	5-51	14-51	2-51	5-51	14-51	2-51	5-51	14-51
Scenario X	All US, Canadian, and Mexican regular and Class A stations and land systems in the UHF TV spectrum.	FCC Radius	None	53,678	49,232	37,829	64%	63%	60%	78	60	36	108	90	60	188	173	133
Scenario Y	All US, Canadian, and Mexican regular and Class A stations and land systems in the UHF TV spectrum.	FCC Radius	FCC Radius	28,266	24,532	17,379	34%	31%	27%	0	0	0	24	12	6	99	86	61
Scenario Z	All US, Canadian, and Mexican regular and Class A stations, land systems in the UHF TV spectrum, and all TV translators.	FCC Radius	FCC Radius	27,156	23,523	16,547	32%	30%	26%	0	0	0	24	12	6	95	82	58
Scenario UL-1	All US, Canadian, and Mexican regular and Class A stations and land systems in the UHF TV spectrum.	FCC Radius plus 46, 30, and 17 miles for low VHF, high VHF, and UHF	FCC Radius plus 5 miles	21,028	18,093	12,752	25%	23%	20%	0	0	0	12	6	0	74	63	45
Scenario UL-2	All US, Canadian, and Mexican regular and Class A stations and land systems in the UHF TV spectrum. Channels 2-4 and 14-20 excluded.	FCC Radius plus 46, 30, and 17 miles for low VHF, high VHF, and UHF	FCC Radius plus 5 miles	15,160	15,160	9,820	18%	19%	16%	0	0	0	0	0	0	53	53	34

Figure 1

Minimum Bandwidth of White Space by MTA -- Scenario Z

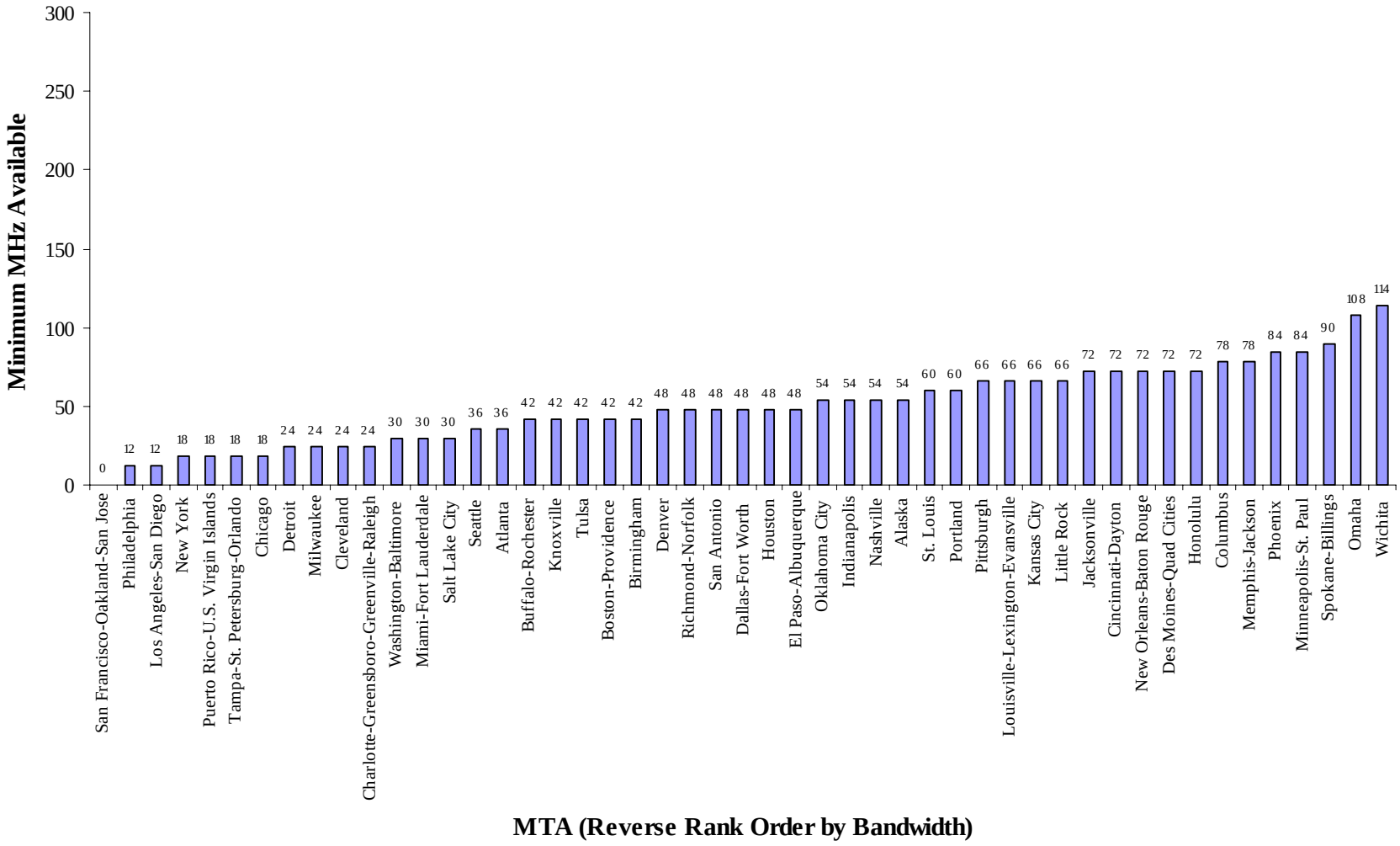


Figure 2

Percent of Population with a Given Amount of White Space -- Scenario Z

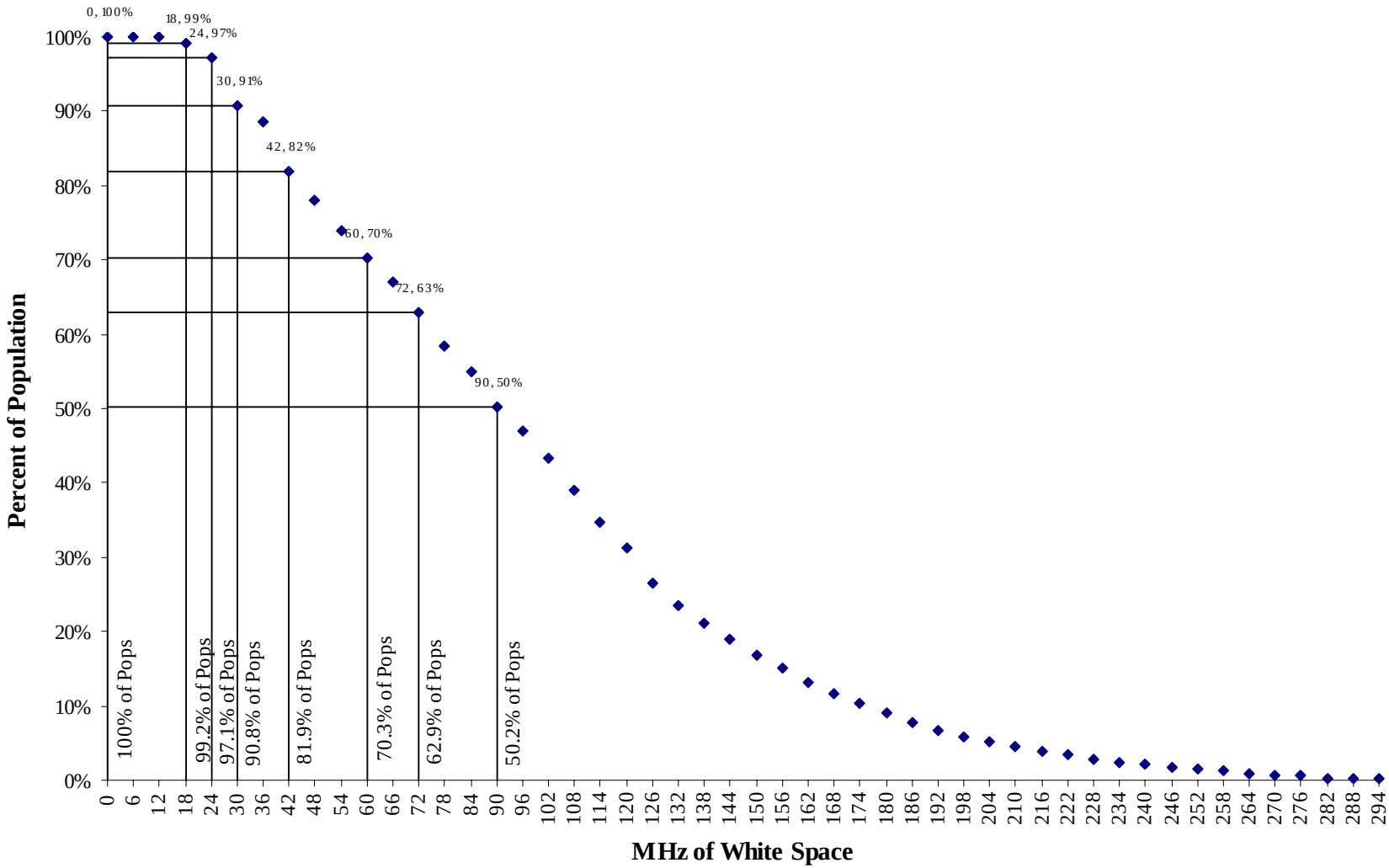


Figure 3

Minimum Bandwidth of White Space by MTA -- Scenario UL-2

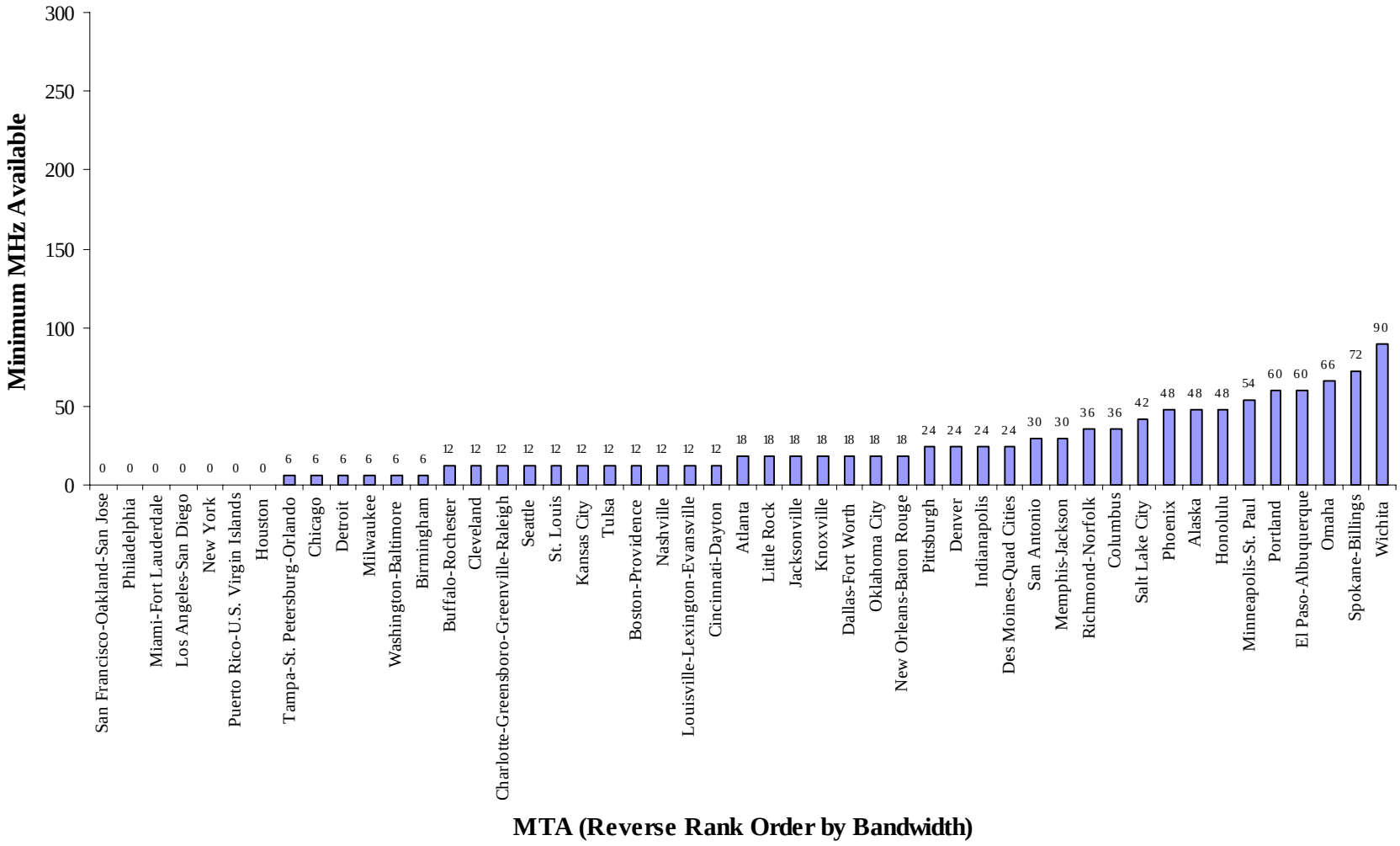
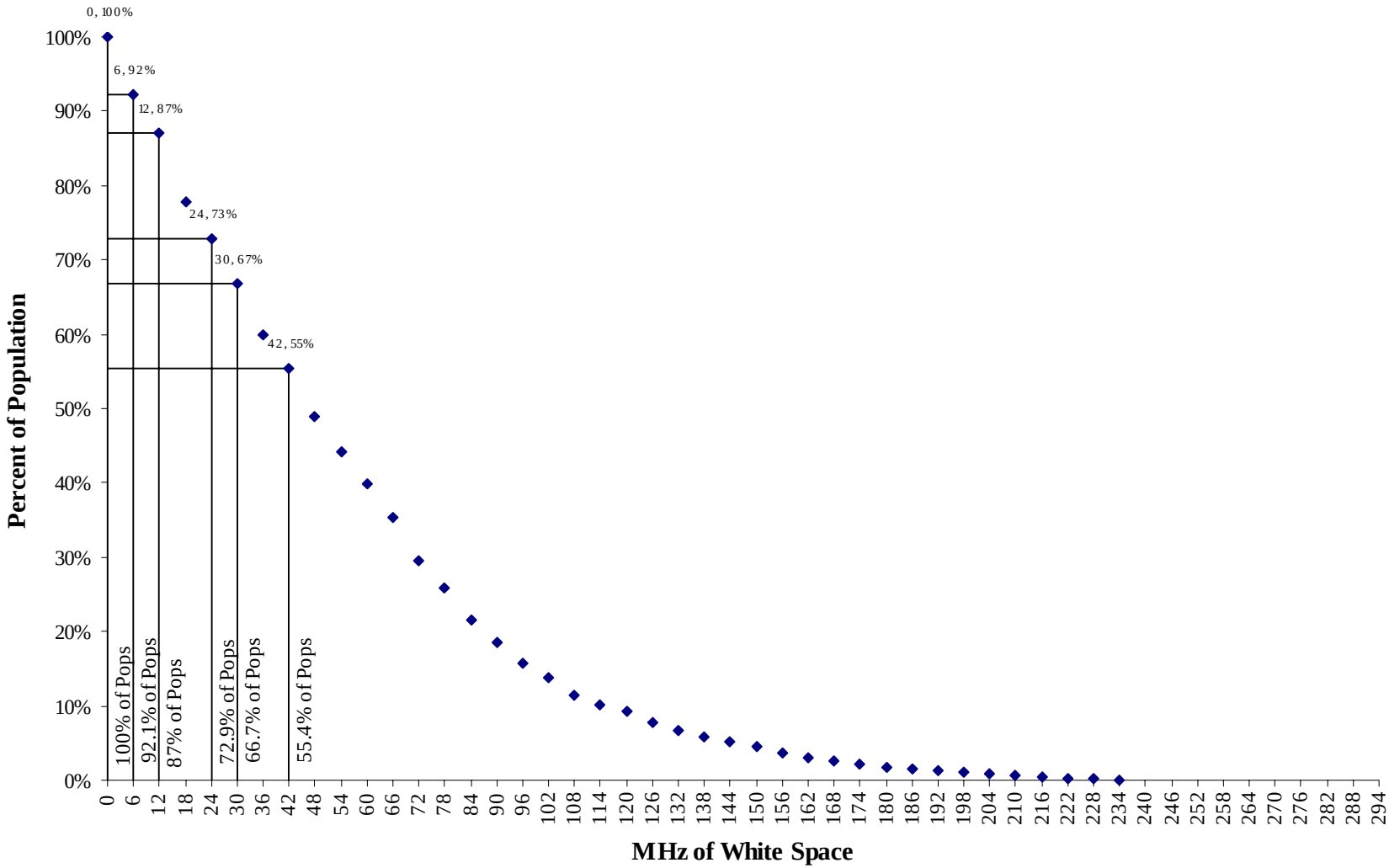


Figure 4

Percent of Population with a Given Amount of White Space -- Scenario UL-2



IV. UNLICENSED USE OF THE TV WHITE SPACE

Overview: Unlicensed advocates make what may appear, on the surface, to be a compelling case for shared access to the TV white space. However, their key arguments underscore the value of *access* to vacant TV spectrum, not necessarily unlicensed access. Other arguments fail to address potential problems and limitations associated with unlicensed access, generally, or access to *the TV band*, specifically. We highlight three key problems with an unlicensed approach to the white space. First, technical and economic factors will likely discourage the necessary investment in unlicensed systems either for short-range data transfer or for long-range applications. Second, these impediments to investment, together with the large amount of unlicensed spectrum that already exists, mean that the incremental benefits from an additional allocation will be limited, and the opportunity cost will be high. Third, over the long run, an unlicensed underlay will create a constituency of squatters and their suppliers, which will impede the evolution of the TV band to higher value uses.

A. The Flawed Case for Unlicensed Access to the White Space

Opportunity Cost of Status Quo: The basic economic argument that proponents make for unlicensed use of TV white space boils down to the opportunity cost of the status quo. When asked why his company advocated open access to the white space, Intel's Mike Chartier summed it up this way: vacant TV spectrum represents a valuable resource that is currently going to waste.[26] The New America Foundation makes the same case in more detail; their reports cite the exceptional qualities of the TV band and note that digital technology has turned TV white space into usable spectrum much as air conditioning turned the Southwest into prime real estate.[27] The bottom line: having this valuable spectrum sit idle means a benefit foregone.

Even more costly than letting white space sit idle, according to unlicensed advocates, is the FCC's practice of allowing broadcasters to lay claim to it—*e.g.*, for the use of wireless microphones. Unlicensed advocates criticize this transfer on the grounds that low frequency spectrum is better suited for mobile broadband than broadcasting. They argue that broadcasters' campaign to win free rights to unused spectrum, together with their opposition to unlicensed use of white space, will delay that inevitable change.[28]

The basic logic behind these arguments is compelling: TV white space *is* valuable, and allowing it to sit idle *does* impose an opportunity cost. But it does not follow that the FCC should, in effect, give the white space away by opening it up to one and all. It is at least as plausible (more

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[26] Mike Chartier, Director of Spectrum Policy, Technology Policy and Standards, Intel Corp., Comments at "MSTV@50: Shaping the Future of Television," October 3, 2006.

[27] J. H. Snider, "Reclaiming the Vast Wasteland: The Economic Case for Re-Allocating the Unused Spectrum (White Space) Between TV Channels 2 and 51 to Unlicensed Service," New America Foundation, Working Paper # 13 (February 2006).

[28] According to the New America Foundation, these FCC actions amount to a $6 billion transfer of spectrum rights. Snider, *op. cit.*, p. 2.

so, we maintain) to suggest that the FCC should sell or otherwise assign the spectrum rights to the white space on an exclusive basis—an option that unlicensed access would preclude.

In addition to arguing that TV white space is a valuable resource that is going to waste, unlicensed advocates maintain that its propagation characteristics would allow unlicensed devices to operate more cheaply and effectively than they can in the higher frequency bands where most unlicensed activity now occurs (2.4 and 5 GHz). In particular, they emphasize the potential benefits to underserved rural areas. Here again, however, the argument applies not just to an unlicensed regime: devices designed for licensed spectrum will also operate more cheaply and effectively at a low frequency, all else equal, making it less expensive to serve rural areas.

In sum, the major argument for unlicensed access to the white space—the opportunity cost of the status quo—should be seen as an argument for *access* to the white space. Moreover, because an unlicensed regime would preclude licensed access, it would impose its own opportunity cost.

Transaction Costs: The other (often implicit) economic rationale for unlicensed white space is transaction costs. Pierre de Vries, one of the few proponents of unlicensed spectrum to address this issue directly, maintains that the TV band is better suited to unlicensed use because it is a "junk band"—much like the 2.4 GHz band, which was considered "garbage."[29] What makes the TV band "junk" is, above all, its "Swiss cheese" character: broadcasters (the holes in the cheese) occupy a different pattern of channels in each of the 210 TV markets. According to de Vries, this non-regular pattern of broadcast usage, combined with other conditions that he believes will hold—limited quantities of white space in major urban areas, stringent interference rules to protect broadcasters, and multiple white-space licensees—would make it prohibitively complex and costly to have a market in spectrum rights. By contrast, unlicensed access would avoid the need for costly negotiations and coordination among parties. It would also eliminate the need for spectrum auctions or subleases—a particular advantage in rural areas, where transaction costs could swamp the benefits, in de Vries's view.

However, insofar as an unlicensed approach would minimize transaction costs, it would do so by having users forego the more extensive and efficient uses of the white space that frequency coordination and interference negotiation could achieve under a market approach. This is a fundamental source of inefficiency under the FCC's legacy command-and-control regime, and an unlicensed regime would perpetuate the problem. We will discuss this issue in more detail in Section V. We will also explain there why, contrary to the claims of unlicensed advocates, those coordination activities need not be prohibitively complex or costly.

The claim that the white space is better suited for unlicensed activity because it is in a "junk band" is problematic in another respect. That characterization of the TV band is not necessarily

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[29] Pierre de Vries, "Populating the Vacant Channels: The Case for Allocating Unused Spectrum in the Digital TV Bands to Unlicensed Use for Broadband and Wireless Innovation," New America Foundation, Working Paper # 14, August 2006. See also de Vries's "Talking Points for a Debate with Tom Hazlett on TV Band White Space Use," George Mason University School of Law, November 14, 2006. [http://gmu.edu/departments/law/////nctl/iep/deVries.11.14.06.htmURL link]

wrong. But unlicensed advocates miss the irony: the white space is "junky" in good part because broadcasters have no incentive or ability to sell or lease unneeded bandwidth. Stated differently, the inefficient usage of the TV band is a direct reflection of the fact that the spectrum is regulated by a command-and-control regime that offers little incentive for efficiency and in fact rewards hoarding of spectrum. An unlicensed approach to the white space would perpetuate that problem by precluding private negotiations in favor of rule-based interference management.

Transaction costs are also at the heart of the case for unlicensed access to the white space made by J. H. Snider of the New America Foundation. Snider argues that fundamental economic forces are driving the world toward greater reliance on terrestrial low-power wireless communications. One such force is that high-power wireless service has close, wired substitutes whereas low-power wireless service does not. A second driver of low-power networks is the skyrocketing demand for spectrum: large cell sites make less and less economic sense, in his view, because they can be subdivided to create more capacity. Asserting that unlicensed spectrum works best for these low-power wireless networks, Snider calls for an (unlicensed) underlay that would cover the entire radio spectrum, including the TV band.[30]

However, Snider's unquestioned assumption—that low-power wireless networks are best supported by unlicensed spectrum—is problematic. He defines "low-power networks" narrowly—essentially as networks made up of LAN devices. In fact, modern wireless handsets operate at powers that are every bit as low (maximum powers of about 1 watt and average powers of about 10 milliwatts), and these handsets use licensed spectrum.

Snider's call for a spectrum-wide underlay raises major issues that others will no doubt address in the broader spectrum governance debate. However, a specific objection to his proposal and others like it relates to the white-space debate: allocation of the TV band for low-power, short-range wireless networks would be the equivalent of using land in downtown Tokyo to grow rice.

To elaborate, the TV band is useful for mobile and long-range services because it has better propagation characteristics than higher frequencies—a major plus in rural areas in particular. WiFi and other short-range services fail to take advantage of this property of the TV spectrum while potentially disrupting other services that do want to exploit it. Similarly, it is easier to generate significant power in the TV band than at higher frequencies, which is also useful in rural areas. By restricting users to low power limits, an unlicensed approach fails to take advantage of this valuable feature of the TV spectrum.

In short, the TV white space is "overqualified" for the use to which unlicensed advocates want to put it. Even if Snider and other unlicensed advocates are right about the inexorable growth of low-power WiFi networks, it would be a spectral "sin" of omission to use vacant TV channels to satisfy that demand. Ironically, this is just the crime of which unlicensed advocates, quite rightly, accuse the current regime.

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[30] Snider, *op.cit.*.

Public Policy Goals: Unlicensed white space is also touted as a cost effective way to meet key policy goals. The most politically salient claim is that it would facilitate broadband access to underserved rural areas. However, insofar as the claim turns on the superior features of the TV band, a licensed system could exploit those same advantages, as we have noted. Unlicensed advocates counter that rural providers can't always get licensed spectrum even if they want it, because of the high transaction costs of sublicensing. However, many underserved areas are not viable markets because of the high cost of providing service. For those markets, lower transaction costs in the form of unlicensed white space will not help.

Ultimately, only a licensed approach offers the certainty necessary for wireless providers to make the large investments in long-range infrastructure that rural broadband requires. Unlicensed advocates have yet to overcome the "tragedy of the commons," and rural service providers are among the most vulnerable. This inescapable problem will almost certainly impede investment in rural broadband in an unlicensed environment.

No less problematic is the claim by some unlicensed advocates that open access to the white space would provide a way to challenge the existing broadband duopoly of cable and DSL. Unlicensed spectrum is an effective way to provide opportunistic services, such as text messaging and WiFi hot spots, for which radio links need not be always-available (no one notices if a text message is delayed by a few seconds) or pervasive in their coverage (WiFi is available in some seats in a hot-spot restaurant but not others). But key services provided by cable and DSL require reasonably reliable radio links and/or extensive coverage—capabilities that licensed spectrum can provide far better than unlicensed spectrum can. For this reason, unlicensed spectrum services have failed to put any substantial competitive pressure on the wireless telecommunications industry.

Finally, unlicensed access to the white space is deemed by its proponents to be friendly to innovation because it does not require new entrants to pay for spectrum. According to de Vries's analysis of the white space issue, "unlicensed bands allow entrepreneurs to enter a market without incurring the cash drain of obtaining a license."[31] However, the notion that free entry must be "free" reflects a misconception, as a recent critique of the commons approach explains:

> [I]t is simply not true that freedom of entry requires valuable resources to be given away without charge. On the contrary, such a giveaway approach deprives the economy of the assurance that the valuable resources will go to those who need them most urgently, as well as the other efficiency attributes for which the market mechanism is noted. In contrast, a spectrum-utilization arrangement based on auctioning of licenses is a regime of open-entry that offers those advantages. That freedom of entry does not require valuable resources to be provided without any charge to those who want to use them is easily confirmed by observation of the way in which free entry works in arenas in which it is evidently present. Surely, in no industry is entry less constrained than it is in farming. Yet to achieve such free entry it has not been necessary for land, seeds and fertilizer to be provided without charge. Entry into air passenger transportation is also

[31] de Vries, *op. cit.*, p. 18.

> unrestricted, indeed so much so that the resulting creation of new airlines threatens the viability of the incumbents. Yet it has not been found necessary to offer the entrant free aircraft or free landing slots to induce establishment of new firms. On the contrary, granting of free resources as a means to enhance entry would only invite waste of these resources and their employment by those not in a position to make the most efficient use of them.[32]

There is a more fundamental reason that an unlicensed regime is not likely to produce an optimal pattern of innovation over the long run: the benefits from investments in spectrum-conserving innovations will go to all users, not just to those who purchase the innovation:

> If manufacturer A's investment in research and development succeeds in reducing interference problems and thereby makes it possible to expand the volume of spectrum activity, only part of the resulting increase in business is likely to go to A. Much of it will also go, in the form of a beneficial externality, to equipment manufacturers B, C and D, some of whom may even be direct rivals of A. Because a substantial portion of the benefits of A's research and development expenditures go to others, it will certainly not pay A to spend as much on research and development as the public interest requires.[33]

In sum, an unlicensed white-space regime would be plagued by dual externalities: the free rider problem would discourage investment in innovation on the part of manufacturers, just as the prospect of a commons tragedy would discourage investment in infrastructure by service providers.

B. Three Key Problems with an Unlicensed White-Space Regime

For the reasons just stated, we believe that the economic and policy benefits of open access to the white space have been overstated. Three additional (and related) considerations underscore that assessment. First, technical and other factors will likely discourage the necessary investment in unlicensed systems in the short run—particularly for long-range applications. Second, given the large amount of unlicensed spectrum that already exists, the incremental benefits from an additional allocation will be limited, and the opportunity cost will be high. Third, over the long run, an unlicensed underlay will impede the evolution of the VHF and UHF bands from their current use to mobile broadband and other higher value uses.

1. Impediments to Investment

There are fundamental impediments to the use of unlicensed TV spectrum either for short-range data transfer or for long-range voice and data communications. We believe these impediments, and the chilling effect they would have on investment, would more than offset the superior propagation characteristics of this spectrum. Support for this conclusion comes in part from the

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[32] Baumol and Robyn, *op. cit.*, pp. 33-34.

[33] *Ibid.*, pp. 32-33.

recent experience with unlicensed spectrum in the PCS band and non-exclusive licensed spectrum at 3650 MHz.

Short-Range Data Transfer

For short-range data transfer, unlicensed TV spectrum would be inferior to the existing unlicensed bands at 2.4 GHz and 5 GHz. A key issue for many wireless users is the data rate. There is no assurance that more than 6 MHz of contiguous spectrum in the TV band would be available for unlicensed use at any location, and the proposed FCC rules seem to presuppose that the unlicensed device signal will be contained in 6 MHz. Thus the market would likely provide devices that operated in a single 6 MHz channel as a form of lowest common denominator. A 6 MHz channel would support data rates that are reasonably competitive with those of current wide-area services such as 5 MHz HSDPA and 1.25 MHz EV-DO channels; but it would a poor competitor to the 20 MHz channels at 2.4 GHz and 5 GHz that 802.11 devices employ.

Specifically, at short ranges—*e.g.*, within a household, where signal attenuation is not usually the limiting factor in WLAN performance—the maximum practical data rate of a TV white-space device would be only about one-third or one-quarter that of an 802.11 device operating in the current unlicensed bands. Although there are steps one might take to compensate for this limitation (*e.g.*, dynamic channel bonding), they would require more transmitters and receivers in the consumer device, and they would introduce other complexities—offsetting some of the advantages of the TV band.

Figure 5 illustrates the relative performance in terms of bandwidth and range of a wireless LAN that exploits the contiguous bandwidth available in three different locations: a white-space channel, the 2.4 GHz unlicensed band, and the 5 GHz unlicensed band. Note that both axes are logarithmic. The unlicensed band at 5 GHz is by far the widest but it has shorter range. The range at 2.4 GHz is greater than at 5 GHz, but there is only one-sixth as much bandwidth in an individual channel. The range for a wireless LAN using the white space would be longer still, but the per-channel bandwidth would be only one-tenth that of the 2.4 GHz band.[34]

[34] Figure 5 is intended to be illustrative, not exact; the values for bandwidth and range used in the figure are reasonably representative of current technology.

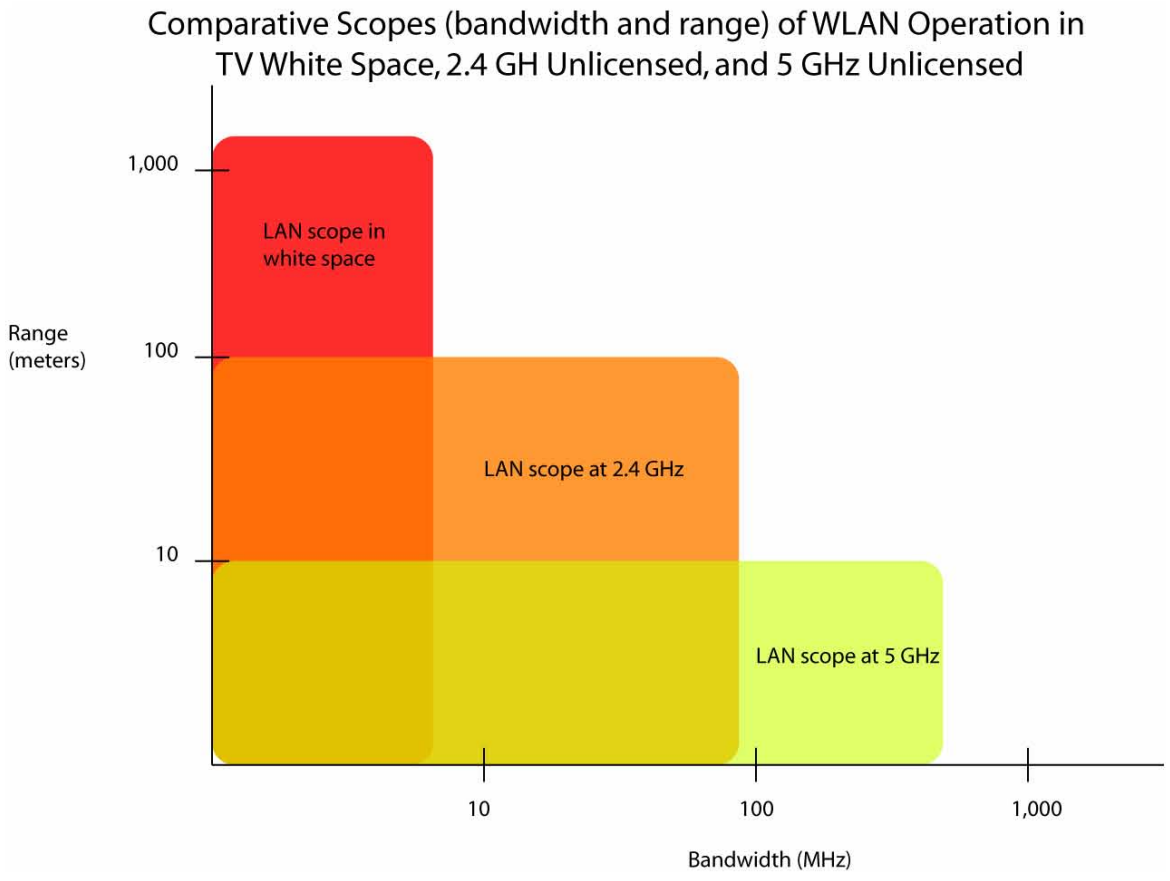

Figure 5. Scope of WLAN Services

Generally speaking, the "market niche" for unlicensed white space consists of those applications that require significant range but not significant bandwidth.[35] That is a narrow niche. In our view, for the typical user, the bandwidth advantages of the 2.4 GHz and 5 GHz bands would outweigh the range advantage of the white space. Granted, some users would buy LAN gear designed for the white space in addition to the comparable 802.11 equipment; but relatively few users would buy it in place of 802.11 equipment.

In addition to greater raw bandwidth, operations in the 2.4 GHz and 5 GHz unlicensed bands would have other advantages over comparable operations in the TV white space. For one, the higher frequencies permit units with multiple antennas to have greater antenna separation. Generally speaking, antenna separation (measured in units of radio wavelengths) is correlated with capacity.

[35] More precisely, the white space would have a comparative advantage over the 2.4 GHz and 5 GHz bands for low-bandwidth applications that require ranges greater than those achievable at 2.4 GHz and that cannot use repeaters to provide that range.

In part because they support higher data rates than other unlicensed bands, the 2.4 GHz and 5 GHz bands have spawned a huge installed base of interoperable equipment known by the name of the relevant IEEE standard (802.11). Manufacturers and users of this equipment benefit from large scale and network economies and a resulting bandwagon effect. IEEE is developing a separate standard (802.22) for the TV white space, but it is aimed at fixed wireless service for rural areas and will not target urban or in-home service.[36] Both because the 802.11 standard will remain dominant and because the 802.22 standard will be limited in scope, manufacturers will face weak incentives to develop equipment for use in the white space.

Yet another impediment to the development and adoption of wireless devices for use in the white space will be the need for those devices to protect incumbent broadcast and land mobile operations in the TV band. Most of the protective mechanisms that are under discussion (*e.g.*, beacons and geo-location) call for an additional receiver or other electronic device to be installed in the consumer white-space terminal. Supplementary electronics would add cost and reduce battery life. Even if the added cost were small, it would further reduce the ability of unlicensed wireless LANs in the white space to compete with the installed base of 802.11 devices.

In sum, the combination of limited data rates, network externalities and the added costs to avoid interference with incumbents will pose a substantial barrier to the adoption of this band for the market needs served today by wireless LANs. Similar factors, together with the FCC's complex coordination rules, fatally impaired the data portion of the unlicensed PCS (UPCS) spectrum.

To explain, the UPCS spectrum at 1910-1920 MHz had essentially the same propagation characteristics as the nearby 2.4 GHz band, which unlicensed data devices can use under Part 15 rules. However, the 2.4 GHz band is eight times larger, which permits higher data rates. The size of the 2.4 GHz band also gives users the option of changing channels to avoid interference. Those advantages, together with the fact that that unlicensed services had a several-year head start at 2.4 GHz, meant that the 2.4 GHz band could support a much larger market than the UPCS band was likely to ever generate.

The UPCS spectrum faced other problems as well. The FCC required unlicensed users to coordinate with the remaining licensed (fixed microwave) users, which added uncertainty and cost. And the FCC's complex radio-channel sharing protocol may have increased the burden on equipment suppliers.

Not surprisingly, at least in retrospect, use of the UPCS band was minimal—the lower half of the band, devoted to data, apparently received no use whatsoever.[37] In response, the Commission

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[36] Carl Stevenson, President and Chief Technology Officer, WK3C Wireless, Comments at "MSTV@50: Shaping the Future of Television," October 3, 2006. Stevenson is the chair of the IEEE 802.22 working group—the IEEE committee that is developing the 802.22 standard. See http://www.ieee802.org/22/.

[37] According to a 2004 FCC document: "The record of deployment of UPCS services, to date, has been mixed. Currently, the most widespread application of the 1920-1930 MHz UPCS band is for wireless PBX systems. However, a search of our equipment authorization database has found no UPCS equipment authorized for the 1910-1920 MHz band." FCC 04-219 at para. 12, footnote omitted.

reallocated the data portion of the unlicensed PCS band for licensed use. The reallocated spectrum will likely be used for a wireless service similar to what adjacent PCS bands support.

Unlike the UPCS band, unlicensed white space would no doubt attract users, but the likely applications would provide only modest value beyond that of those found in other unlicensed bands today. For example, the white space would support low-cost cordless phones with greater range than today's 5 GHz units, which would be useful in settings (*e.g.*, farms and university and industrial campuses) that require multiple base stations to get good coverage now. Similarly, the TV band would be useful for applications that fit naturally inside of a single TV channel, such as baby monitors and remote surveillance cameras. Because signals in the TV band do not require line-of-sight, the white space might also be attractive for moderate capacity point-to-point links such as those used to connect Wi-Fi hot spots to backbone networks or for the kind of opportunistic point-to-point links that are needed in emergencies. In sum, the white space would get used in an unlicensed regime, but those uses would likely add little value beyond what is already possible.

Long-Range Communications

Nor are we likely to see significant investment in the infrastructure necessary for long-range communications in unlicensed TV spectrum. The reason is simple: such an operation would have no protection against potential interference—either from licensed service providers or from other unlicensed operators. The risk of interference would impose a cost on unlicensed service providers that their licensed competitors, such as the licensees at 700 MHz, will not face.[38]

3.65 GHz Band: The recent experience with the 3.65 GHz band supports our view that the absence of exclusive spectrum rights discourages investment in long-range infrastructure. Under rules adopted in 2005, the FCC created a form of commons in the 3.65 GHz band: all systems operating at 3650-3700 MHz were required to adaptively "share" the band using contention-based protocols.[39]

Cisco, which manufactures short-range 802.11 systems, supports the 2005 rules.[40] However, several firms that manufacture equipment for long-range services, including Motorola, Intel and Alvarion, have petitioned the FCC to ask that it reconsider a licensed approach.[41] According to Motorola:

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[38] One of us (Jackson) participated in the due diligence investigation, by a potential investor, of an unlicensed WISP that provided service to subscribers at distances exceeding 10 miles from its antenna sites. The investor was concerned about the WISP's vulnerability to interference problems and ultimately chose not to invest.

[39] Wireless Operations in the 3650-3700 MHz Band, Report and Order and Memorandum Opinion and Order, ET Docket No. 04-151, FCC 05-56, Mar. 16, 2005

[40] Cisco, *Opposition to Petition for Reconsideration*, ET Docket 04-151, August 11, 2005.

[41] Covad, a wireless access provider that serves parts of California and Nevada, took an intermediate position; Covad said the spectrum should be licensed to control interference but that the licenses should be awarded at no cost on a first-come, first-served basis (i.e., no auction).

> …the use of a contention-based protocol among multiple unaffiliated users will not allow rapid deployment at 3650 MHz nor offer the most efficient use of the spectrum, particularly in dense urban areas….The combination of exclusive licensed use along with flexible technical standards and secondary market leasing provisions will offer the most efficient and rapid deployment of wireless broadband services across the U.S. using this new band.[42]

The WiMAX Forum, which stressed the importance of quality of service for providers deploying long-range wireless broadband technologies, was even more direct, predicting that "'tragedy of the commons' problems are likely to be severe in large urban areas."[43]

Cisco maintains that the position taken by manufacturers of long-range equipment reflects their financial interest in WiMAX, which is suited to licensed spectrum. But it goes without saying that the manufacturers are self-interested; the same can be said of Cisco. What is significant about the manufacturers' position (and it is consistent with their decision to invest in WiMAX, more broadly) is that it reflects a belief that interference will suppress equipment sales.

Many service providers have also weighed in to say that the current FCC rules will produce interference and that there is no easy or efficient way to control interference in an unlicensed environment. For example, TDS Telecom, which serves more than 900 rural and non-urban communities in 28 states, urged the FCC to adopt a licensed approach in place of contention-based protocols, which it views as "insufficient guards against harmful interference:"

> Deployment of wireless broadband requires investment in equipment, software, labor, marketing and other resources. TDS Telecom cannot take the risk that its wireless network will be rendered useless in 5-10 years due to limitless entry into the band.[44]

The Wireless Internet Service Providers Association (WISPA), although formally supporting the FCC's 2005 rules, submitted comments that appear quite critical of aspects of the unlicensed rules. WISPA refers to the "aggressively inefficient system designs that we've seen all too often under the current rule structure." WISPA also raised questions about how the interference that its comments imply is inevitable will be handled:

> We're also worried about the lack of channel planning. What happens when an inefficient radio system bumps into a highly efficient one and keeps the "better" one from operating. When a system using 5 MHz of spectrum and a system using 25 MHz want the airspace at the same time which gets to go?[45]

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[42] Motorola Petition for Reconsideration, ET Docket No. 04-151, June 10, 2005.

[43] WiMAX Forum, ex parte comments, ET Docket 04-151, June 28, 2006.

[44] TDS, ex parte comments, ET Docket, 04-151, February 14, 2006.

[45] Ex parte letter in ET Docket No. 04-151, August 3, 2005. WISPA suggested rules that would promote efficiency and limit the amount of spectrum any one operator could use. WISPA's point—that unlicensed rules do not provide for priority of one user over another—is a fundamental one. Although WISPA doesn't

Other Interference Scenarios: In addition to the kind of unintentional interference at issue in the 3650 MHz proceeding, the TV band could well be plagued by "strategic" interference. Consider a licensed wireless access provider (Firm L), and an unlicensed competitor that operates in the TV band (Firm U). Firm L offers its subscribers wireless LAN devices that use the white space. As an "unfortunate" side effect, those devices create interference that degrades the service of nearby customers of Firm U.

Other unintended scenarios are not hard to imagine. Under current FCC rules, Firm L could apply for a license for a TV translator or low-power TV station and locate the station transmitter near one of Firm U's base stations. Firm U would be obliged to quit operating on the channel on which Firm L had located its transmitter because it would no longer be considered white space.

Alternatively, Firm L could perform a "public service" by installing a one-watt unlicensed white space device either to retransmit TV signals or to transmit information such as weather forecasts using the ATSC format. If the unlicensed unit was installed near a base station receiver, Firm L's white space device would jam the desired signals from Firm U's subscribers.

Another conceivable scenario involves a community broadcaster that employs the white space to offer an unlicensed TV service. If the service were to use ATSC transmissions and on-channel repeaters, viewers would be able to pick up the signal with their over-the-air TV antenna. If, in addition, a manufacturer were to develop low-cost repeaters for such a service, it would consume a significant amount of the available white space. Granted, over-the-air TV would probably not be a very efficient way to provide such a service, but the provider might be someone who entered community broadcasting for pleasure rather than profit.

Unlicensed operation in the white space—in addition to creating interference for individual unlicensed users—also runs the risk of raising the noise floor in the white space—particularly in the UHF bands. The current unlicensed bands at 900 MHz and 2.4 GHz have experienced a substantial rise in noise levels above thermal noise. A comparable rise in the UHF noise floor—due to, say, cordless telephones—would impair the operation of long-range unlicensed systems.

2. Diminishing Incremental Benefits, High Opportunity Cost

The standard "pitch" for open access to the white space cites the large benefits that unlicensed spectrum in the 2.4 GHz band has produced, and then asserts that additional allocations of unlicensed spectrum will produce more of the same. The implicit logic is a kind of straight-line extrapolation: if X is good, then two X is twice as good. For example, Dell refers to the white space as "a multi-billion market, just waiting to explode, if next-generation home and office wireless networking devices are enabled in the white spaces."[46]

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acknowledge it, the logical solution is a system of licensed rights, which provide protection against interference.

[46] Dell, ex parte letter in ET Docket 04-186, January 12, 2007.

However, this reasoning fails to isolate the *incremental* value of an additional allocation of unlicensed spectrum—*i.e*, those benefits that would not arise *but for* open access to the TV band. At the same time, it ignores the (incremental) opportunity cost of such an allocation.

Incremental Benefits

A large amount of spectrum has already been allocated for unlicensed use—a fact that unlicensed advocates tend to downplay. Table 2 shows the major allocations of unlicensed spectrum that permit "high-power" operations. (We have excluded those unlicensed bands that are limited to very low-power operations. Note also that a wide variety of unlicensed uses, such as medical telemetry and automobile radar, take place outside the bands listed here.). Table 2 shows that approximately 11 GHz of spectrum is available for unlicensed use, which represents more than ten percent of the entire spectrum below 100 GHz. Looking just at the lower range, 760 MHz of the spectrum below 6 GHz—or about 13 percent—is available for unlicensed use.

The supply of unlicensed spectrum is large not just in absolute terms, but by comparison to that of liberally licensed spectrum—that is, the bands such as cellular and PCS that permit substantial technical and economic flexibility. Moreover, until recently, the large blocks of unlicensed spectrum the 5 GHz band had seen relatively little use, although that has begun to change.

Because the existing supply of unlicensed spectrum is large, additional allocations of unlicensed spectrum will likely provide diminishing returns—contrary to what the claims made by unlicensed advocates imply. Recall our earlier conclusion that the likely short-range applications of the white space would provide only modest value beyond that of those found in other unlicensed bands today.

The persistent claim that unlicensed white space will stimulate significant innovation is similarly overstated. Granted, unlicensed use of the 2.4 GHz band spawned WiFi and other major innovations. However, there is little if any evidence that additional unlicensed spectrum will create significant *new* opportunities for innovation, given the large supply that already exists.

In response to the diminishing-returns charge, unlicensed advocates stress the unique advantages of the spectrum below 2 GHz, of which only 26 MHz permits unlicensed operation at relatively high powers. In effect, they redefine the relevant universe of spectrum, excluding what they call the "nosebleed bands" where most unlicensed activity takes place. But low frequency is not always a plus (recall our earlier observation regarding antenna separation). Even where it is a plus, other attributes matter as well, as shown by our conclusion that the bandwidth advantage of the unlicensed bands above 2 GHz will outweigh the other advantages of the less-plentiful white-space spectrum in many cases.

Table 2

Major "High-Power" Unlicensed Spectrum Allocations			
Block	**Bandwidth (MHz)**	**Power Limit (watts)**	**Comments**
902-928 MHz	26	1	
2400-2483.5 MHz	83.5	1	
5725-5850 MHz	125	1	
24.0-24.25 GHz	250	Limit is on field strength, not power.	Power limit in FCC rules is given as a field strength limit (2500 mv/m at 3 meters, see 47 CFR 249). Maximum power varies with antenna size.
57-64 GHz	7 GHz	0.5	At these high frequencies, radio waves typically require a line-of-sight path from transmit antenna to receive antenna. This band is a resonance of the O_2 molecule and cannot be used for long-range applications.
92-95 GHz	3 GHz	0.5	Limited to indoor use.
1920-1930 MHz	10 MHz	Varies with bandwidth	Unlicensed PCS band. Of little utility
5.15-5.35 GHz, 5.47-5.725 GHz 5.725-5.825 GHz	200 MHz 225 MHz 100 MHz	Varies. The maximum is 1 watt.	The band 5.15-5.25 GHz is restricted to indoor use.
Total	11.0195 GHz		
Total below 6 GHz	759.5 MHz		Excludes unlicensed PCS band (10 MHz)

As another counter to the diminishing-returns argument, unlicensed proponents point to the growing demand for (unlicensed) low-power wireless networks. However, the fact that demand is growing for devices that operate in unlicensed spectrum does not necessarily imply that an additional allocation of unlicensed spectrum will yield benefits. Because unlicensed spectrum is a public good, it is difficult to determine what the benefits from an incremental increase in supply would be. Policymakers routinely calculate the benefits of an incremental increase in public goods such as national security or highway safety as part of the budget process. But unlicensed spectrum is different in that the government can make allocate it at no real cost—*i.e.*, without having to face the real opportunity cost.

An Economic Framework for Analyzing Benefits: Coleman Bazelon, an economist and spectrum expert with The Analysis Group, recently developed an economic framework for the very task at hand—analyzing the incremental value of an unlicensed versus a licensed allocation of spectrum in the TV band, given existing allocations.[47] Bazelon's key insight is that an incremental allocation of unlicensed spectrum would create value solely through its effect on externalities. The major effect would be congestion relief: unlicensed spectrum generates congestion because users do not internalize the cost that their use of the spectrum imposes on others; an allocation of additional unlicensed spectrum could reduce that cost. Bazelon points to innovation as a second externality effect.

Bazelon argues that, given existing allocations, an additional allocation of unlicensed spectrum will not lead *directly* to any increase in consumer surplus (the externality effect will produce an indirect increase in consumer surplus). The logic is straightforward: consumption of unlicensed spectrum and related goods is not constrained by its availability; thus, an increase in the amount of unlicensed spectrum does not generate any consumer surplus.

Bazelon estimates that the marginal value of an unlicensed allocation of TV white space is about $12 million per incremental MHz. This is accounted for solely by congestion relief.[48] (Bazelon acknowledges that there is some positive effect on innovation, but does not have any basis for

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[47] Coleman Bazelon, "Licensed or Unlicensed: The Economics of Incremental Spectrum Allocations," Paper Presented to the Telecommunications Policy Research Conference, September 29-October 1, 2006, Washington, DC. In a related context, Hazlett and Spitzer argue that a marginal analysis is necessary but not sufficient to support an allocation of additional unlicensed spectrum. In their view, before deciding how to allocate additional spectrum, we must estimate what wireless values would be under different rules. Their key point is that the expected value of a property regime would encompass many, if not all, of the spectrum use options permitted unlicensed users because the flexible use regime allows licensees to innovate over business models and market structures. Or, as they state it, "If the kinds of 'open access' rules characteristic of unlicensed bands are efficient, then exclusive spectrum rights holders will have strong incentives to adopt them." Thomas W. Hazlett and Matthew L. Spitzer, "Advanced Wireless Technologies and Public Policy," *Southern California Lew Review* 79 (March 2006).

[48] Of that amount, $5 million is due to reduced congestion in the home, and $7 million to reduced congestion for wireless internet service providers (WISPs), who typically operate in rural areas. (The $7 million is based on the average price paid for spectrum rights in rural areas in the recent AWS auction; Bazelon reasons that AWS license values represent an upper bound on what reduced congestion is worth to WISPs at the margin.) Bazelon does not assign any marginal value to congestion relief in public, since he can find no documented evidence of congestion of public WiFi hotspots outside of convention centers.

quantifying it.) This is less than 10 percent of the incremental value he assigns to a licensed allocation of the same spectrum (Bazelon values a licensed white-space allocation at $152 million per incremental MHz—the average price paid for spectrum in the recent AWS auction).

Opportunity Cost of Unlicensed White Space

Most property rights advocates will acknowledge that enormous benefits have come from the decision to allow unlicensed activity in what was a "garbage band" at 2.4 GHz. But it does not follow that the FCC should pursue the same policy in the TV band—another so-called "junk band"—as unlicensed advocates assert. The difference is opportunity cost.

The opening of the 2.4 GHz band to unlicensed activity did not displace or preclude any licensed activity: the 2.4 GHz band was already reserved for unlicensed use by Industrial, Scientific and Medical (ISM) equipment, such as microwave ovens, which precluded most (high-power) licensed uses—hence the term "garbage" band. In short, unlicensed access to the 2.4 GHz band did not impose any meaningful opportunity cost. By contrast, a decision to open the TV white space to unlicensed activity would preclude licensed activity in the same spectrum, imposing a direct opportunity cost.

In Section V, we discuss the merits of a licensed approach to the white space and argue that its benefits—*i.e.*, the opportunity cost of an unlicensed approach—are significant (among other things, we estimate that an FCC auction of the white-space spectrum rights would generate several billion dollars). But what interests us here is the question of why, given these large potential benefits, the licensed approach been largely ignored in the policy debate.

A major factor may be the perception that licensed access to the white space is not technically or commercially feasible—largely because of high transaction costs. We believe this is a misperception, as we noted earlier, and we will address it in detail in Section V.

Another rationale used to dismiss the possibility of a licensed approach is equally flawed. At a recent conference on spectrum reform, when a speaker representing one of the high-tech firms prominently supporting unlicensed white space was asked why his company did not support licensed access, he responded that it was not politically feasible—an apparent reference to the fate of the Pressler plan and broadcasters' clout with Congress and the FCC. That assessment is out-of-date, however. In part because unlicensed advocates have been so politically effective, it appears likely that Congress and/or the FCC will allow access to the TV white space on some basis. Recognizing that, broadcasters have signaled their preference for a licensed regime because it would provide better mechanisms to control interference than an unlicensed regime.

Yet another rationale is that licensing of the white space is unrealistic because it would take too long. That too is a red herring: the FCC has indicated that it would not allow unlicensed use of the white space during the DTV transition, which ends in early 2009. Two years should be enough time to determine license terms and hold an auction.

In short, a market-based approach to the white space should no longer be dismissed as a non-starter for economic, political or administrative reasons. Since licensing of the rights to vacant TV channels is a viable option, unlicensed access would impose a genuine opportunity cost.

3. Squatters Rights and the Future of the TV Band

Allocation of the TV white space for unlicensed use, and the regulatory controls that would entail, could create a powerful constituency, consisting of tens of thousands of spectrum "squatters" and hundreds of technology and equipment suppliers. Such a constituency would impede the long term transition of the TV band just as surely as dense foliage blocks a high frequency radio wave.

The major problem with traditional FCC spectrum regulation has been its tendency to promote rent-seeking in place of entrepreneurial innovation. As just one example, low-power TV was approved only decades after it was technically feasible, because of resistance by broadcasters.

An unlicensed regime in the white space would be no less susceptible to rent-seeking than the current regime because it relies on government-set rules, as opposed to market forces—what unlicensed advocates call "light regulation." The political economy of regulation is almost as predictable as the physics of spectrum. One iron rule of regulation is that it is hard to take things away from identifiable groups. In addition to creating an incentive for the recipients of concentrated benefits to organize, regulation provides countless opportunities for them to use the courts, the Congress and the administrative process to engage in tactical delay and to distort the policy process in their favor. Thus it provides the ideal terrain on which vested interests can defend the *status quo* and resist the efforts of those who seek to impose a new order.

To their credit, unlicensed advocates have been highly critical of the perverse effects of legacy spectrum regulation: early support for the unlicensed approach was in part a response to the difficulty of bringing spectrum-using innovations, including end-user equipment, to market in a command-and-control environment. Many unlicensed advocates no doubt believe that the creation of a spectrum commons will avoid the creation of vested interests that will oppose change. But history tells us otherwise, as a recent critique of the commons approach to spectrum management explains:

> After all, those who take advantage of the opportunity to make use of a common property will be no more willing to give up that use voluntarily than if they had been required to pay for the privilege. The experience from the reign of Henry VIII to the 18th century of the closure movement undertaken to close down the medieval commons surely shows that this arrangement is no way to avoid the creation of vested interests. Faced with the loss of their means of livelihood, poor farmers and laborers put up a ferocious resistance to the closing of the commons that continues to be noted by historians.[49]

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[49] Baumol and Robyn, *op.cit.*,pp. 51-52.

Recent experience is a reminder of the power of spectrum squatters. The 902-928 MHz band is used for Navy radars, but has also supported a growing number of unlicensed systems that are, in theory, secondary to authorized operations. As these unlicensed activities expanded, the two sets of operations began to conflict: when Navy personnel fired up the radars on Navy ships that were in port, primarily to repair and maintain them, the radars interfered with (civilian) cordless phones. Predictably, the civilians complained to Members of Congress and other policymakers. Eventually, the Navy restricted its use of radars while in port.

Granted, it is difficult to take spectrum away from any group. But liberally licensed users are more likely to adjust to changes in technology and tastes on a continuing basis. Companies like Verizon Wireless and AT&T have seamlessly upgraded their networks and user handsets to new, more efficient digital standards, at a total cost of many tens of billions of dollars. Contrast that with the broadcasters, who have little if any incentive to use the spectrum more productively: technical standards were essentially static from the adoption of color TV in the 1950s until the current move to digital television. During that same period, the performance of TV cameras and TV sets expanded enormously, due to innovation by unregulated manufacturers.

Like broadcasters, unlicensed users of the white space would have no incentive to use the spectrum more efficiently. This is the irony of the claim that the TV band is suited only for unlicensed activity because it is a "junk band." If the TV is a "junk band," it is largely because of the perverse incentives created by a rule-based regulatory regime—the same perverse incentives that an unlicensed approach would perpetuate. Thus, unlicensed advocates are citing the damage done by command-and-control regulation to justify another regulatory regime that would bring more of the same.

Spectrum-Sensing Technology and Other Special-Interest Scenarios

Consider one possible way (there are many) in which unlicensed users might impede the evolution of the TV band to higher value uses. Some experts have proposed that unlicensed devices use spectrum-sensing technology as a way to avoid causing harmful interference to broadcasters: the technology would detect broadcast signals and identify vacant spectrum by the absence of broadcast signals. However, a mechanism designed to detect ATSC TV signals and wireless microphones would no longer serve its desired purpose of detecting TV transmissions if broadcasters allowed to operate with technical flexibility—*i.e.*, if they were authorized to use alternative modulation technologies. That failure would occur because the alternative signals would be unlikely to match the signals that the sensing mechanisms were designed to detect.

It is easy to envision how this might play out. Under one scenario, the prospect of the spectrum-sensing technology being rendered useless could become an impediment to broadcasters getting technical flexibility. In this way, broadcasters could get locked into their existing technology. Alternatively, if the technical standards were changed, the unlicensed devices would be able to invade the non-white-space portions of the TV band. Under either scenario, unlicensed devices would lock the white space into an inefficient pattern of use for decades, and the FCC would lose its flexibility to facilitate more efficient use of the rest of the TV band.

Spectrum-sensing technology is merely an example; in an unlicensed regime, special interests will seek to block the kind of efficient change that would occur naturally in a market-based regime. The clash in this white-space proceeding over the treatment of wireless microphones provides a preview. There are a relatively small number of wireless microphone systems licensed by the FCC and a larger number operating on an unlicensed basis. However, wireless microphone manufacturers have organized a "Microphone Interests Coalition" to persuade the FCC that "the white spaces are not really white at all."[50]

As another example of regulatory "squatting," the burglar alarm industry, which uses cellular spectrum, is currently urging the FCC to require that the older, inefficient analog wireless systems operated by firms such as Sprint be maintained. The alternative would require the alarm industry to buy new terminal equipment.[51] If the alarm industry succeeds, it will benefit slightly, but all other users will be harmed as wireless carriers are forced to incur higher costs and delay the rollout of 3G wireless technologies.

Technical Fixes Cannot Remove the Political Impediment

Modern technologies do offer some promise of moderating the effects of the squatter's rights problem. One possible technological "fix" would be for the FCC to require that unlicensed devices operate with some form of positive control based on up-to-date data that described the limits on permitted operations. For example, the FCC could publish a database describing which geographic locations and frequencies and at what powers devices unlicensed devices could operate. Devices would be required to cease operation unless they had recently downloaded a new copy of the data base from a server run by the device manufacturer. Devices would also have to contain some form of geo-location subsystem (*e.g.*, a GPS receiver) that they could use in conjunction with the database in order to determine allowed operations.[52]

Positive beacons—signals that an unlicensed device must receive before it can operate—are another technique to provide similar control. One can imagine other incremental removal policies. For example, the maximum power that an unlicensed device could use could be ramped down over time on some channels or in the entire band.

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[50] Ex parte notice of Microphone Interests Coalition, ET Docket 04-186, January 26, 2007.

[51] See "Wireless Telecommunications Bureau Seeks Comment on Petition for Rulemaking to Extend Cellular Analog Sunset Date," RM No. 11355, Public Notice, DA 06-2559 (Dec. 20, 2006).

[52] A database-controlled positive authorization system like this would allow the FCC to rapidly clear portions of the white space for other uses. For example, suppose the FCC determined that the white space on TV channels 21-30 were to be made available for public safety use in the ten largest cities. The FCC could modify the database to prevent operation of unlicensed devices in those channels in the proper areas. Almost immediately, the unlicensed devices in the affected geographic regions would restrict their operation to channels other than 21-30. If most devices checked in moderately frequently—say once every two months—then in just a few months the unlicensed devices would have been removed from that spectrum. In contrast, if the regulatory solution were more traditional, outlawing new devices but grandfathering the old devices until they are retired, then it would take many years before the relevant spectrum regions were cleared.

In short, there may be technological "fixes" to the squatter's problem. But the impediment will be political, not technical. If unlicensed use of the white space is only modestly "successful" in terms of attracting users, it will create special interests primed to fight against more efficient use of the white space.[53] If there is no political will to use them, then these technological options will not matter because they will never be exercised. History shows that that political will is likely to be lacking even if removing unlicensed operations from the white space would create benefits far in excess of the costs it would impose on the white space users and manufacturers.

[53] As discussed earlier, we fully expect the white space to attract users; our concern is that the applications will not add significant value beyond those available on other unlicensed bands today. However, consider the alternative—namely, that unlicensed white space, like the unlicensed PCS band, attracts almost no users and the FCC reallocates the spectrum for licensed use. In that case, squatters will not be a problem, but the potential of the white space will have been squandered for a decade.

V. LICENSED USE OF THE TV WHITE SPACE

Summary: A licensed approach to the white space offers three key advantages over an unlicensed approach. First, it should produce more efficient use of the white space, even in the short-run: most important, the parties—the potential interference-generating licensee and the potentially interfered-with broadcaster—would have an incentive to negotiate deviations from FCC interference standards, resulting in greater capacity. Second, licensed access would encourage investment in long-range infrastructure by protecting the licensee against interference from other white-space operations. Third, in the long-run, licensed access would facilitate, not impede, the evolution of the TV band to higher-value uses. Although unlicensed advocates dismiss the licensed alternative on the grounds that the coordination costs would be prohibitive, the FCC generally structures overlay licenses with an eye to limiting those costs, and the white space is not fundamentally different. Below, we describe the licensed option and discuss its key advantages. Next, we address questions about the feasibility of the licensed option. Finally, we estimate what an auction of the white-space spectrum rights would generate in revenue.

A. How Would it Work?

Under this option, the FCC would allocate all spectrum in the TV band (channels 2-51, except 37) to one or more licenses and assign them using an auction or other market mechanism. These exclusive and tradable rights would allow a licensee to use the spectrum in any way desired as long as the usage rights of existing license holders (broadcast and land mobile operators) were protected. Consistent with FCC rules governing analogous situations, a white-space licensee and an incumbent broadcaster would be able to negotiate variations from FCC interference standards.

Potential Applications

Key characteristics of the white space will determine its likely use in a licensed regime:

- Adequate spectrum to support nationwide service but limits on bandwidth in some areas
- Superb propagation characteristics, allowing for reduced capital expenditure
- Spectrum is unpaired, but enough spectrum under some scenarios for dynamic pairing
- Proximity to broadcasters will require additional engineering near the edges

The white space would lend itself to the same high-demand applications that wireless services offer today. That portion of the white space that is nationwide in scope could potentially support broadband PCS, including fixed and mobile voice and data. More generally, the white space could support broadband Internet access, both fixed and mobile. A licensee might offer such a service using white space only or using the white space as a complement to other spectrum.

In addition to (or instead of) operating its own service, a white-space licensee might serve as a band manager—providing sublicenses to spectrum users. The fact that white space will be more plentiful in some areas than others would make this an attractive business strategy. For example, a nationwide white space licensee whose business plan required 12 MHz of spectrum in the primary service area would have additional capacity available in the less dense markets—capacity that could be valuable to someone with a different business plan.

Structure of Spectrum Rights

The range of services that the white space will support depends in part on how the spectrum rights are defined. Two dimensions of those rights will be key. One is the amount of bandwidth covered, which could range from 6 MHz to the full TV band (6 MHz is the natural building block for a white space license, given the channelization of TV, and it is probably the minimum necessary to support commercial service). The other key variable is geographic coverage, ranging from small regions to the entire nation.

Generally speaking, licenses that offer broad coverage along both dimensions promote economic efficiency. First, interference control among licensees is easier if there are fewer boundaries. In the extreme case, in which just one licensee controls all the relevant spectrum, coordination is fully internalized—*i.e.*, it all takes place within the licensee-firm. Second, broader coverage affords more commercial options: with wider channel coverage, a licensee is more likely to have sufficient spectrum in dense urban areas; and a license that covers the full country gives a new entrant the option of offering nationwide service.[54] Nationwide licensing is particularly important for new entrants that want to use a new technology that cannot "roam" onto existing networks. Finally, broad coverage allows for economies of scale in equipment procurement and marketing.

With these efficiency considerations in mind, economists typically argue that overlay licenses should provide nationwide geographic coverage and enough bandwidth to permit a variety of uses and to achieve economies of scale.[55] The Pressler plan is an example of that: it called for five nationwide overlay licenses, which would have given each licensee the (nationwide) rights to a subset of channels in the TV band.

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[54] Nationwide licenses are nothing new. The FCC has granted nationwide licenses (*e.g.*, the recent the G-Block license to Nextel), and several wireless carriers have aggregated smaller licenses to achieve national coverage (had PCS licenses been auctioned off on a nationwide basis, carriers could have avoided substantial transactions costs).

[55] See for example, Evan R. Kwerel and John R. Williams, "Moving toward a Market for Spectrum, *Regulation* (Spring 1993). Purely on efficiency grounds, the optimal package of spectrum rights for the white space would be a single nationwide overlay license covering all 49 channels. For the reasons discussed above, such an approach would minimize the transaction costs and maximize the commercial opportunities associated with operating in the white space. Unlicensed advocates dismiss that idea on the grounds that it would be unacceptable to rural interests and raise competition concerns. The latter concern, at least, is misplaced: a single-license approach would not be anti-competitive, because a white space operator would face competition from the many existing wireless operators as well as some terrestrial and satellite service providers.

However, efficiency is not the only consideration, and smaller licenses tend to be more affordable—a key consideration for smaller providers. The FCC generally auctions off regional licenses of various sizes in an effort to accommodate a range of would-be licensees. Large providers can and do aggregate smaller licenses to achieve national coverage.

Similarly, for the white space, less aggregated approaches to packaging spectrum rights would be entirely feasible. Instead of a nationwide license, the FCC could auction overlay rights to the (entire) band in each of a number of *smaller geographic regions*, such as the 52 Major Economic Areas or the 6 Economic Area Groupings used in PCS auctions. Alternatively, an overlay license could cover just a *subset of all channels*, with the subset chosen such that at least 12 MHz of white space was available for 95 percent of the covered population.[56] Corresponding geographic coverage could be either national or regional. Although 12 MHz is an arbitrary threshold, it would ensure a minimum capability at every location in the license area.

An alternative to an overlay would be to license the *"doughnut" around individual TV stations*, as shown in Figure 6. Doughnut licenses are more restrictive than the broader licenses discussed above because each white space license is paired with a single TV station. The advantage of this approach is that the new license is a natural complement to the incumbent one; when combined, the two create an area license.[57]

Doughnut licenses make sense if broadcasters are the entities most likely to buy the rights to the white space—presumably, as a way to expand their station coverage: such licenses would allow TV stations to internalize the transaction costs associated with coordinating interference control and thus promote efficient use of the white space. Alternatively, if broadcasters were to be given the right to offer non-broadcast services, doughnut licenses would facilitate the evolution of the TV band to higher value applications. However, absent one of those two scenarios (neither of which seems likely at present), a broad overlay license—one that spans many channels in bandwidth and multiple cities in geographic coverage—would probably make more sense.

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[56] For example, a license might cover channels 38-51, or channels 22-25 and 44-51.

[57] There are alternative techniques for defining a doughnut license. One technique for defining the scope of a doughnut license would be to identify mathematically that set of locations that is closer to a specific TV station than to any other TV station on that channel. Alternatively, one could draw the geographic boundaries of the doughnut license along the boundaries of the corresponding station's designated market area (DMA). The latter approach is probably preferable because it would produce an area license that was better suited to the commercial and contractual environment facing a particular station.

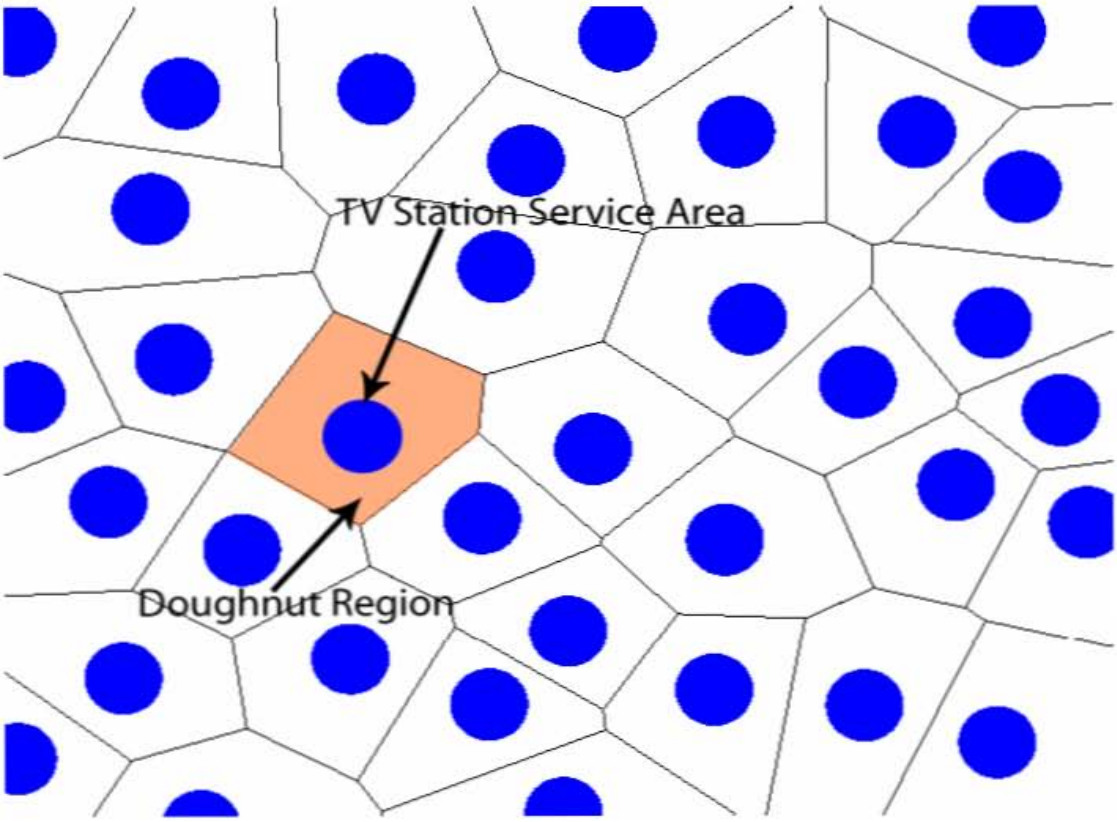

Figure 6. TV Station Service Areas and Associated Geographic Regions for White Space Licenses

Precedent for White-Space Auctions

The FCC has conducted at least fourteen auctions of what amounted to white space outside of the TV band. (See Table 3.) These auctions, which generated more than $1 billion, illustrate a variety of approaches to the structuring of spectrum rights. In Auction 53, the FCC awarded overlay rights to 500 MHz of spectrum (12.2-12.7 GHz) in 214 geographic service areas to be used for terrestrial broadband services; the incumbent licensees that had to be protected were direct broadcast satellite (DBS) service operators and point-to-point public safety microwave systems. In that auction, the FCC explicitly contemplated overlay operations similar to those discussed above. According to the Commission:

> MVDDS licensees may use this spectrum for any digital fixed non-broadcast service (broadcast services are intended for reception of the general public and not on a subscribership basis) including one-way direct-to-home/office wireless service. Licensees are permitted to provide one-way video programming and data services on a non-common carrier and/or on a common carrier basis. Mobile and aeronautical services are not authorized. Two-way services may be provided by using other spectrum or media for the return or upstream path.[58]

[58] Auction 53 Fact Sheet. Available at

Table 3

Table A1. FCC "White Space" Auctions

Auction	Radio Service	Net Auction Bids	Notes
6	BRS (MMDS)	$216,316,333	
7	900 MHz SMRS	$204,267,144	Licensed as paired 0.125 segments
16	800 MHz SMRS	$96,232,060	Licensed in blocks of 1, 3 or 6 MHz
26	929 and 931 MHz Paging	$4,122,500	
34	800 MHz SMR General Category	$337,494,900	
36	800 MHz SMR Lower 80 Channels	$28,978,385	
40	Paging	$12,897,127	
42	Multiple Address Systems	$1,202,725	
53	Multichannel Video Distribution and Data Service (MVDDS)	$118,721,835	DBS “white space.” Of the fixed microwave incumbents in this spectrum, only public safety incumbents were protected against interference from the white space licensees.
55	900 MHz SMRS	$4,861,020	Licensed as paired 0.125 segments
57	Automated Maritime Telecommunications System (AMTS)	$1,057,365	
59	Multiple Address Systems	$3,865,515	
61	Automated Maritime Telecommunications System (AMTS)	$7,094,350	
63	Multichannel Video Distribution and Data Service (MVDDS)	$133,160	DBS "white space"
	Total	$1,037,244,419	

All information in the above table was taken from the FCC’s Auction web site—specifically the *fact sheet* pages for each auction.

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http://wireless.fcc.gov/auctions/default.htm?job=auction_factsheet&id=53

In other cases (*e.g.*, Auctions 34, 36 and 55), the overlay rights packages covered a subset of the total band in 175 separate geographic regions. In practice, these licenses were much like the doughnut licenses described above; Nextel, which had the rights to the "hole" in the doughnut in most of those regions, won the auction, and thus was able to convert its site licenses to more efficient area licenses. The FCC described the protection to be afforded to incumbents by the winners of Auction 34:

> Incumbent licensees are present in the 800 MHz SMR band. Incumbent 800 SMR systems are entitled to co-channel protection by EA licensees, as well as adjacent channel interference protection. Incumbent systems, however, are not allowed to expand beyond existing service areas unless they obtain the EA license for the relevant channels.[59]

One Approach to Licensing Regions

The Commission asked for specific proposals for license regions and band plans (FNPRM, para. 4). As discussed above, larger license regions better serve efficiency, generally speaking. We believe that there is a strong argument to be made for a single nationwide license for the entire white space. Such a license would provide a new entrant with sufficient spectrum to provide a nationwide service of reasonable capacity and it would also eliminate any interference coordination costs among white-space licensees.

However, we recognize that there are countervailing values in addition to pure efficiency. Consequently, we propose a variety of geographic and bandwidth regions. As the FNRPM notes there are natural subdivisions in the TV spectrum that provide natural boundaries for licensing. We follow these natural boundaries in our recommendations which are shown in Table 4. We also recommend that the Commission use combinatorial auctions or some other form of package bidding that would allow new entrants to avoid circumstances in which they were locked into purchasing less than the necessary coverage for a new service.

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[59] FCC Fact Sheet for Auction 34. Available at: http://wireless.fcc.gov/auctions/default.htm?job=auction_factsheet&id=34.

Table 4

One Approach to Licensing Regions	
TV Channels	**Geographic Regions**
2-6	734 Cellular Market Areas
7-13	176 Economic Areas (EAs)
14-36	12 Regional Economic Area Groupings (REAGs)
38-51	12 Regional Economic Area Groupings

B. Advantages of Licensed Operation

Licensed use of the white space offers both short-run and long-run advantages over unlicensed use. Either set of advantages provides reason enough to opt for a licensed approach.

1. Promotes Efficiency in the Short Run

More Efficient Use of the White Space: Licensed use of the white space would promote greater efficiency than unlicensed use even in the short run. Perhaps most significant, licensed white-space systems could be engineered-in more closely to the edges of broadcast coverage than unlicensed system, creating significant additional capacity. This would be possible because of more flexible interference rules as well as the incentives that property rights would create for negotiation beyond those rules.

To elaborate, in a licensed environment, if white-space operations created an interference problem, a broadcaster could identify the source of the interference and deal with the interferer—either directly or through the FCC. In an unlicensed environment, both tasks would be more difficult. As a result, the FCC would be likely to impose—and broadcasters would be likely to accept—less protective interference standards for licensed white-space operations than for unlicensed operations.

Moreover, assuming the rules permitted it, broadcasters and the white-space licensee could bargain about deviations from those standards. For example, the licensee could purchase the right to operate on the edge of the broadcaster's coverage. One can envision other agreements between a white space licensee and a broadcaster that would permit much tighter system engineering than would be possible under the rules.

Neighboring licensees can negotiate such variations under current FCC rules covering broadcast, PCS and cellular operations. For example, the FCC's broadcast rules (47 CFR 73.6022(a)) state:

> Class A TV stations may negotiate agreements with parties of authorized and proposed analog TV, DTV, LPTV, TV translator, Class A TV stations or other affected parties to resolve interference concerns; *provided,* however, other relevant requirements are met with respect to the parties to the agreement. A written and signed agreement must be submitted with each application or other request for action by the Commission. *Negotiated agreements under this paragraph can include the exchange of money or other considerations from one entity to another*. Applications submitted pursuant to the provisions of this paragraph will be granted only if the Commission finds that such action is consistent with the public interest. (emphasis added)

To be sure, a broadcast station could not agree to incursions by a white-space operator that would significantly harm broadcast coverage and jeopardize the public service benefits provided by its license. But it is easy to envision "win-win" agreements between the two parties with respect to operations on the edge of the broadcaster's coverage—especially if broadcast service was unavailable in any event in the affected area (*e.g.*, due to terrain blockage that was not reflected in the calculation of the station's protected contour) or if the only people whose coverage was affected were those traveling in cars. Moreover, public service benefits can take different forms: a broadcaster might grant a white space operator additional operating flexibility in exchange for revenue that would be used to harden the broadcast facilities, thereby providing enhanced emergency service.

Experience demonstrates the benefits of such negotiated agreements among licensees. Research by an FCC engineer, John R. Williams, showed that "frequency coordination" among microwave operators produced much more tightly engineered systems—with resulting higher capacity—in the northeast, where demand for spectrum was higher than in other areas of the country.[60] Currently, a similar process in the 700 MHz band is helping to facilitate the digital TV transition.

In sum, a licensed regime would create the opportunity and incentive for broadcasters and white-space operators to negotiate away from the FCC-imposed interference rules—rules that themselves are likely to be less protective in a licensed environment. By contrast, in an unlicensed regime, there would be no mechanism for white-space users to pay broadcasters to accept additional interference. This is the single most important short-run difference between a licensed and an unlicensed regime for the TV band.

Unlicensed advocates claim that the FCC provides such a mechanism in its role as a regulator. The problem with FCC as interference-tradeoff-facilitator is that it cannot take money from winners to compensate losers; thus it continually blocks or foregoes efficiency-enhancing moves because potential losers object. In addition, the FCC often lacks a clear view of the size of the potential gains and losses. That is a weakness of any non-market institution; compounding it here is the tendency for government entities to assess benefits and costs using political as well as economic criteria.

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[60] John R. Williams, "Private Frequency Coordination in the Common-Carrier Point-to-Point Microwave Service," FCC OPP Working Paper Series, Number 21 (September 1986).

Better Incentives for Investment: In addition to encouraging more extensive use of the white space, licensed access would create better incentives for investment in long-range wireless telecommunications infrastructure. A service provider operating in the white space must have one or more access points in order to offer efficient long-range and rural service. Because any single access point represents a significant portion of the service provider's network, interference to such an access point threatens the provider's investment as well as its brand reputation. Service providers investing in long-range systems have a strong preference for licensed spectrum over unlicensed spectrum, because it allows them to avoid that threat.[61]

More generally, wireless service providers operating in licensed spectrum have greater control over service quality. A key issue is service reliability. People want voice calls everywhere, all the time. Similarly, they do not want music or TV programs to go on and off as they walk around listening to and watching their mobile wireless devices. Licensed spectrum, unlike unlicensed spectrum, can support those wireless applications that require reasonably reliable radio links and/or extensive coverage.

In contrast, as we discussed earlier, the incentives to invest in service-provider infrastructure, particularly long-range infrastructure, is substantially weaker in unlicensed spectrum than in licensed spectrum. To the extent that one wishes to see the white space provide an additional path connecting homes and businesses to the Internet, a licensed regime is likely to result in far more investment and service than an unlicensed regime.

2. Facilitates Long-Run Transition of TV Band

In addition to these short-run benefits, a major benefit of licensed operation will come in the long run: licensed operation in the white space will facilitate evolution away from the use of the UHF spectrum for TV. If broadcasters were given flexible use rights to the spectrum implicitly defined by their licenses, those rights could be combined with the white-space overlay rights to provide a variety of services. Over a decade or so, broadcasters and overlay licensees could reengineer the broadcast system, freeing up most of the broadcast station's spectrum for higher value uses while maintaining a core of over-the-air broadcast service. Ultimately, the overlay license or licenses and the broadcaster licenses could merge into a license structured much like today's PCS licenses.

This kind of evolution is not just theory. The FCC auctioned off overlay licenses in the MDS service (now called BRS), SMRS, and paging, so as to facilitate such a transition. See, for example, FCC auction 6 (MDS, 1995), auction 16 (SMRS, 1997), and auction 48 (paging, 2003). (By contrast, the MVDS license auction squeezed in a new operator, but in a way that moved

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[61] Short-range systems, such as 802.11 hotspots face somewhat different incentives with respect to interference. Perhaps most important, the economics of coverage expansion are quite different. If interference knocks out 802.11 coverage in one corner of a Starbucks coffee shop, for a few hundred dollars, Starbucks can put another 802.11 access point in the ceiling and run the necessary Cat 5 wiring back to the network hub. No such low-cost remedy is possible if interference destroys reception at a base station serving hundreds of subscribers.

farther away from a property rights regime in the DBS band.) The FCC fact sheet for auction 48 describes how the new license relates to the incumbent licenses:

> Incumbent (non-geographic) paging licensees operating under their existing authorizations are entitled to full protection from co-channel interference. Geographic area licensees are likewise afforded co-channel interference protection from incumbent licensees. Adjacent geographic area licensees are obligated to resolve possible interference concerns of adjacent geographic area licensees by negotiating a mutually acceptable agreement with the neighboring geographic licensee.

In the case of PCS, licenses were auctioned off but PCS licensees had to protect the incumbent public-safety microwave systems for a number of years. If a PCS operator wanted those microwave systems to leave early, the PCS operator had to persuade (*i.e.*, pay) the microwave operator to do so. The approach worked, and microwave operations were cleared off the PCS band with little difficulty.

A major impediment to the use of a similar, transitional approach in the TV band is the political opposition—much of it from unlicensed advocates—to having broadcasters receive a windfall in the form of flexible use rights.[62] However, giving broadcasters a windfall is preferable to having them tie up the TV spectrum indefinitely. Professor Hazlett compares the broadcasters to the mule that blocked Gen. Patton's convoy in World War II, and concludes that, "[d]istasteful though it is, the efficient solution is not to shoot the mule but to bribe it to saunter along."[63] Among other benefits, the competition made possible by the "bribe" would limit the size of the windfall, as Hazlett explains:

> Rather than blocking new technologies, broadcast stations would seek out more efficient video distribution platforms, capturing part of the social gains created….The outcome would be that networks would compete to offer current services at much lower prices, and jockey to introduce an array of innovative applications. This is the pro-consumer way to reform, and it is the one way to curb windfalls without punishing consumers with the collateral damage of delay and inefficiency.[64]

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[62] Neuchterlein and Weiser write that much of the reluctance to adopt more market-oriented spectrum reform stems from political objection to having licensees that didn't pay for their spectrum receive a windfall. As one flaw in that objection, they note that the public's claim to compensation for spectrum is weak. "Policymakers …sometimes forget that auctions are properly justified not as mechanisms for compensating the public for the use of "its" airwaves, but as a means of assigning spectrum rights as quickly as possible to those who would make the most efficient use of them." Neuchterlein and Weiser, *op. cit.*, pp. 245-246.

[63] "Hostage Standoff," *The Political Spectrum* (March 19, 2001).

[64] Testimony of Thomas W. Hazlett, Senate Committee on Science, Commerce and Transportation, Hearing on the Digital Television Transition (June 9, 2004).

C. Is it Really Feasible to License the White Space?

A key (perhaps *the* key) question about a licensed approach to the white space is its practical and commercial feasibility. Unlicensed advocates, in particular, maintain that the administrative and coordination costs of a licensed regime would swamp the benefits. Others, including FCC officials, have raised legitimate questions about how a licensed approach would accommodate wireless microphones and new broadcast licensees. It is essential to address the feasibility issue.

As a starting point, note that the TV white space offers several advantages as an environment for licensed operations. First, the primary systems to be protected—broadcast stations and land mobile operations—are well defined. Consequently, it should be reasonably easy for a licensee to protect these systems from interference. Second, the noise level in most of the white space is quite low, which would facilitate long-range operations.

Further evidence that licensing would work comes from those systems that have successfully used the TV white space on that basis for decades. A prominent example is land mobile radio, which has operated on channels 14-20 in several major metropolitan areas since the 1970s. Granted, land mobile systems rely on a relatively simple spectrum-sharing technique (pure geographic separation), whereas licensed systems for the TV white space would require more complex techniques (*e.g.*, close-in engineering of base stations using directional antennas, frequency coordination and interference negotiation). Nevertheless, the longstanding operation of land mobile services demonstrates the basic feasibility of a licensed approach in the TV band.

Transaction Costs

"Swiss Cheese": To the limited extent that they have acknowledged the licensed alternative, unlicensed advocates have tended to dismiss it on the grounds that the transaction costs would be prohibitive, as we discussed briefly in Section IV. According to this argument, the "Swiss cheese" character of the white space, combined with limits on the amount of white space in certain areas and the prospect of multiple white-space licensees, would make it extremely difficult to achieve the basic conditions for a market in white-space spectrum rights.[65]

One condition for such a market is reasonably well-defined property rights. Defining property rights in spectrum can be difficult because the rights are based on notions like avoiding harmful interference, which themselves can be hard to specify. Unlicensed advocates argue that it would be particularly tricky to define spectrum rights in the white space because the operating parameters would differ from market to market. For example, a channel that was available in Baltimore might not be available in nearby Washington, DC.

Although private parties can be expected to reach agreement on interference rights under a market-based approach, the patchwork nature of white space would make such negotiations prohibitively complex, according to unlicensed advocates. For example, a white-space licensee might have broadcasters A and B as neighbors to its channel N in one place, and broadcasters C

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[65] de Vries, *op. cit.*, pp. 14-15.

and D next to its channel N someplace else. Conversely, with multiple white-space licenses, broadcaster A could be dealing with licensee X in some places and licensee Y in others. By this argument, the sheer number of parties (and potential ambiguity as to their identity) would also make it difficult to negotiate variations from FCC interference standards—a major advantage claimed for the licensed approach.

An assessment of these arguments should start with a simple point that often gets overlooked: transaction costs are an issue only because licensed operations would make more extensive and efficient use of the white space than unlicensed operations. A white-space licensee could always eliminate (or significantly reduce) transaction costs by using the white space in the same way that unlicensed advocates propose—namely, with low-power devices and rule-based sharing protocols. Consumers would be no worse off under that scenario than under an unlicensed scenario; in fact, they would probably be better off because broadcasters might well tolerate less protective FCC interference standards in a licensed regime, as we discussed earlier. In sum, the issue of transaction costs arises only if licensed usages of the white space create spectrum opportunities that would not exist in an unlicensed regime.

Second, the transaction-costs argument is based on an assumption that white-space licenses will be carved up geographically. If the FCC were to auction off one or more nationwide licenses, the transaction costs related to negotiation among white-space licensees would be internalized.

Unlicensed advocates acknowledge this point but respond that the prospect of nationwide licenses is unrealistic: in their view, the FCC would have no choice but to divide white-space license assignments geographically in order to meet the needs of rural political interests. That may or may not be right. But even if licenses were assigned regionally, rather than nationally, the coordination problem among white-space licensees should be manageable.

To elaborate, the FCC has granted many regional overlay licenses, and it has almost always been able to minimize coordination costs. First, the Commission defines regions large enough that relatively little of the geographic area falls within coordination distance of the border (*e.g.*, Alaska might be a single licensing area). Second, the geographic boundaries are drawn so as to fall in less dense areas (*e.g.*, a boundary might run between New York City and Philadelphia but it would not run down the middle of 5th Avenue). Third, the Commission uses a variety of mechanisms to define harmful interference in a relatively unambiguous fashion.[66]

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[66] In some cases, it has used simple geographic separation rules (*e.g.*, a requirement that "transmit stations of the overlay licensee must be separated by more than 50 miles from base stations of the incumbent license"). In other cases, the Commission has used engineering rules to define harmful interference. These rules include the prohibition of the overlap of the 37 dBμ contours or adherence to the interference criteria set out in publications such as EIA TSB 10E, TIA TSB 88B, or OET-69. Typically such rules are based on a mathematical model that estimates the magnitude of a potentially interfering signal and determines whether it amounts to harmful interference, based on a description of the transmitting equipment, protected receivers, relevant antennas, and surrounding terrain. Such mathematical models are relatively low cost and reasonably accurate, and the results are more reproducible than actual measurements. Consequently, they provide an excellent basis on which to set the starting point for Coasian bargaining over interference adjustments.

In sum, with well-drawn regional licenses, coordination among white-space licensees should not be a significant burden. Coordination between licensees and broadcasters is a more challenging problem, but that too is manageable because any single negotiation—*i.e.*, the negotiation associated with a single base station or a single small geographic region—would have only a limited number of parties. Many negotiations would have only two participating parties (the service provider and the co-channel broadcaster). A smaller number of negotiations would require two additional parties (the broadcasters on the upper-adjacent and lower-adjacent channels).

As with geographic coverage, the transaction costs related to channel coverage would be internalized if the white space license(s) covered the entire area—in this case, all of the channels in the TV band. However, even if only a subset of those channels were covered, it would be possible to draw the boundaries of the license in a way that eliminated or substantially reduced adjacent channels issues between white space licensees. The key is the naturally occurring gaps in the TV band: channels 13 and 14 are not adjacent, and channel 37 is reserved for radio astronomy. If the licenses conformed to those gaps—with one license covering channels 2-13, another covering channels 14-36 and a third covering 38-51—there would be no first-adjacent channel issues among white space licensees.

Rural Spectrum Access: Unlicensed advocates also point to transaction costs as the basis for their claim that rural areas would not benefit from licensed access to the white space. According to this argument, a large telecommunications firm that held white-pace licenses covering rural areas might be unwilling to lease or sell spectrum access to a start-up WISP because the transaction costs would swamp the benefits to the license-holder.

Rural service providers appear to have a strong preference for licensed spectrum.[67] Moreover, rural spectrum is relatively inexpensive. Thus, if WISPs cannot get affordable access to licensed spectrum, transaction costs may be part of the reason. The FCC's rules for spectrum leasing may be one source of that impediment. Rural service providers' lack of experience with those rules may be another.

However, transaction costs probably are not the major impediment to ubiquitous rural broadband. Rather, the cost of providing service to many underserved areas is itself too high—that is, it is not economic for commercial providers even at the cheap price of rural spectrum. Insofar as underserved areas are not viable markets, lower transaction costs in the form of unlicensed white space will not help.

Moreover, even if transaction costs are a serious impediment to rural service, a licensed approach to the white space could help to address the problem. As we discussed earlier, the greater availability of white space in certain areas, many of them rural, will make it attractive for

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[67] National Telecommunications Cooperative Association, "NTCA 2005 Wireless Survey Report" (January 2006). NTCA respondents indicated that they would prefer access to additional licensed spectrum over additional unlicensed spectrum by a margin of 73 percent to 27 percent.

licensees to serve as band managers or sublessors. Thus, the transaction costs may be lower for access to licensed white space than it has been for access to existing licensed spectrum.

In sum, it is easy for advocates for potential service providers to say that the impediment to rural broadband is spectrum availability (*i.e.*, high transaction costs). But insofar as the real problem is the lack of adequate economic return, as we believe it is, unlicensed white space will not provide a solution.

Wireless Microphones

The TV white space is home to thousands of wireless microphones, which are used in TV studios, at sports events and for electronic news gathering. Many wireless microphones are licensed, albeit on a secondary basis. However, a large number are used on an unlicensed basis—apparently in violation of FCC rules.

These licensed wireless microphones, many of them operated by broadcasters, represent clear evidence that operations in the white space are feasible. However, the need to protect wireless microphones from interference creates a challenge to an overlay licensee. Many of the users of these microphones have no reasonable alternative—at least in the short run. Moreover, these microphones use a relatively simple radio link (standard analog FM) that is less efficient in its use of radio spectrum and less tolerant of interference than more modern counterparts.

Wireless microphones change location over periods of time measured in hours or days, not months or years, as is the case with TV stations. Consequently, interference-avoidance mechanisms using a static or slowly-changing geographic database will not be able to protect these devices. Various mechanisms (*e.g.*, alerting beacons) have been proposed to permit unlicensed devices to detect and avoid interfering with wireless microphones.

Michael Marcus and two co-authors propose that wireless microphones ultimately be replaced with other technology.[68] Although such replacement could be part of a long-run plan for efficient use of the TV spectrum, there is a good case for protecting the current investment in wireless microphones during the transition. The operators of licensed wireless microphones themselves have made a significant investment, based on current FCC rules, as have those businesses that ultimately depend on the wireless microphones. Thus, any approach to the white space should handle licensed wireless microphones in a way that is fair as well as efficient.

Several transition policies are possible. One would be to move the wireless microphone users into a subset of all white-space channels.[69] By limiting wireless microphones to a fraction of each TV channel, this approach would accommodate their continued operation while making most of the spectrum available for use by the white-space licensee. Another approach would be to require individual white-space licensees to protect wireless microphones for a period of 5

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[68] Michael J. Marcus, Paul Kolodzy and Andrew Lippman, "Why Unlicensed Use of Vacant TV Spectrum Will Not Interfere With Television Reception," New America Foundation, Issue Brief # 19 (July 2006), p. 8.

[69] Marcus *et al*. also suggest this alternative.

years—for example, by setting aside a fraction of their licensed bandwidth for the wireless microphones to use on a coordinated basis. Licensees that used OFDM or a similar technology could provide substantial interference protection to wireless microphones by transmitting zero power on those OFDM carriers that would otherwise interfere with nearby microphones. In sum, reasonable coordination policies, together with the appropriate technologies, could protect wireless microphones, albeit at some cost to the capacity and/or efficiency of the licensed system.

It is important to note that wireless microphones will be an issue for unlicensed as well as licensed operations in the white space. However, in a licensed regime, the parties will be able to negotiate and make side-payments. An unlicensed regime, by contrast, would preclude those efficiency-enhancing agreements.

New TV Licenses

As phrased here, the white-space licensee would have exclusive use of the white space. It would no longer be possible to grant new TV broadcast licenses or translator licenses. Given the nature of land-mobile technologies—the fact that land mobile service in an urban area is provided by hundreds of licensees operating transmitters using 25 kHz and 12.5 kHz slivers of spectrum, providing protection to land-mobile operations is probably best accomplished by protecting an entire TV channel in any urban area in which that channel is used for land mobile.

Of course, the FCC could adopt other rules—such as permitting the continued licensing of TV stations. Doing so would create uncertainty that would decrease the value of the white space and probably decrease auction revenues. Moreover, people have had more than half a century to apply for TV licenses and two decades to apply for LPTV licenses; thus there are not many good license opportunities still vacant. Consequently, shutting down TV licensing would have little impact on the availability of TV service to consumers. And, of course, those wishing to offer a new TV service could negotiate rights to do so from the white-space license holder.

D. Estimated Auction Value of the White Space

Under a licensed approach, the FCC could auction the exclusive, tradable rights to use of the white space just as it has auctioned other spectrum rights. Using calculations of the amount of white space, as summarized in Section III and Appendix A, we estimate the auction value of those rights. Under our most conservative licensed scenario, we find that the rights to the white space would generate an estimated $3.6 billion to $6 billion. Although policymakers should not focus excessively on the size of potential auction revenues, neither should they ignore them.

Starting Point for a Valuation of the White Space

Demand: Demand for licensed spectrum that can support wireless service remains strong, as the FCC's recent AWS auction demonstrated. This trend is likely to continue. Spectrum and wireless base stations are substitutes: a capacity-limited wireless system can expand by using more spectrum at existing cell sites or by building additional cell sites; the former is considerably

less expensive than the latter, even at current spectrum prices. Thus, as long as they continue to attract subscribers and generate increased usage, such systems will demand additional spectrum.

Demand for the white space should be solid for the same reason. As we have discussed, that portion of the white space that is nationwide in scope could potentially support broadband PCS, including fixed and mobile voice and data. More generally, the white space could be used to provide wireless broadband service, both fixed and mobile. The UHF white space (500 MHz to 700 MHz) is particularly well suited for providing wireless services over relatively long distances, which would allow a network to be deployed using far fewer cell sites than would be required at higher frequencies.

Quantity: In Section III, we concluded that there will be a critical mass of white space in the TV core under any of our licensed scenarios. Recall the key statistics on our most conservative licensed scenario (Scenario Z):

- 95 percent of the U.S. population will be covered by at least 24 MHz of white space;
- Every market trading area (MTA) except one (San Francisco-Oakland-San Jose) will have at least two channels (12 MHz) of white space available everywhere in the MTA;
- More than 90 percent of basic trading areas (BTAs) will have at least two channels (12 MHz) that are entirely vacant (100 percent white space) everywhere in the BTA.

Caveat: It is more difficult, analytically, to estimate how the market would value the white space (price) than to estimate how much white space there is (quantity). Key variables that would affect price remain uncertain, including how the FCC would structure the licenses and the exact services that licensees would offer. Another unknown factor—the FCC's interference protection rules—could affect the unit price of white space as well as the quantity. Given these major sources of uncertainty, our goal is to provide only a "ballpark" estimate of the value of the white space, and in doing that, we try to avoid conveying any false sense of precision.

Market Comparable Approach

We use a market comparable (or market) approach to valuing the rights to the white space. This approach, which has its roots in real estate, uses the prices paid for equivalent licenses in the market as the basis for the valuation.[70]

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[70] The other valuation technique that economists frequently use is the income approach. This approach is based on the assumption that the value of a spectrum license is equal to the expected future benefits (income) to the license holder discounted at a rate that reflects the time value of money and the risk involved. The income and the market comparable approach should yield similar results because the prices paid for comparable licenses reflect the present value of the future income stream that ownership of the license being valued would provide.

Base Case: We use the 2.5 GHz BRS/EBS band as the market comparable under our "base case" estimate of the value of white space. The 2.5 GHz BRS/EBS band is a reasonable comparable for two reasons. First, the 2.5 GHz band is not systematically paired. Second, 2.5 GHz face impediments to operation as a result of the need to either accommodate or transition site-specific incumbent licensees.[71] These factors have contributed significantly to the fact that 2.5 GHz license values are below what they would otherwise be, given the prime location of the spectrum. In recent secondary transactions, 2.5 GHz licenses have sold for $0.15 to $0.20 per MHz-pop; that is only a third of what AWS licenses commanded, on average, in the recent FCC auction, and only about 10 percent of the price of PCS licenses.

We use the low end of the price range for 2.5 GHz EBS/BRS licenses ($0.15) as the basis for our "base case" Scenario Z estimate.

High-End Case: The 2.5 GHz band may be a conservative measure of the value of at least some of the white space—specifically, the 24 MHz of nationwide spectrum, which could be used to support a PCS operation. Thus, under our "high-end" case, we use the AWS spectrum as a comparable for the nationwide white space (for the rest of the white space, we continue to use the 2.5 GHz band).

The AWS spectrum sold for $0.54 per MHz-pop; we use $0.50 as the basis for valuing the 24 MHz of nationwide white space under our "high-end" version of Scenario Z.

Valuation Estimate

Table 5 shows our "base case" and "high-end" estimates for the value of the spectrum rights to the white space under Scenario Z.

Using the price of 2.5 GHz licenses ($0.15) as the basis for valuing all of the white space ("base case"), we estimate that exclusive, tradable rights to the white space could be worth as much as $3.7 billion.[72] That may seem like a "big" number, particularly given the relatively low per MHz-pop value we have assigned to the white space; the reason: the sheer quantity of white space is large, even under our most conservative licensed scenario.

Under our "high-end" version of Scenario Z, in which we use $0.50 to value the choicest part of the white space, we estimate that the total value could be as high as $6 billion.

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[71] Granted, other factors might lead one to adjust 2.5 GHz prices upward or downward as an estimate of the value of white space, but in our view, these factors balance out. For example, the 2.5 GHz band has large contiguous blocks of spectrum, which would be more attractive than the white space, with its patchwork quality in key metropolitan markets. But the propagation characteristics of the white space are far superior to those of the 2.5 band, which would allow for a significant savings in the capital expenditure for basic coverage.

[72] We also used our "base-case" assumption to calculate the value of the white space under the other scenarios. Those figures range from a high of $7.8 billion (Scenario X) to a low of $2.0 billion (Scenario U-2).

Table 5

Estimated Value of White Space -- Scenario Z

Metric	"Base Case" Estimate	"High End" Estimate [2]
Total MHz-Pops in TV White Space (Billions)	27.2	20.6
Total MHz-Pops in 24 MHz National License (Billions)	N/A	6.6
Total MHz-Pops (Billions)	27.2	27.2
Value of Spectrum at $0.15 per MHz-Pop ($ Billions) [1]	$3.7	$2.7
Value of Spectrum at $0.50 per MHz-Pop ($ Billions)	N/A	$3.3
Total Value ($ Billions)	$3.7	$6.0

[1] $0.15 represents the national average for 2.5 GHz BRS/EBS spectrum, which we use for our valuation of the white space. We use the relative BTA spectrum values from FCC Broadband PCS Auctions 5 and 11 to estimate the value corresponding to the $0.15 for each BTA and then aggregate nationwide. Because much of the white space is found in BTAs with below average relative license values (per the PCS auctions), the weighted average $/MHz-Pop for the white space overall is lower than $0.15 / MHz-Pop.
[2] Based on 1) license(s) for 24 MHz nationwide and 2) license(s) for the remainder white space. Only for the purpose of this calculation, we assume that the 24 MHz of nationwide spectrum would be licensed as different sets of four channels in each BTA. In cases where there were not four 100% vacant channels in a BTA, we selected the four channels that had the highest percentage of vacancy in terms of population.

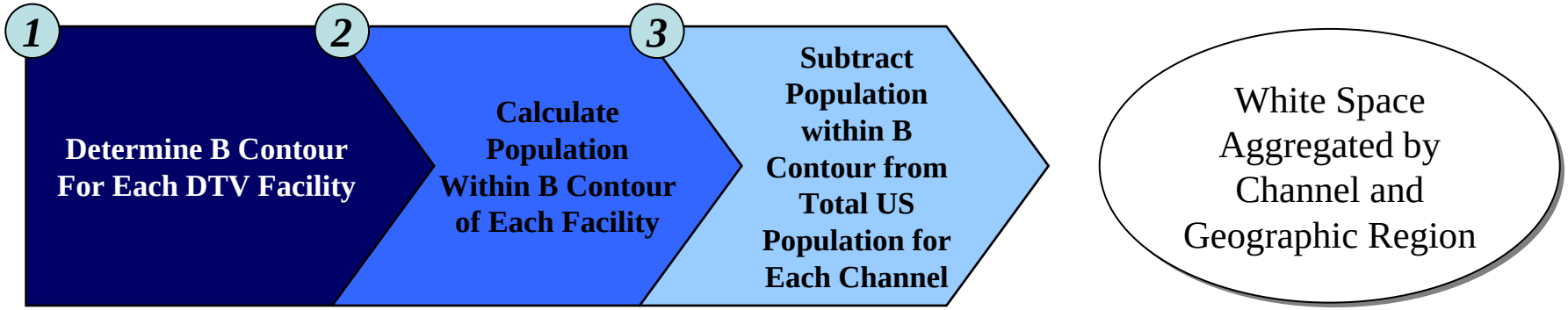
APPENDIX A

Calculation of White Space in the TV Core Following the DTV Transition

Appendix Contents

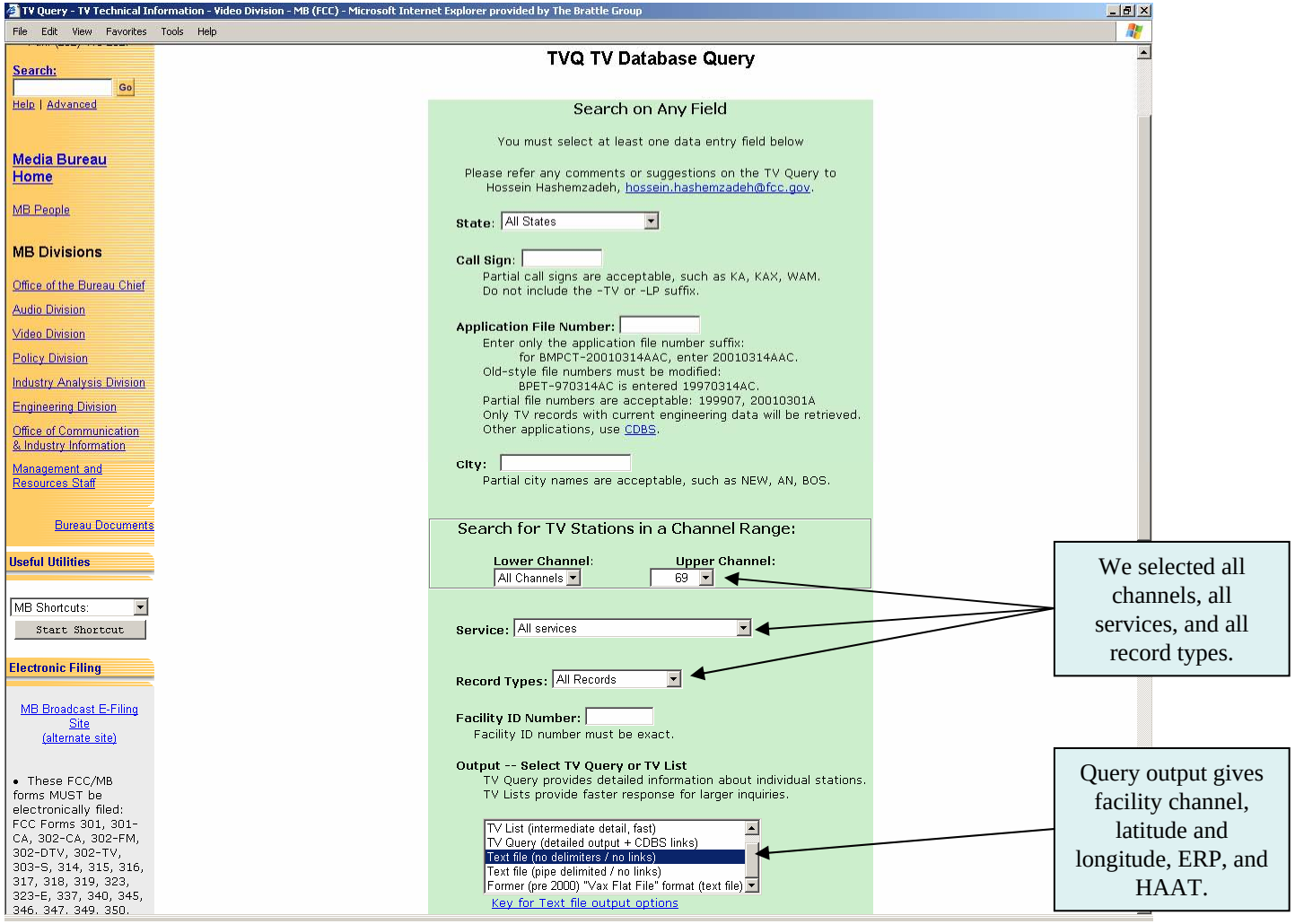
- Methodology
- Results
- General Observations

We were asked to calculate how much unused wireless spectrum ("white space") there will be in the TV core following the DTV transition. We took the approach outlined here.



We will discuss each of these steps in more detail in the following pages.

We downloaded TV facility data from the FCC's TV Query page (www.fcc.gov/fcc-bin/audio/tvq.html), which runs queries on the FCC Media Bureau's Consolidated Database System for TV, FM, and AM Stations or "CDBS".



We selected all channels, all services, and all record types.

Query output gives facility channel, latitude and longitude, ERP, and HAAT.

Source: FCC CDBS / TV Query, downloaded May 16, 2006

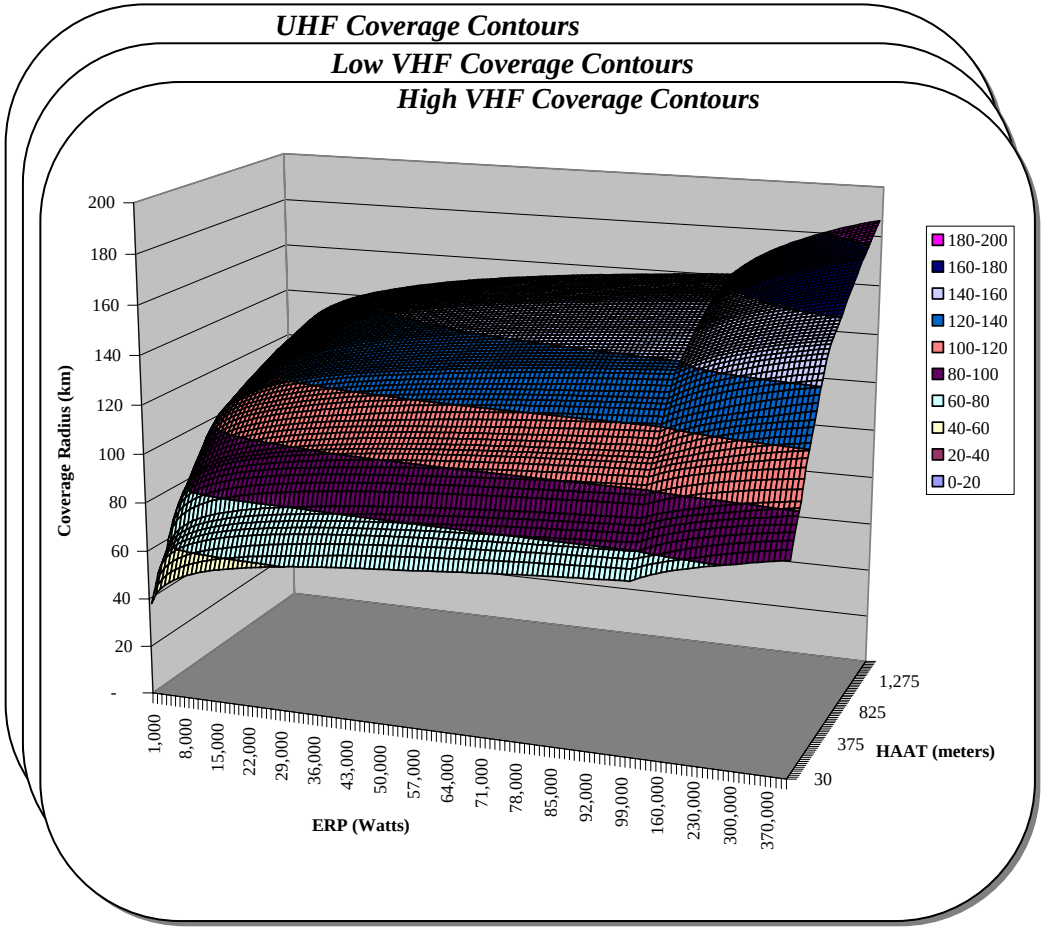
We incorporated more than 10,000 antennas into our analysis. This includes all of the 1,789 tentative digital channel designations for stations participating in the 1st and 2nd rounds of the DTV channel election process (per FCC, May 23, 2006).

Composition of Facilities Used in White Space Calculation

	Facility Treatment Category Characteristics			*Total Facilities by Country*			
Facility Treatment Categories	**Station Type**	**Channel Location**	**Records Included**	**U.S.**	**Canada**	**Mexico**	**Total**
Data Source Totals							
Total Records Considered from TV Query of CDBS				18,257	2,394	558	21,209
Total Unique Facility IDs				12,510	2,373	551	15,434
Included Unique Facility ID in White Space Calculation							
Digital TV Stations	DTV	Core	Lic. & Apps	1,618	840	148	2,606
Digital Low Power TV Stations	DTV	Core	Lic. & Apps	632	-	-	632
DTV Channel Substitution Records	DTV	Core	Lic. & Apps	174	4	-	178
Digital Class A TV Stations	DTV	Core	Lic. & Apps	37	-	-	37
New DTV Allotment Records	DTV	Core	Lic. & Apps	32	-	-	32
DTV Channel Change Records	DTV	Core	Lic. & Apps	27	-	-	27
Digital Special Temporary Authority Records	DTV	Core	Lic. & Apps	1	-	-	1
Non-core DTV Stations (assuming NTSC channel)	NTSC	Non-Core	Lic. & Apps	130	-	-	130
Core NTSC Licensed Stations (assuming NTSC channel)	NTSC	Core	Lic.	89	435	28	552
Subtotal - DTV Stations				2,740	1,279	176	4,195
Class A TV	NTSC	Core	Lic. & Apps	515	-	-	515
TV Translators (included in some scenarios)	NTSC	Core	Lic. & Apps	7,315	124	24	7,463
Subtotal - Other Protected NTSC Facilities				7,830	124	24	7,978
Total Included Facilities in White Space Calculation				10,570	1,403	200	12,173
Excluded Unique Facility ID from White Space Calculation							
Non-core DTV Facilities with no core application	DTV	Non-Core	Lic. & Apps	18	205	45	268
NTSC Allotments and Boosters	NTSC	Both	Lic. & Apps	348	659	285	1,292
Land Mobile Records in CDBS (using 47 CFR 90.305(a) instead)	NTSC	Core	Lic. & Apps	24	-	-	24
Core NTSC Applications	NTSC	Core	Apps	247	54	7	308
Non-core NTSC Channels with No DTV Application	NTSC	Non-Core	Lic. & Apps	89	38	2	129
Non-core Translators with No DTV Application	NTSC	Non-Core	Lic. & Apps	1,214	14	12	1,240
Total Excluded Facilities from White Space Calculation				1,940	970	351	3,261

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

We calculated the average coverage radius for each facility using contours for Low VHF, High VHF, and UHF.



Other Radius and Power Assumptions

- For those NTSC facilities which we included in our analysis, we assumed they would operate at 25% of their current power (ERP) after transitioning to DTV.
- For Mexican and Canadian DTV facilities with no power (ERP) available in the CDBS, we assumed they would each operate at 300 kWs.
- For each NTSC TV Translator, we assumed a 10 mile radius.
- We use the distance specified in 47 CFR 90.305(a) for land mobile protection (*i.e.*, 128 km and 48 km for channel 16 in New York)
- We also block out a 100 mile radius around land mobile operations on Long Island in channel 19.

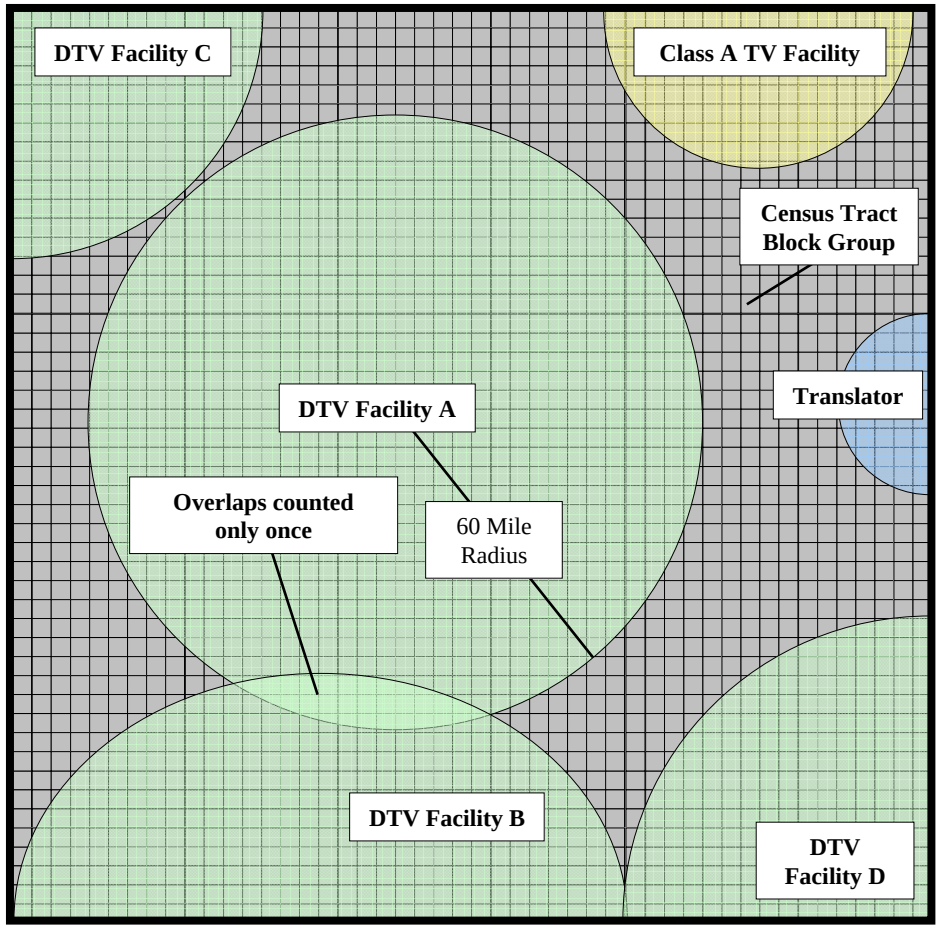
Source: Charles Jackson

We then calculated which Census tract block groups were within the coverage radius of each facility.

Population Coverage Methodology

- The US Census provides population data at the state, county, zip code, tract, and block group levels. The block group is the finest level of detail provided by the Census. There are more than 200,000 block groups each with an average population of about 1,300. The Census also provides a lat-long centroid for each block group.
- We developed a program to calculate the distance between each facility and each block group. If the distance is less than or equal to the coverage radius of that specific facility, we count the whole population within that block group as covered by that facility.
- We conduct this analysis on each channel separately. When we include adjacent channel protection, we treat each DTV facility as operating at three channels.

Illustrative DTV Facility & Census Tract Block Group Overlay for Specific Channel

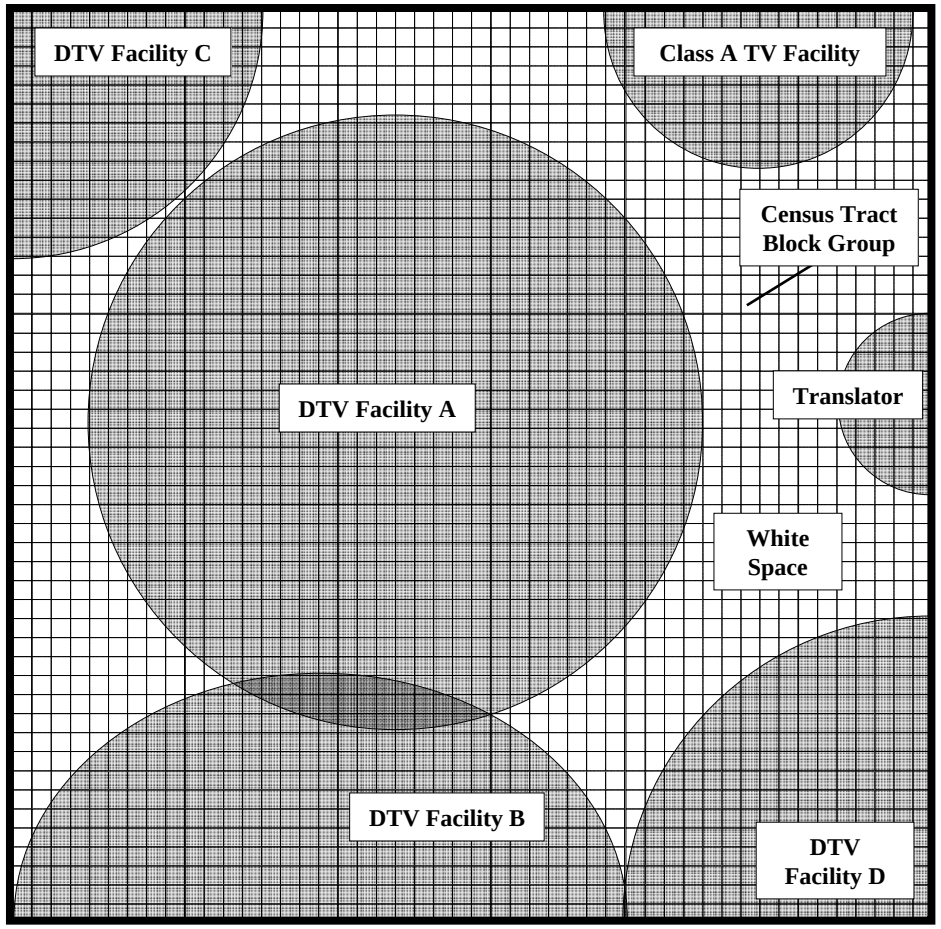


For each channel, we subtracted the population in the covered block groups from the total US population. The uncovered population represents the white space.

Population Subtraction Methodology

- For each channel, we consider any census tract block group not within the B contour of any DTV antenna as white space.
- For any geographic region, *e.g.*, an "MTA" (major trading area), the white space for any given channel is calculated as the total population in that MTA less the population within the B contour of any DTV antenna.
- We repeat this analysis for each channel.
- We aggregate our results by channel.

Illustrative TV Facility & Census Block Group Overlay for Specific Channel



In addition to presenting nationwide results, we show our results by individual MTA (major trading area).

MTA	2000 Census Population	Number of Block Groups	Average Population per Block Group
Alaska	626,932	533	1,176
Atlanta	8,731,699	5,135	1,700
Birmingham	3,555,114	2,697	1,318
Boston-Providence	10,009,759	7,996	1,252
Buffalo-Rochester	2,792,296	2,454	1,138
Charlotte-Greensboro-Greenville-Raleigh	11,613,265	7,801	1,489
Chicago	13,220,193	10,201	1,296
Cincinnati-Dayton	4,888,525	3,993	1,224
Cleveland	5,084,468	4,238	1,200
Columbus	2,392,826	1,933	1,238
Dallas-Fort Worth	11,688,918	8,892	1,315
Denver	4,907,635	3,801	1,291
Des Moines-Quad Cities	3,157,069	2,834	1,114
Detroit	10,658,459	9,076	1,174
El Paso-Albuquerque	2,533,752	1,851	1,369
Honolulu	1,211,537	646	1,875
Houston	6,307,777	3,977	1,586
Indianapolis	3,333,121	2,657	1,254
Jacksonville	2,740,381	1,737	1,578
Kansas City	3,202,863	2,716	1,179
Knoxville	1,944,407	1,427	1,363
Little Rock	2,385,905	1,850	1,290
Los Angeles-San Diego	22,223,875	14,178	1,567
Louisville-Lexington-Evansville	3,905,399	3,092	1,263
Memphis-Jackson	3,761,294	2,968	1,267
Miami-Fort Lauderdale	6,436,114	3,629	1,774
Milwaukee	4,941,046	4,053	1,219
Minneapolis-St. Paul	6,621,619	5,676	1,167
Nashville	2,165,007	1,393	1,554
New Orleans-Baton Rouge	5,399,308	3,938	1,371
New York	28,198,690	22,114	1,275
Oklahoma City	2,029,571	1,780	1,140
Omaha	1,794,352	1,685	1,065
Philadelphia	9,510,948	7,602	1,251
Phoenix	4,906,177	3,415	1,437
Pittsburgh	4,048,998	3,532	1,146
Portland	3,738,321	2,691	1,389
Puerto Rico-U.S. Virgin Islands	3,808,610	2,477	1,538
Richmond-Norfolk	4,238,094	3,017	1,405
Salt Lake City	3,319,967	2,266	1,465
San Antonio	3,716,676	2,474	1,502
San Francisco-Oakland-San Jose	13,782,432	9,279	1,485
Seattle	4,604,715	3,777	1,219
Spokane-Billings	2,178,445	1,976	1,102
St. Louis	5,018,297	4,097	1,225
Tampa-St. Petersburg-Orlando	6,660,705	3,772	1,766
Tulsa	1,224,694	963	1,272
Washington-Baltimore	8,799,742	5,904	1,490
Wichita	1,206,230	1,070	1,127

Source: 2000 US Census

Note: MTAs are geographic regions defined by Rand McNally and adopted by the FCC for wireless spectrum license areas. There are 51 MTAs in the US. We exclude 2 MTAs (Guam & N. Mariana Islands and American Samoa) from our analysis.

Alternative Presentation Methodologies

- Given that our results are at the block group level, we can present the amount of white space in a number of ways:
  - For the US as a whole
  - By county and state
  - By discrete area (*e.g.*, city or zip code)
  - By metropolitan area (*e.g.*, MSA and PMSA)
  - By typical FCC geographic license area (*e.g.*, BTA, CMA, MEA, EA, etc.)
  - By television market (*i.e.*, Nielsen DMA)

Appendix Contents

- Methodology
- Results
- General Observations

Below, we present the results of five different scenarios, corresponding to different assumptions as to FCC rules on interference.

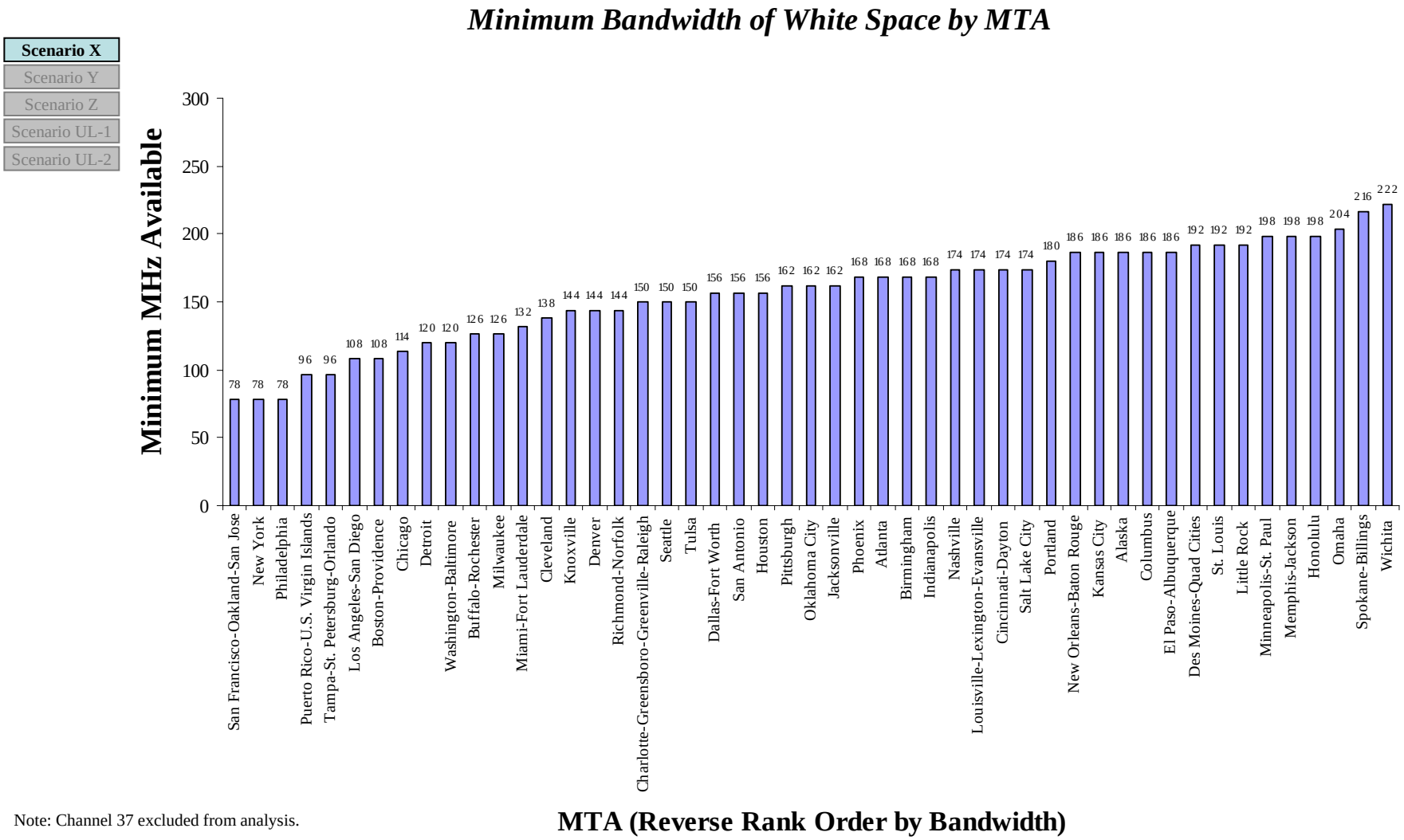
Measures of White Space under Alternative Interference-Protection Scenarios

	Included Facilities	Co-Channel Protection	Adjacent-Channel Protection	*Total MHz-Pops in White Space (Millions)*			*Percent of MHz-Pops in White Space*			*White Space Bandwidth Covering 100% of Total Population*			*White Space Bandwidth Covering 95%+ of Total Population*			*Average White Space Bandwidth Available Nationwide*		
				2-51	5-51	14-51	2-51	5-51	14-51	2-51	5-51	14-51	2-51	5-51	14-51	2-51	5-51	14-51
Scenario X	All US, Canadian, and Mexican regular and Class A stations and land systems in the UHF TV spectrum.	FCC Radius	None	53,678	49,232	37,829	64%	63%	60%	78	60	36	108	90	60	188	173	133
Scenario Y	All US, Canadian, and Mexican regular and Class A stations and land systems in the UHF TV spectrum.	FCC Radius	FCC Radius	28,266	24,532	17,379	34%	31%	27%	0	0	0	24	12	6	99	86	61
Scenario Z	All US, Canadian, and Mexican regular and Class A stations, land systems in the UHF TV spectrum, and all TV translators.	FCC Radius	FCC Radius	27,156	23,523	16,547	32%	30%	26%	0	0	0	24	12	6	95	82	58
Scenario UL-1	All US, Canadian, and Mexican regular and Class A stations and land systems in the UHF TV spectrum.	FCC Radius plus 46, 30, and 17 miles for low VHF, high VHF, and UHF	FCC Radius plus 5 miles	21,028	18,093	12,752	25%	23%	20%	0	0	0	12	6	0	74	63	45
Scenario UL-2	All US, Canadian, and Mexican regular and Class A stations and land systems in the UHF TV spectrum. Channels 2-4 and 14-20 excluded.	FCC Radius plus 46, 30, and 17 miles for low VHF, high VHF, and UHF	FCC Radius plus 5 miles	15,160	15,160	9,820	18%	19%	16%	0	0	0	0	0	0	53	53	34

Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

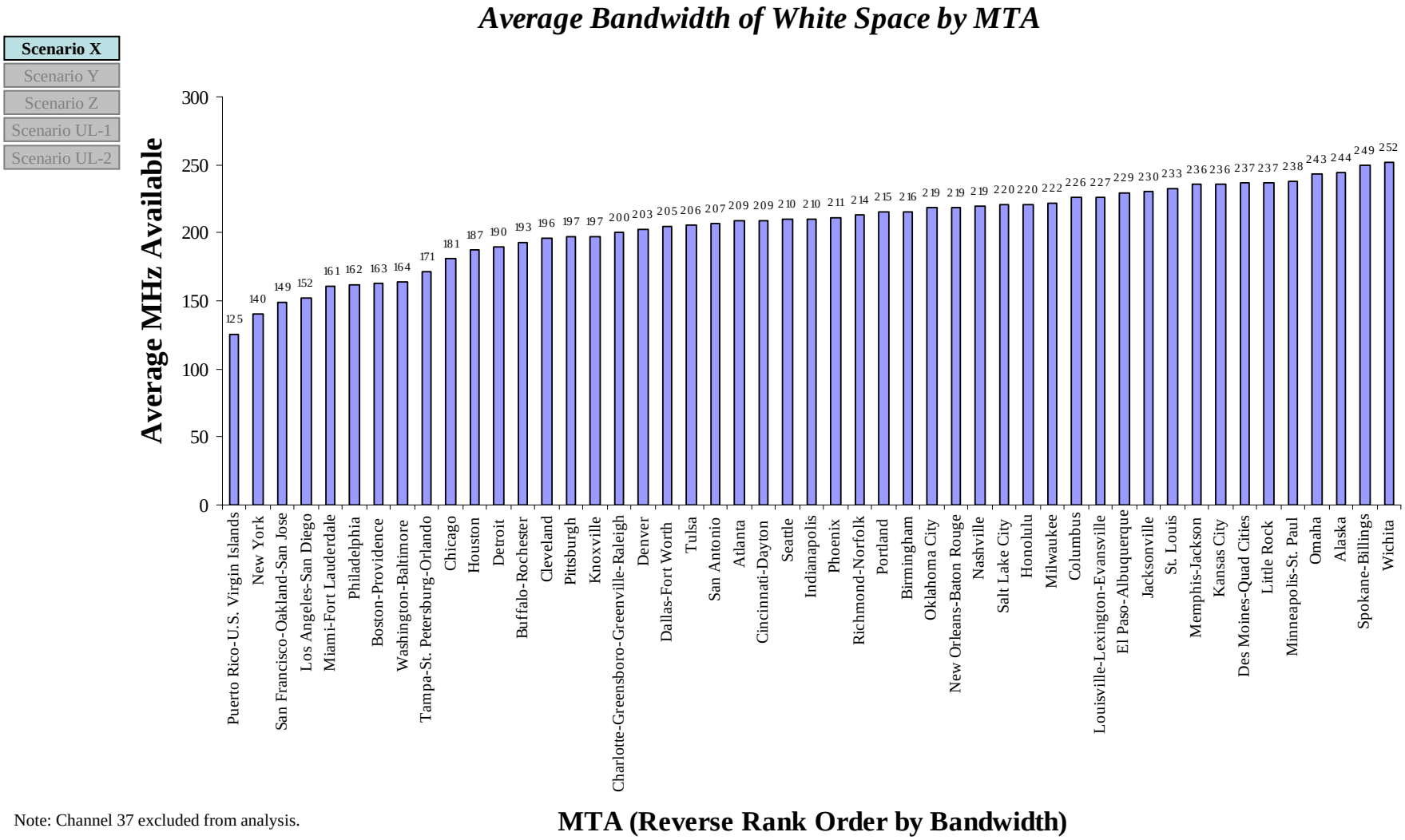
For Scenario X, we estimate there will be at least 78 MHz of white space nationwide.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

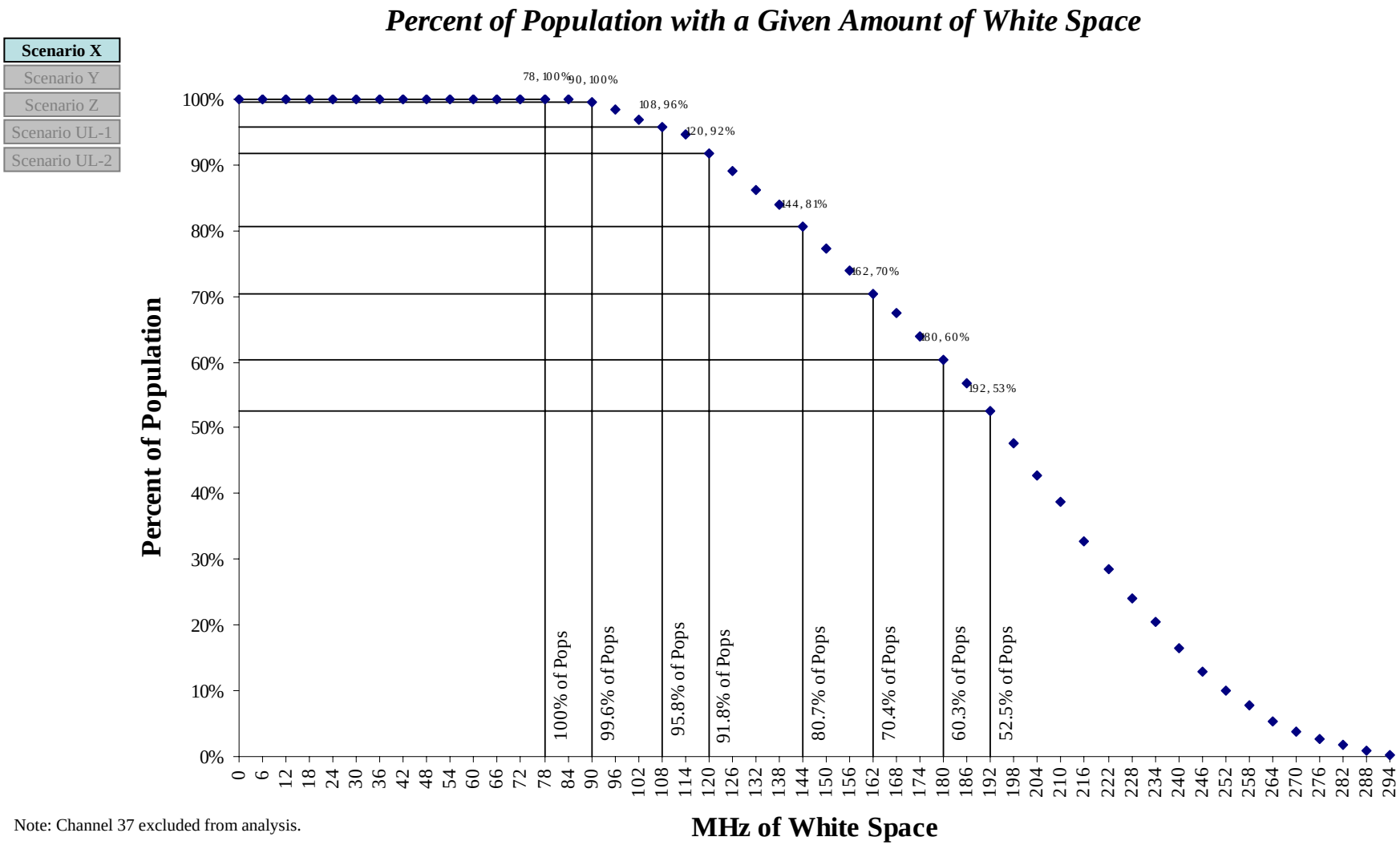
We estimate there will be an average of 188 MHz of white space, with about 150 MHz in the most concentrated MTAs.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

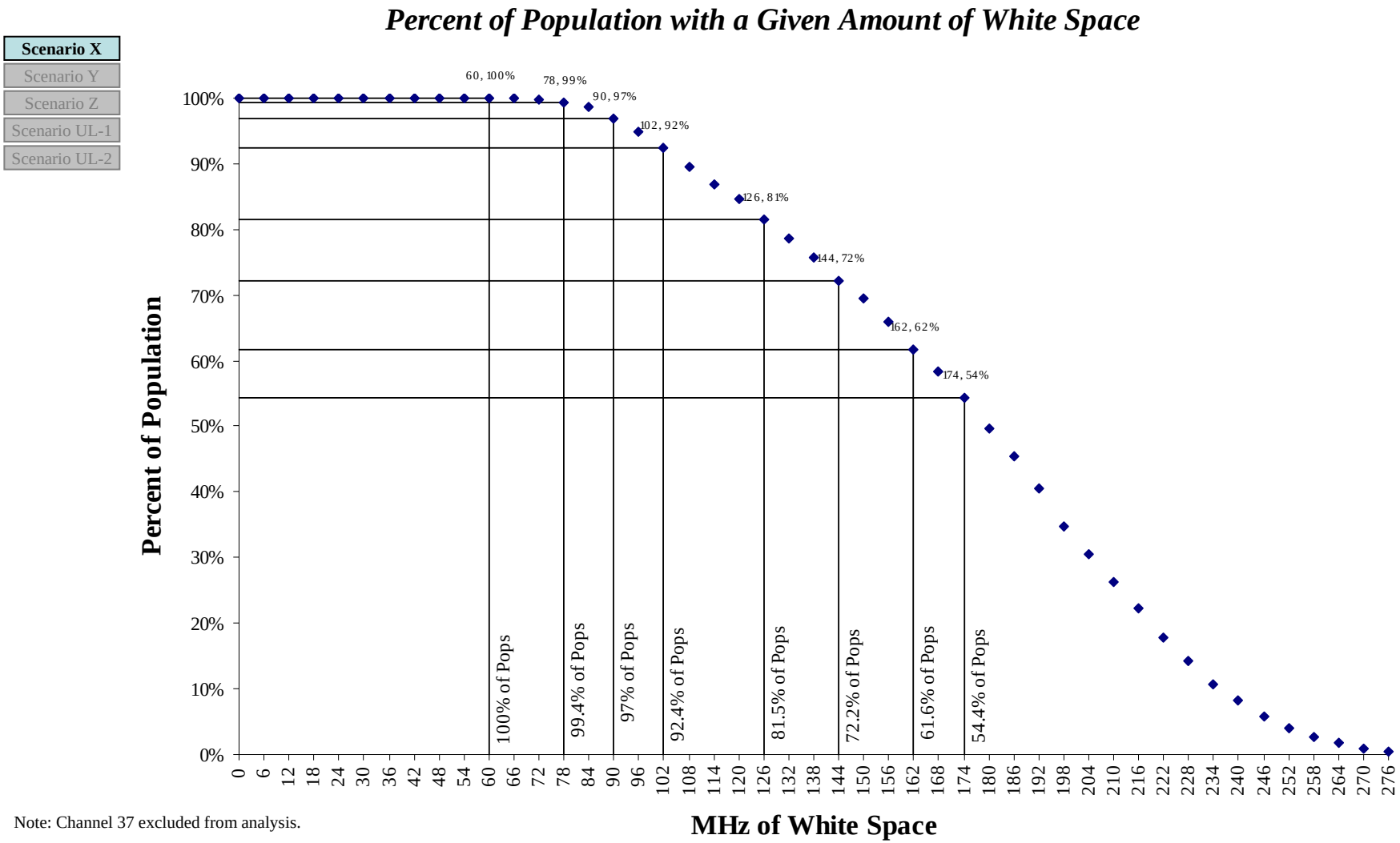
For channels 2-51, we estimate that 108 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

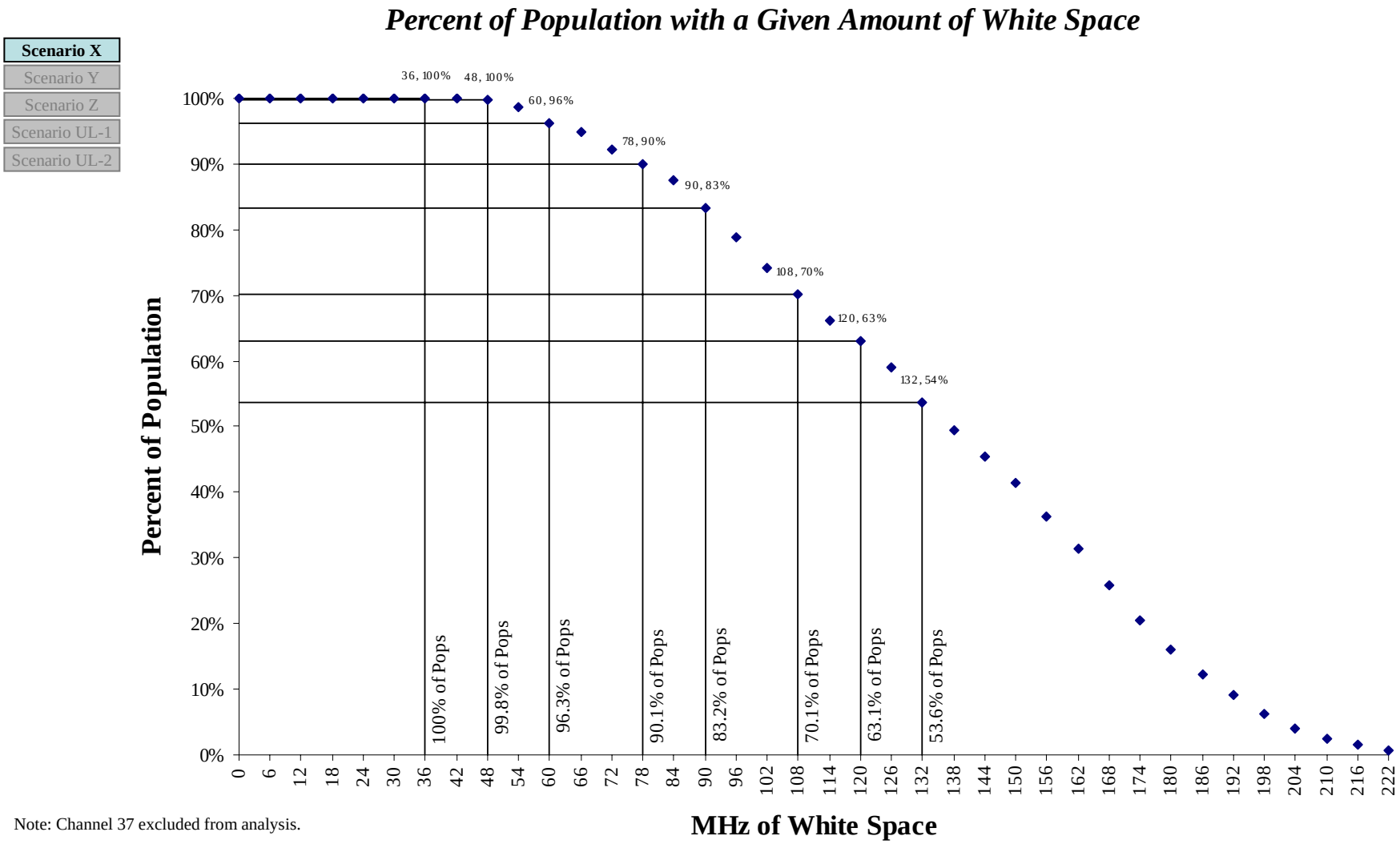
For channels 5-51, we estimate that 90 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

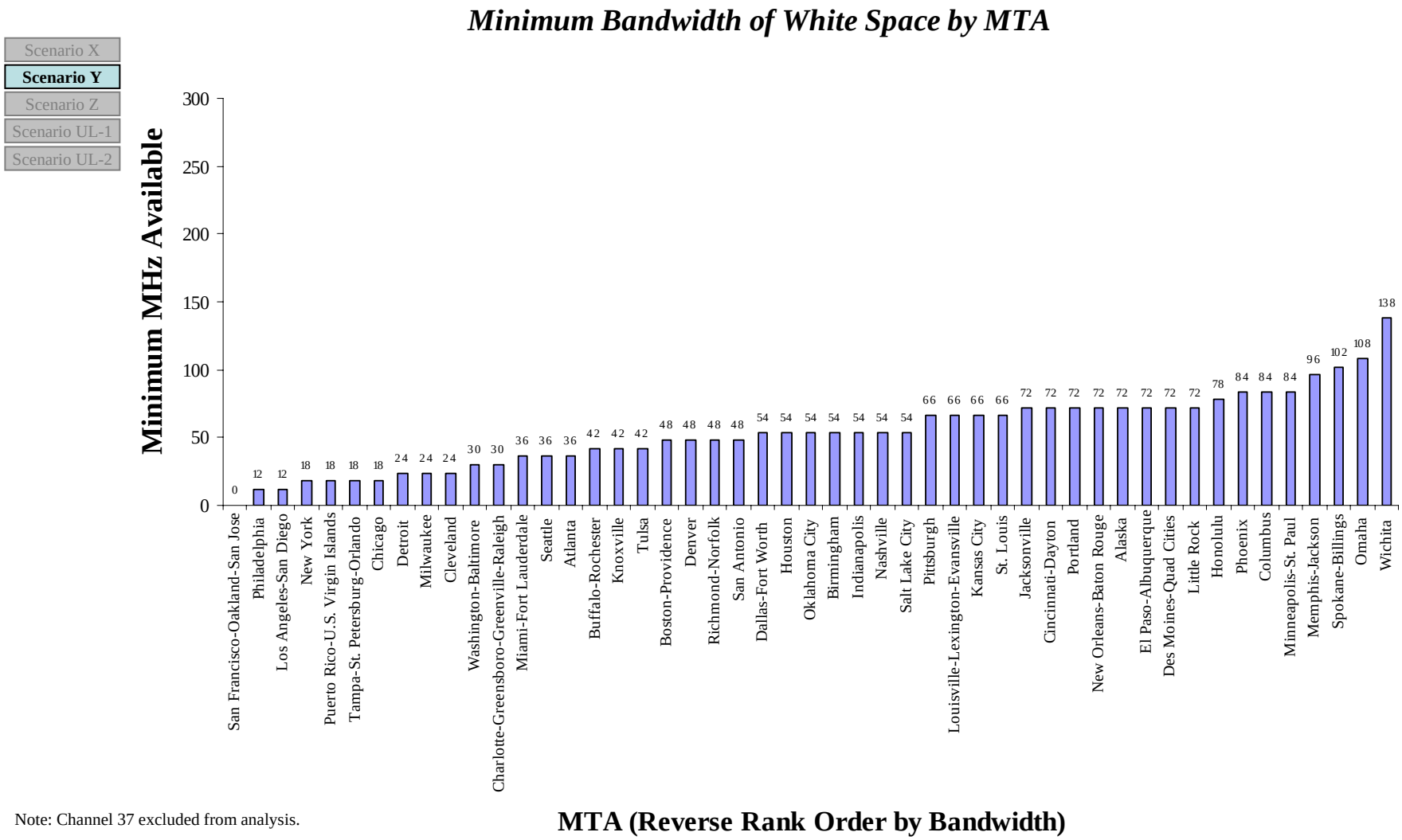
For channels 14-51, we estimate that 60 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

For Scenario Y, we estimate there will be at least 12 MHz of white space available everywhere except in portions of the San Francisco MTA.

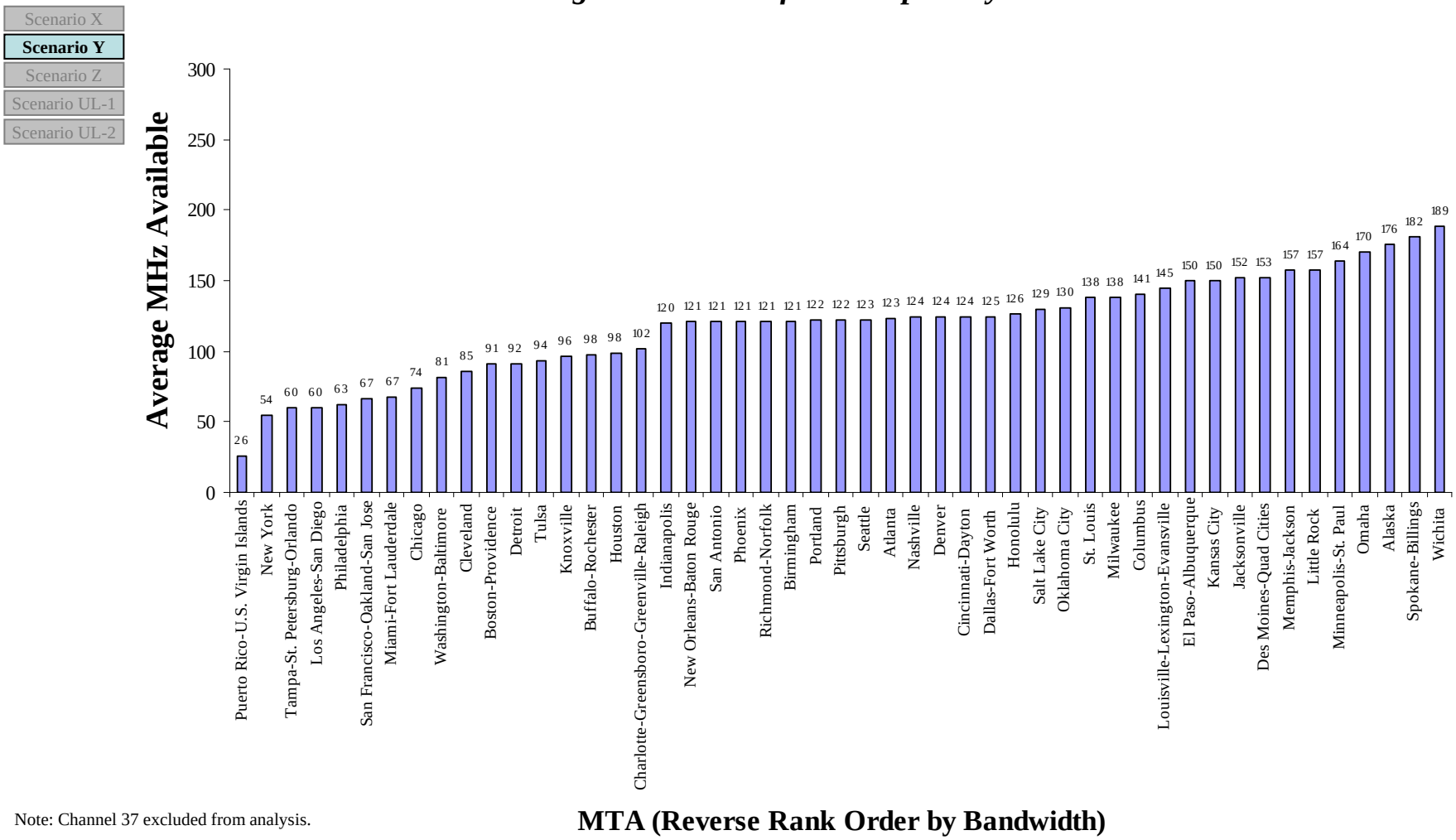


Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

We estimate there will be an average of 99 MHz of white space, with about 50-60 MHz in the most concentrated MTAs.

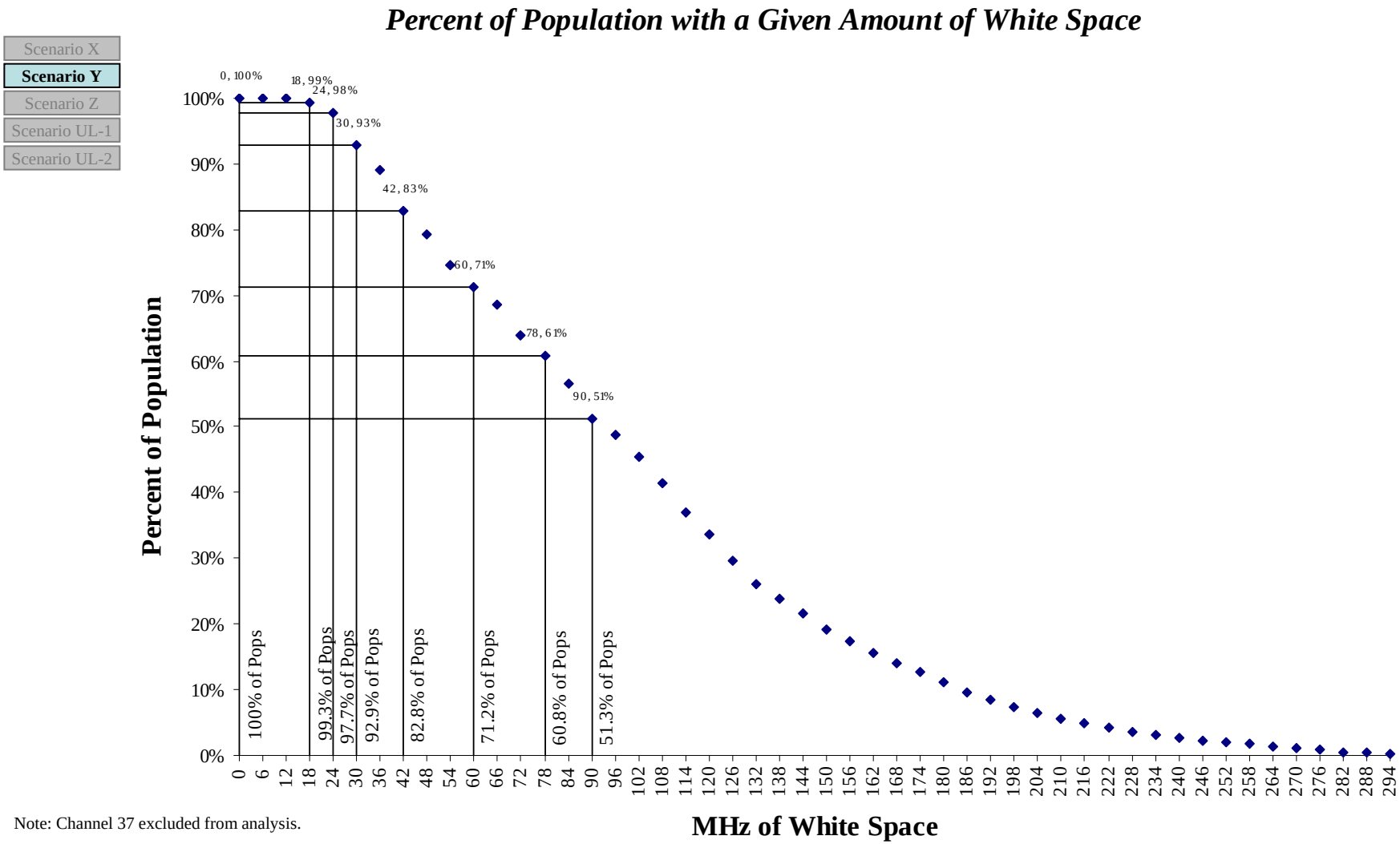
Average Bandwidth of White Space by MTA



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

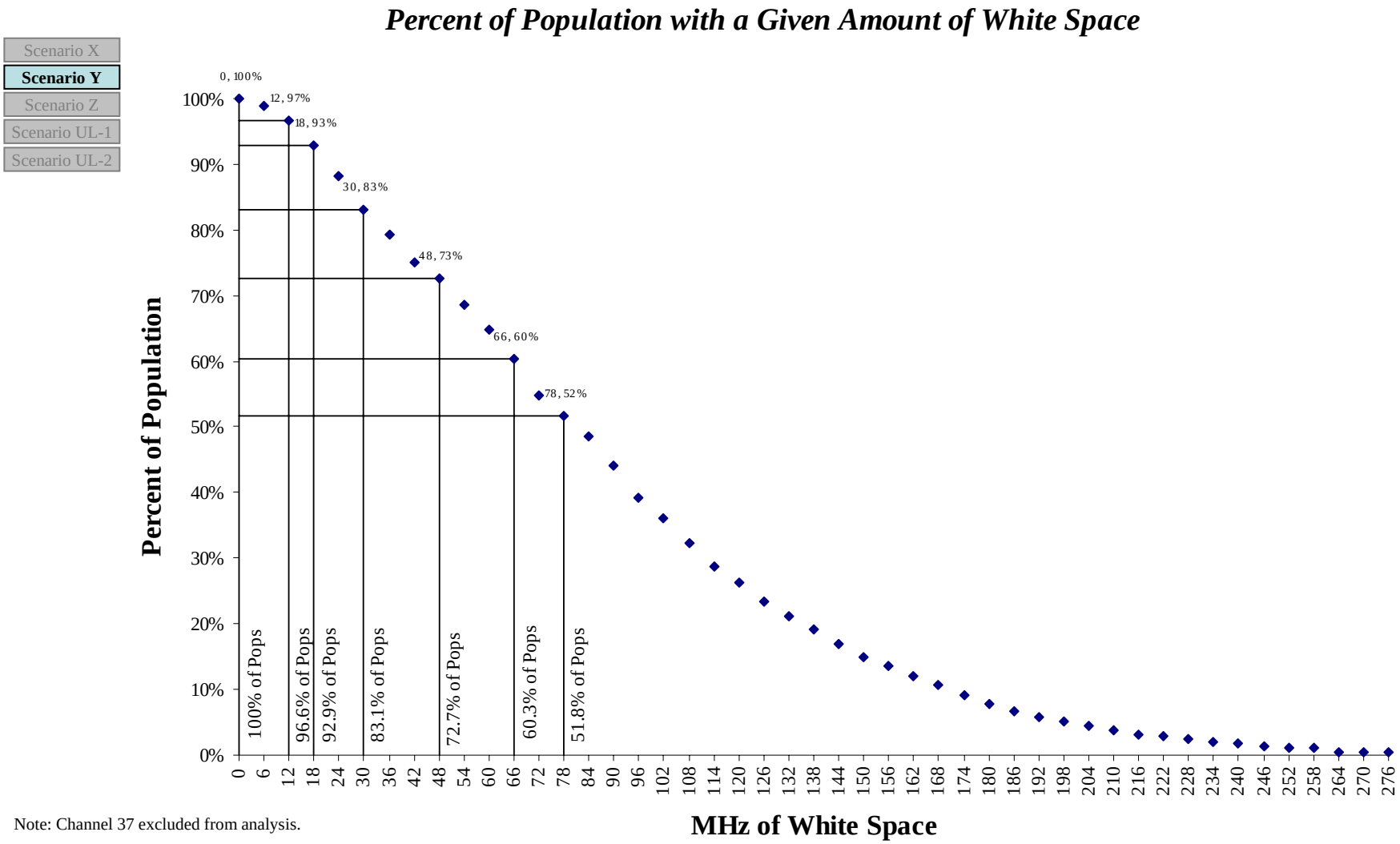
For channels 2-51, we estimate that 24 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

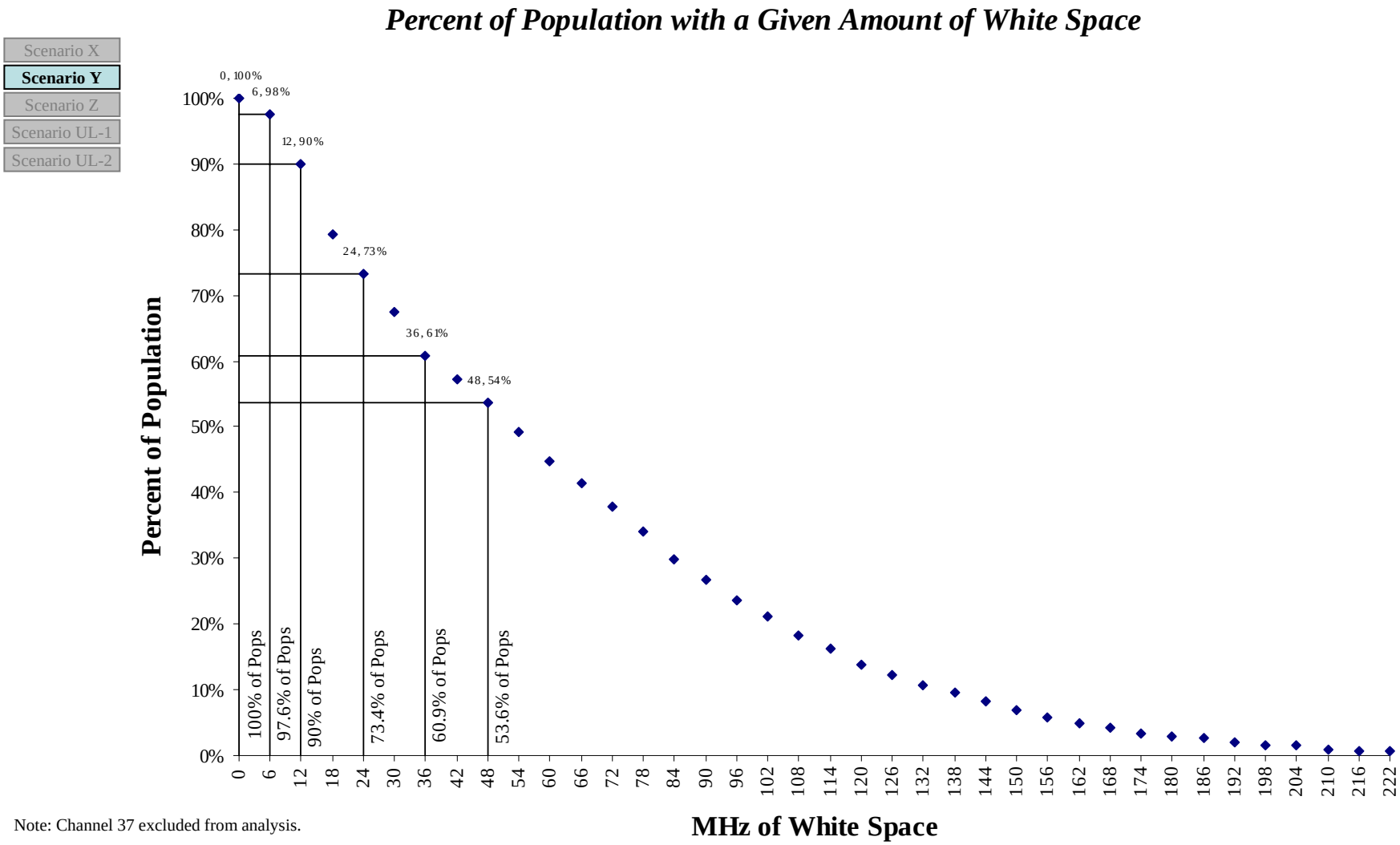
For channels 5-51, we estimate that 12 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

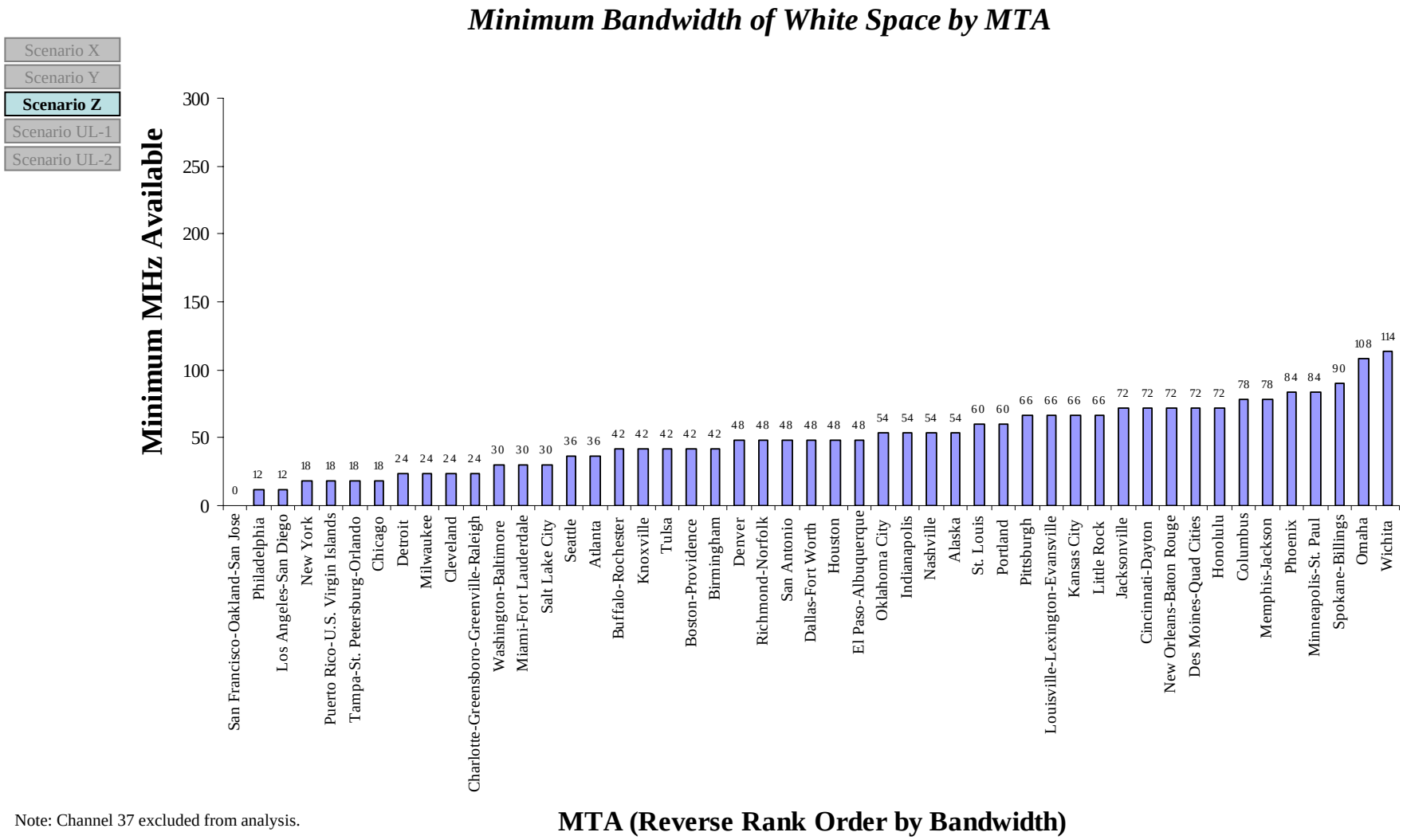
For channels 14-51, we estimate that 6 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

For Scenario Z, we estimate there will be at least 12 MHz of white space available everywhere except in portions of the San Francisco MTA.



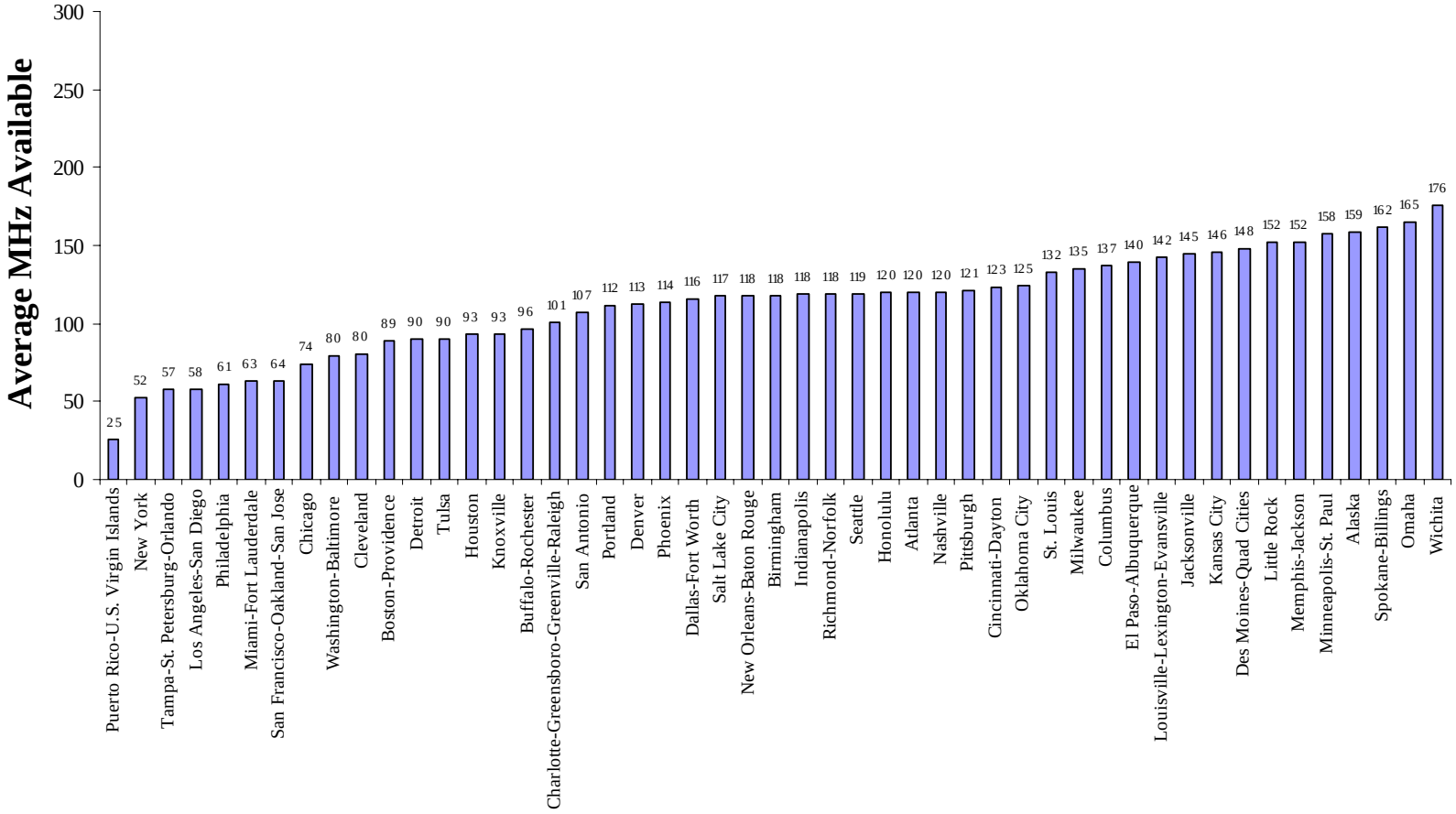
Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

We estimate there will be an average of 95 MHz of white space, with about 50-60 MHz in the most concentrated MTAs.

Scenario X
Scenario Y
Scenario Z
Scenario UL-1
Scenario UL-2

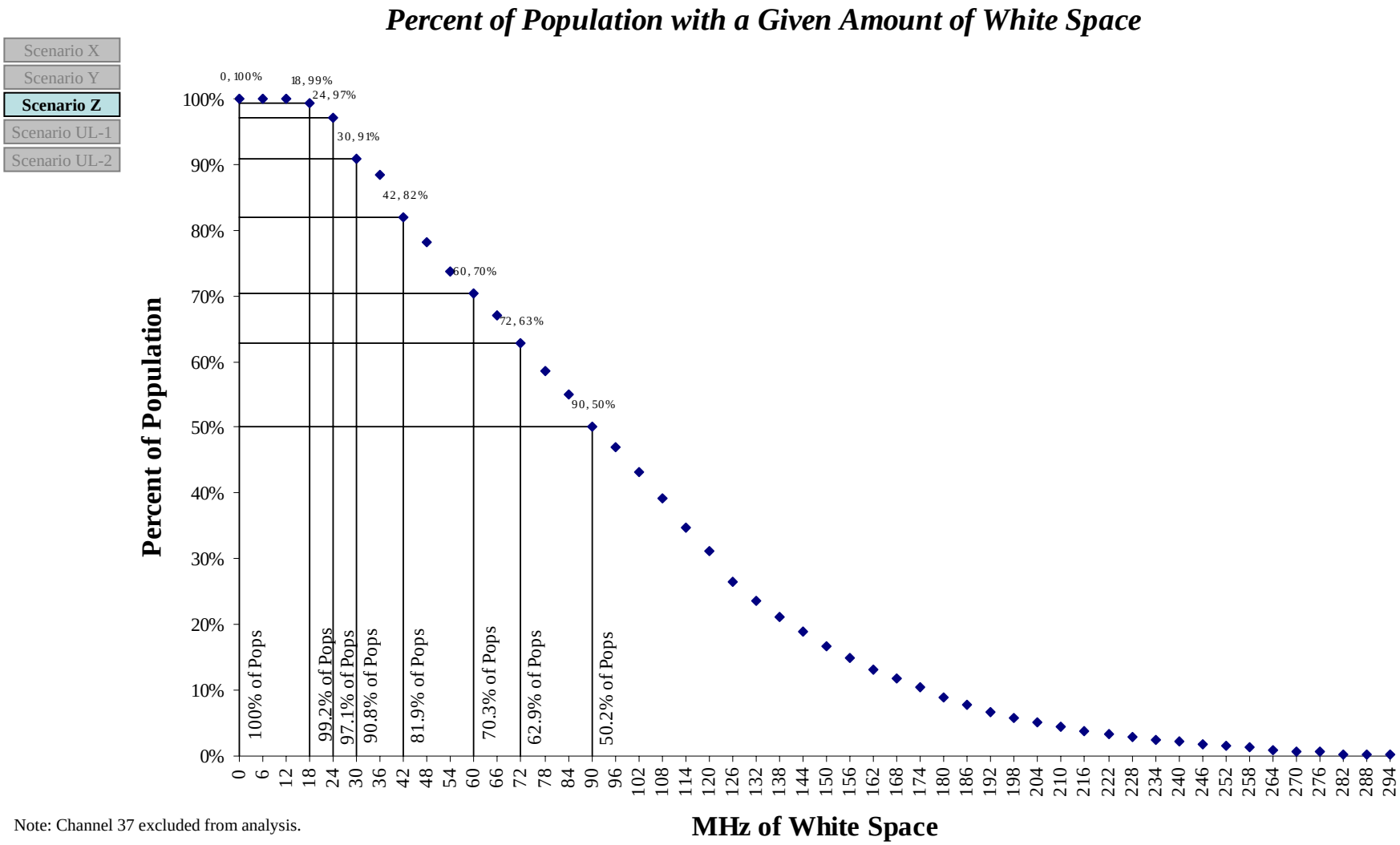
Average Bandwidth of White Space by MTA



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

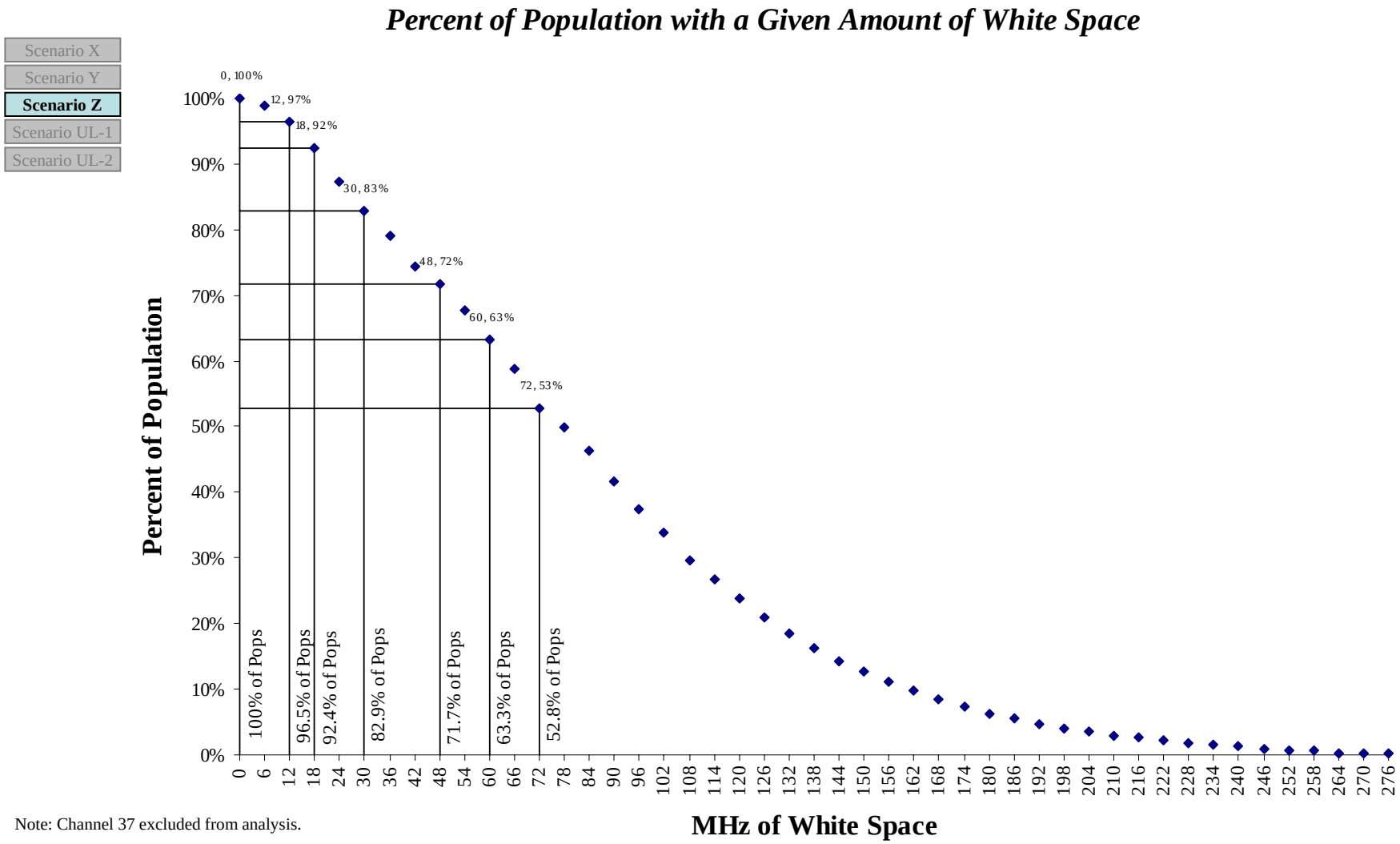
For channels 2-51, we estimate that 24 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

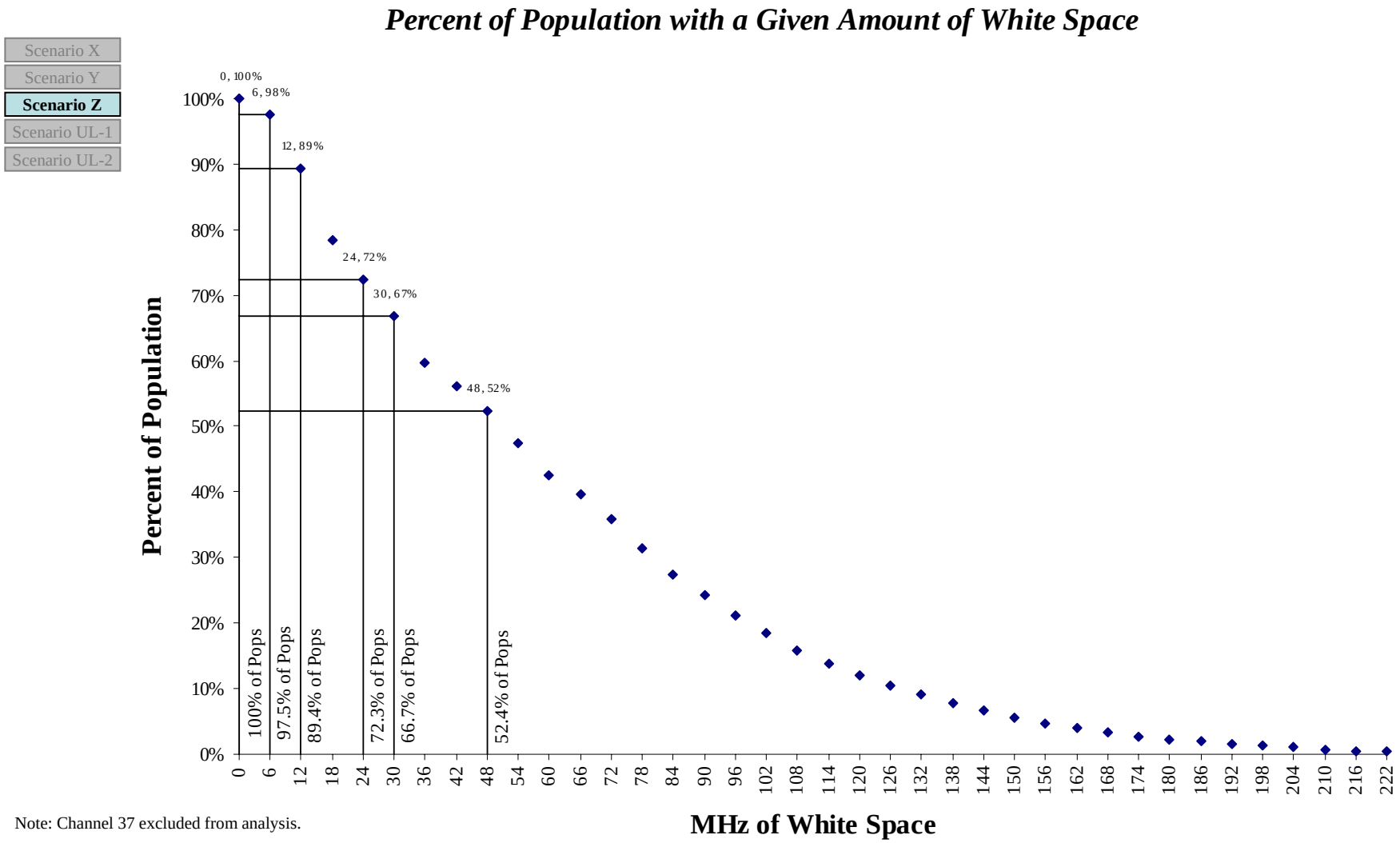
For channels 5-51, we estimate that 12 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

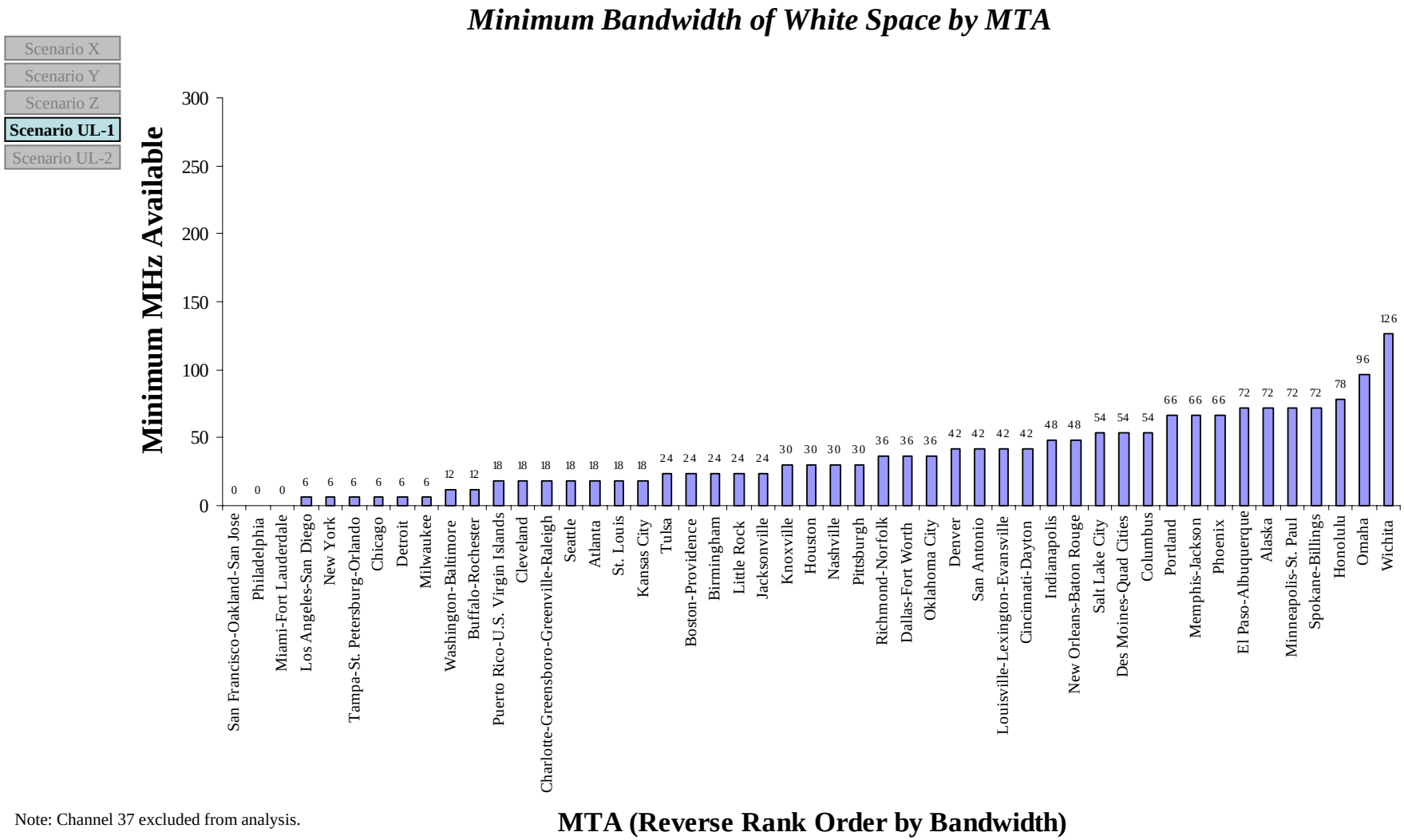
For channels 14-51, we estimate that 6 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

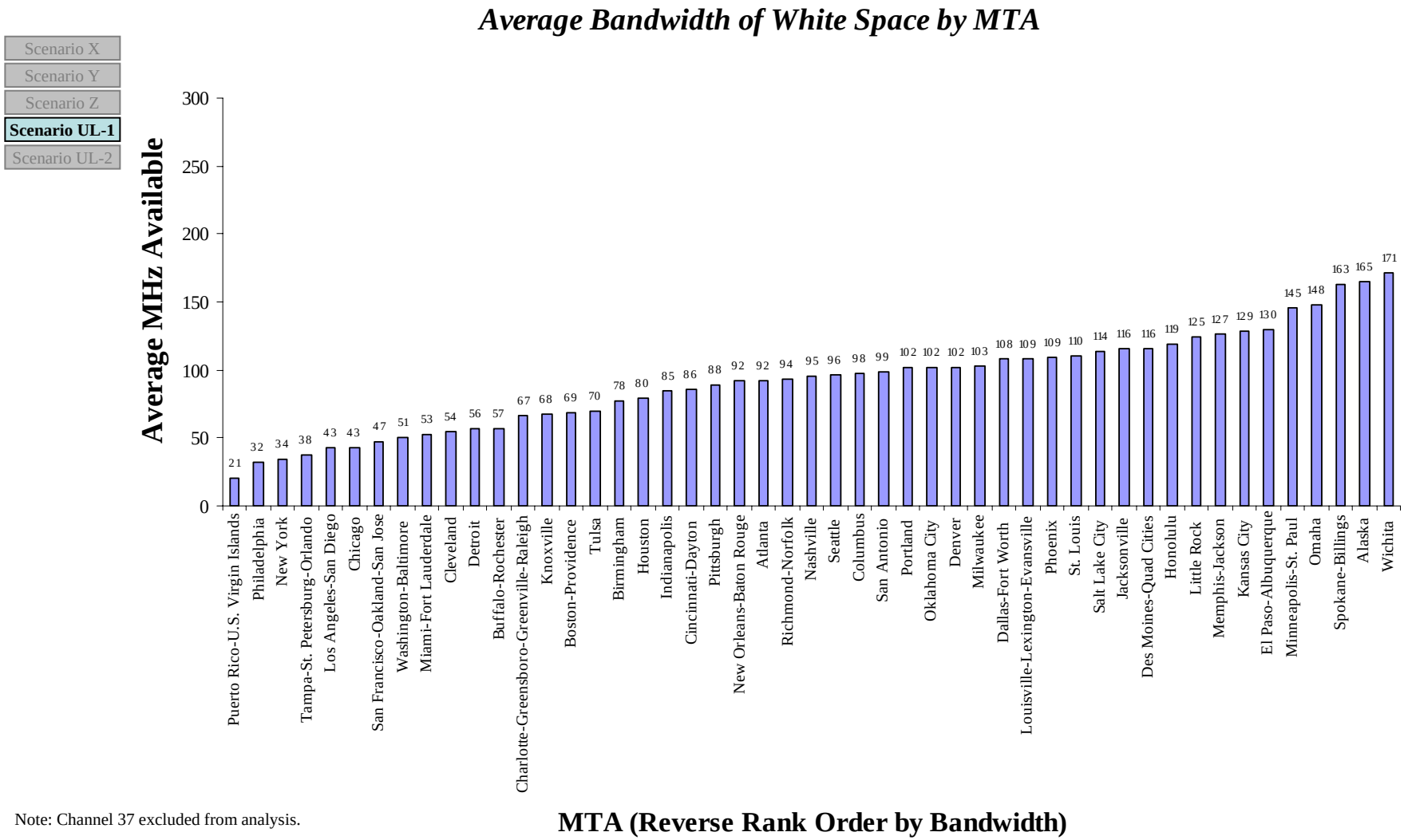
For Scenario UL-1, we estimate there will be at least 6 MHz of white space available everywhere except in portions of three MTAs.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

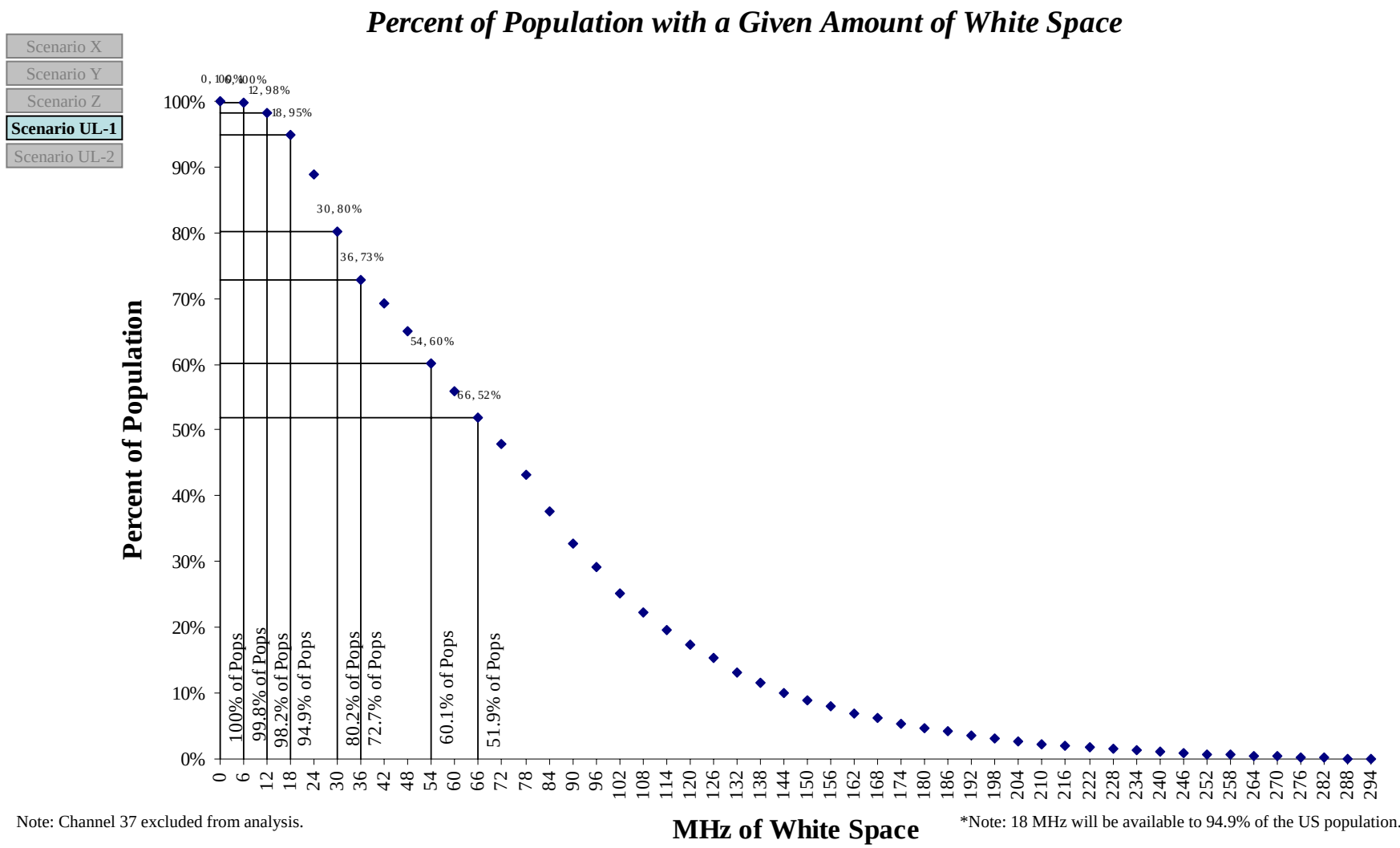
We estimate there will be an average of 74 MHz of white space, with about 30-40 MHz in the most concentrated MTAs.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

For channels 2-51, we estimate that 12 MHz of white space will be available to 95%* of the US population.

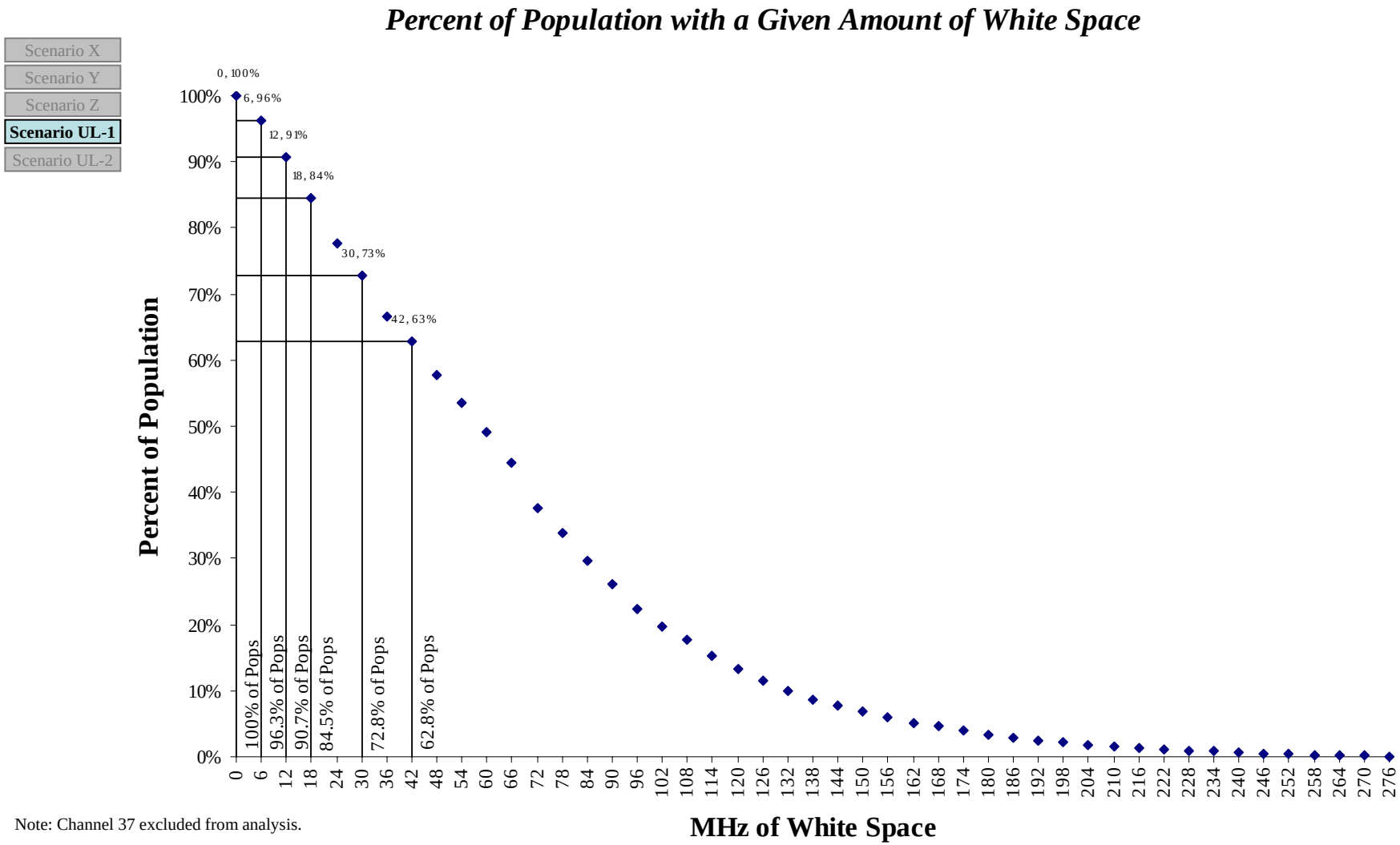


Note: Channel 37 excluded from analysis.

*Note: 18 MHz will be available to 94.9% of the US population.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

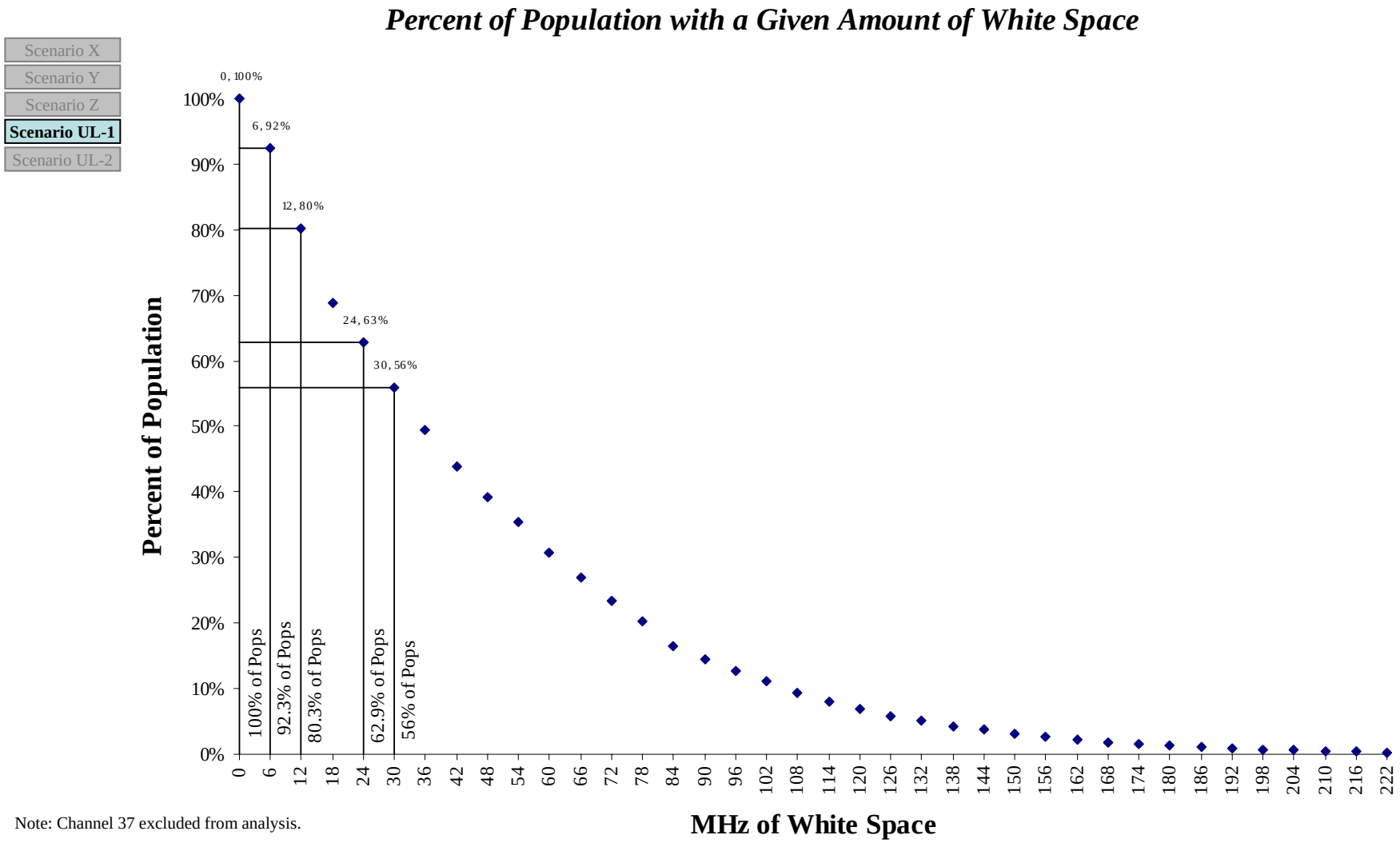
For channels 5-51, we estimate that 6 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

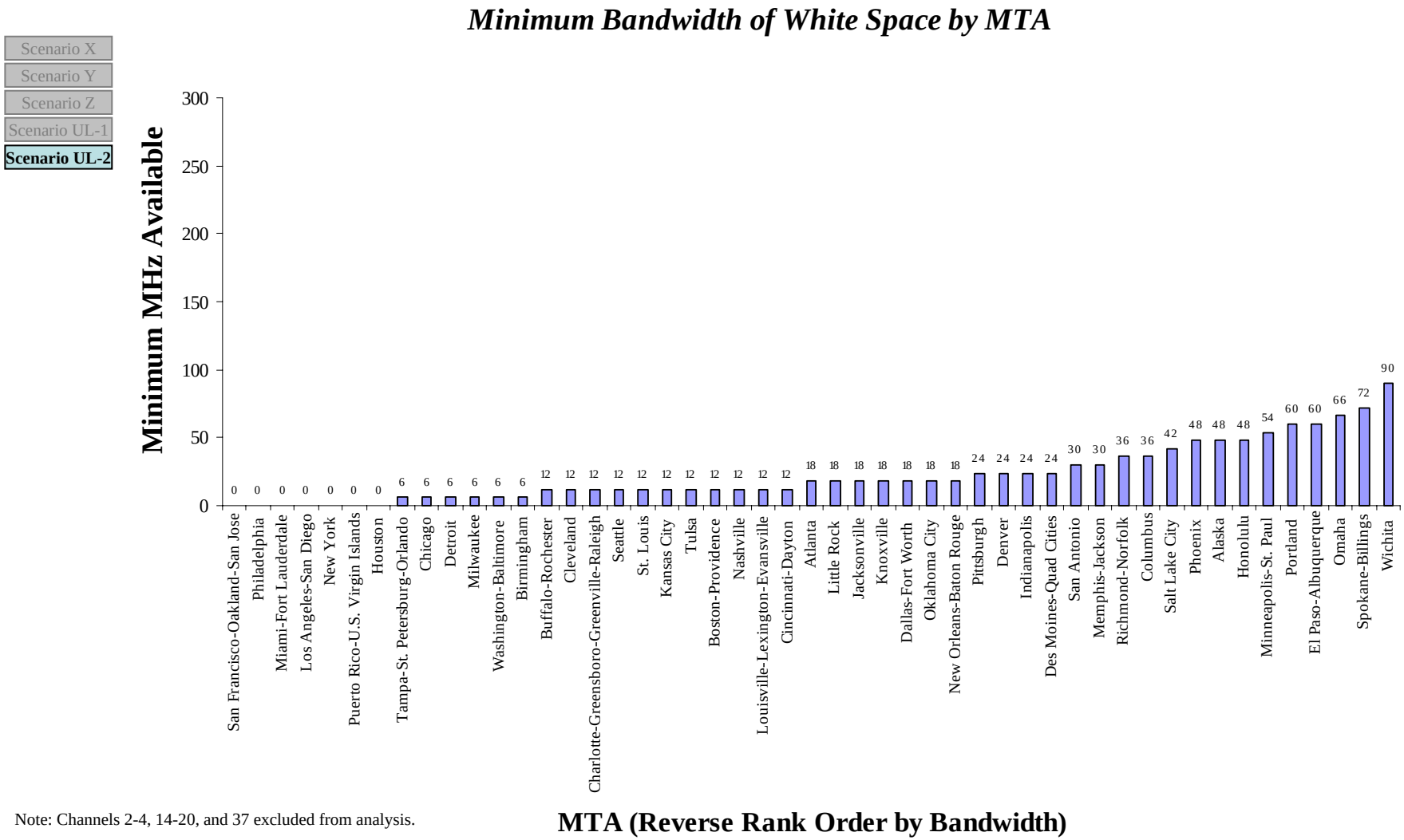
For channels 14-51, we estimate that 0 MHz of white space will be available to 95% of the US population.



Note: Channel 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

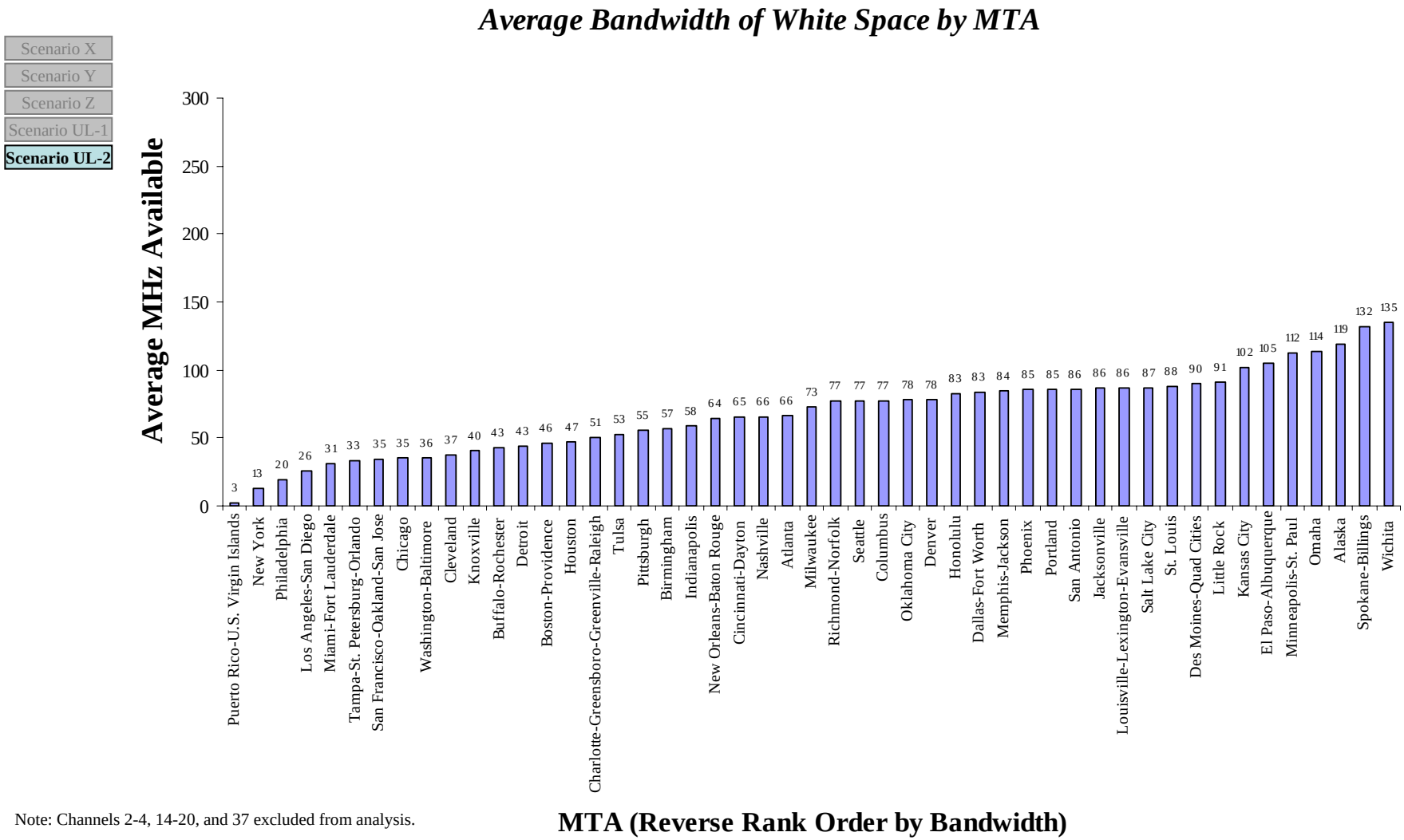
For Scenario UL-2, we estimate there will be at least 6 MHz of white space available everywhere except in portions of seven MTAs.



Note: Channels 2-4, 14-20, and 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

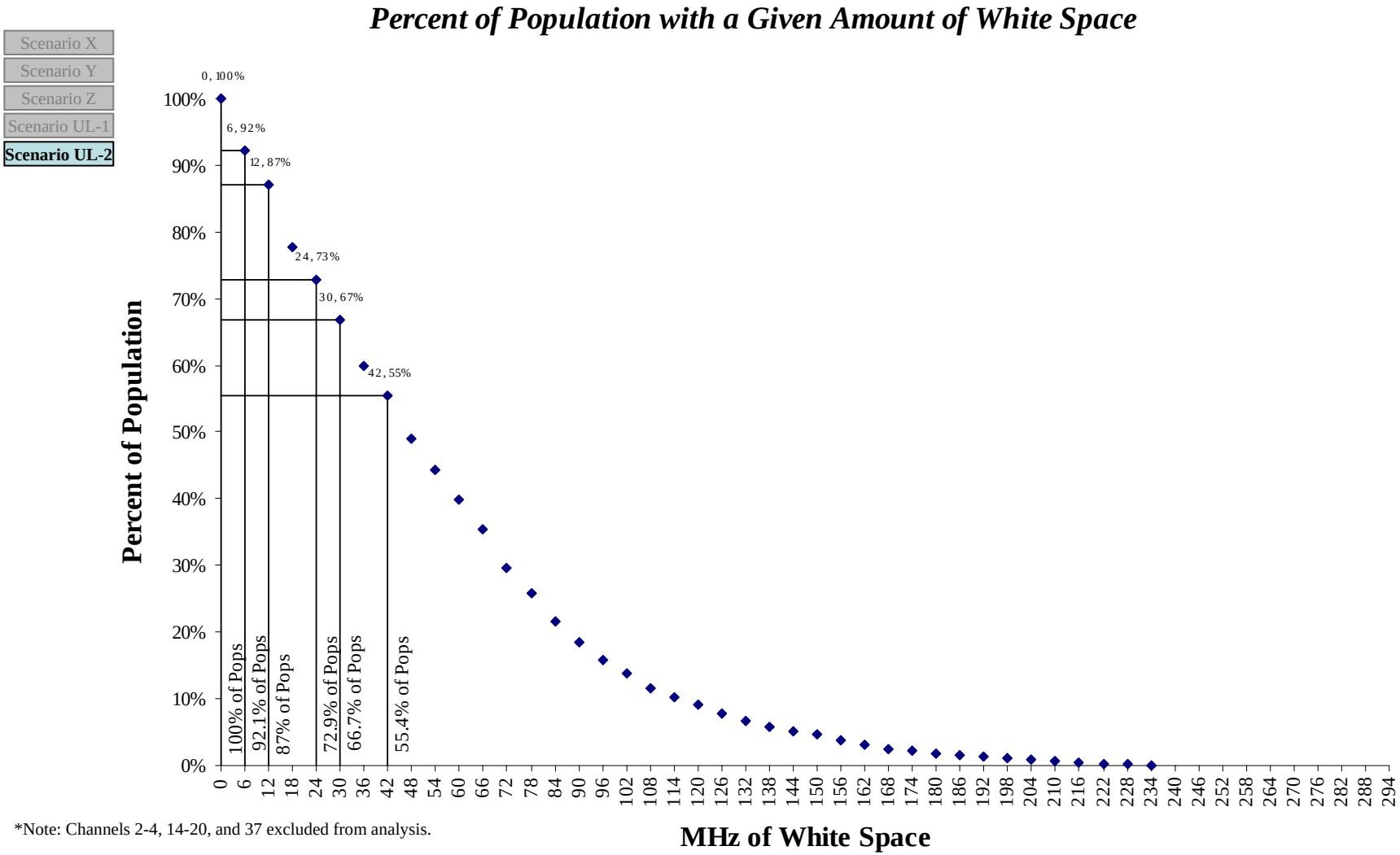
We estimate there will be an average of 53 MHz of white space, with about 20-30 MHz in the most concentrated MTAs.



Note: Channels 2-4, 14-20, and 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

For channels 2-51*, we estimate that 0 MHz of white space will be available to 95% of the US population.

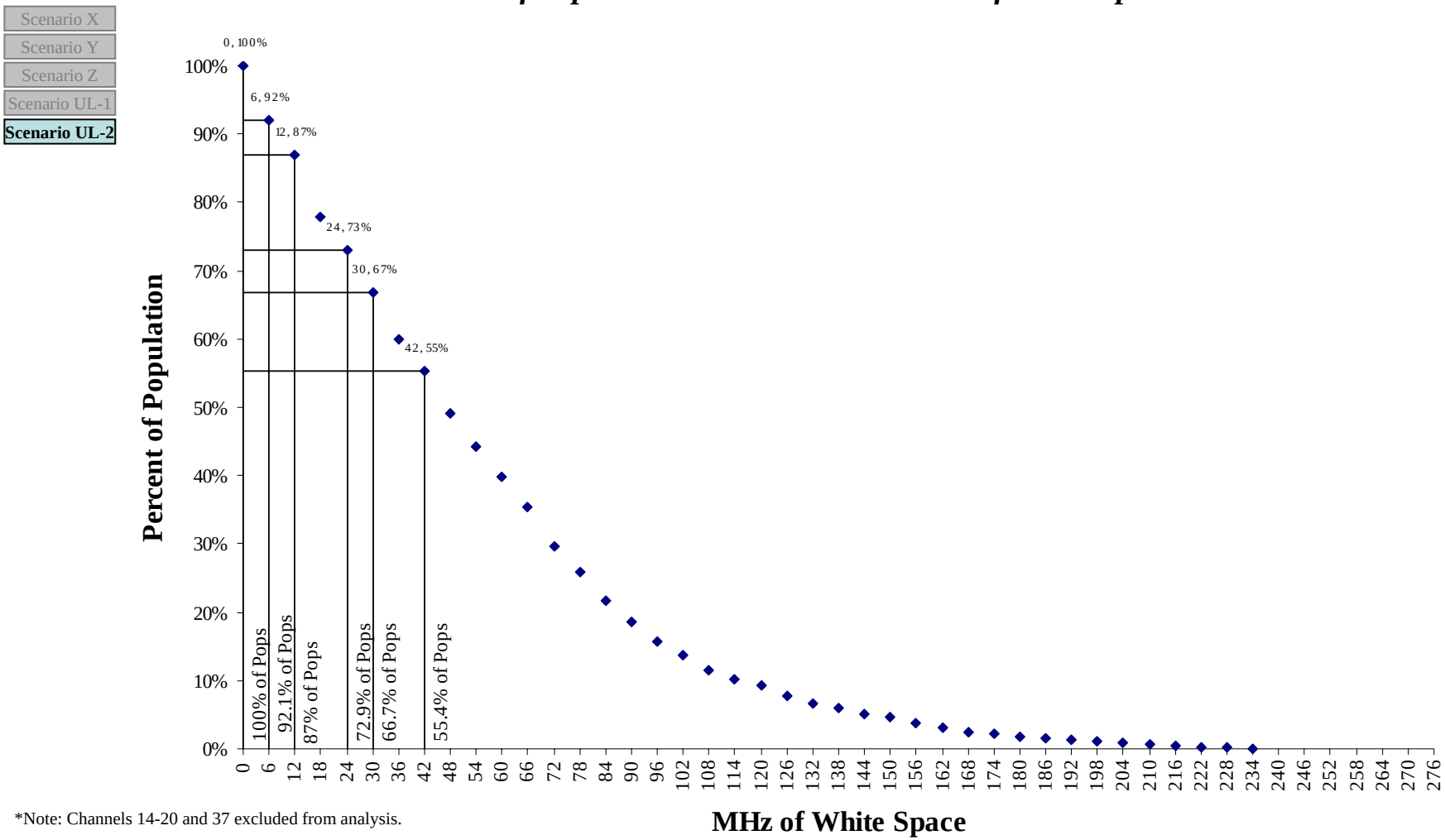


*Note: Channels 2-4, 14-20, and 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

For channels 5-51*, we estimate that 0 MHz of white space will be available to 95% of the US population.

Percent of Population with a Given Amount of White Space



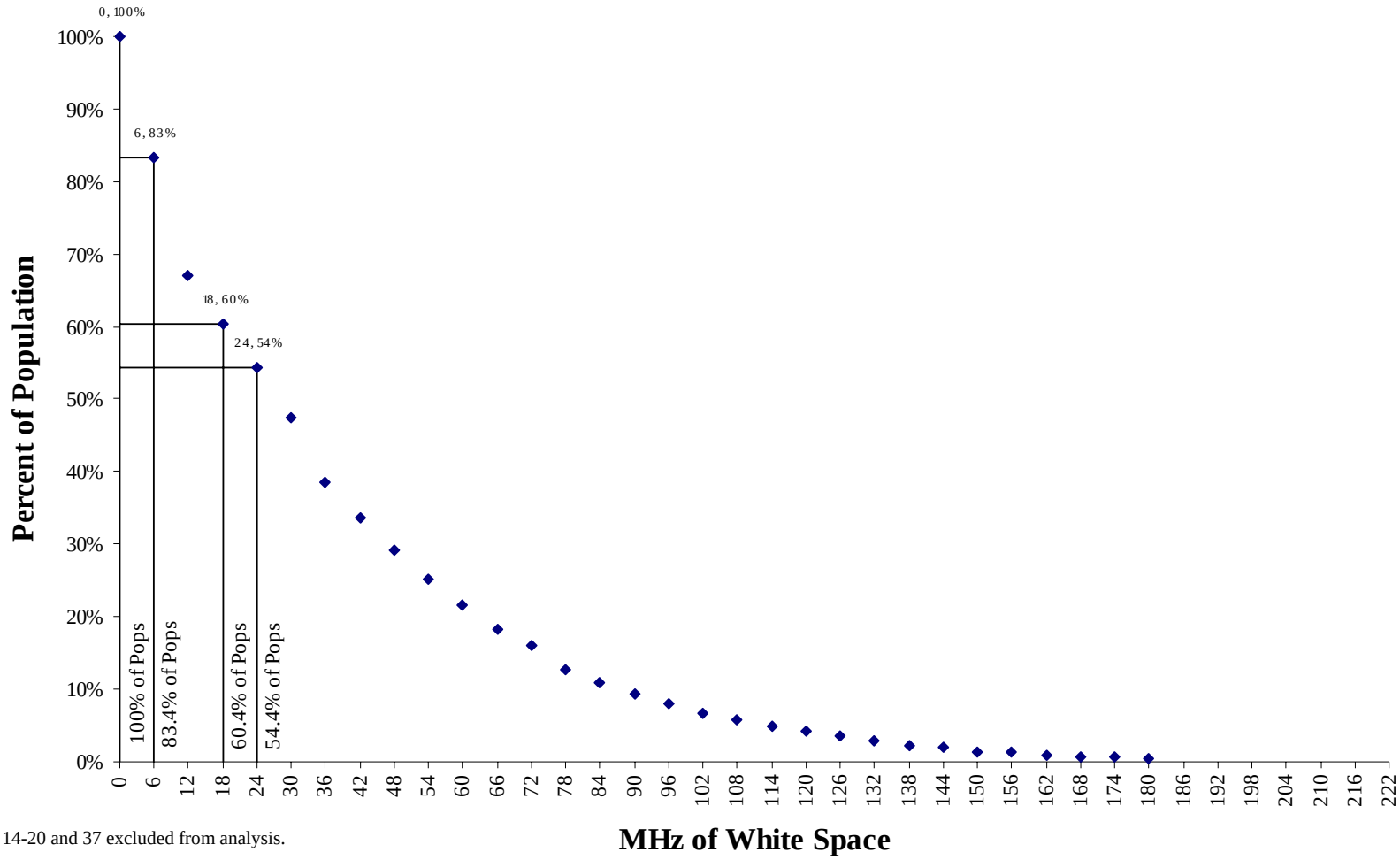
*Note: Channels 14-20 and 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

For channels 14-51*, we estimate that 0 MHz of white space will be available to 95% of the US population.

Scenario X
Scenario Y
Scenario Z
Scenario UL-1
Scenario UL-2

Percent of Population with a Given Amount of White Space



*Note: Channels 14-20 and 37 excluded from analysis.

Source: FCC CDBS / TV Query; US Census; Brattle Group Analysis

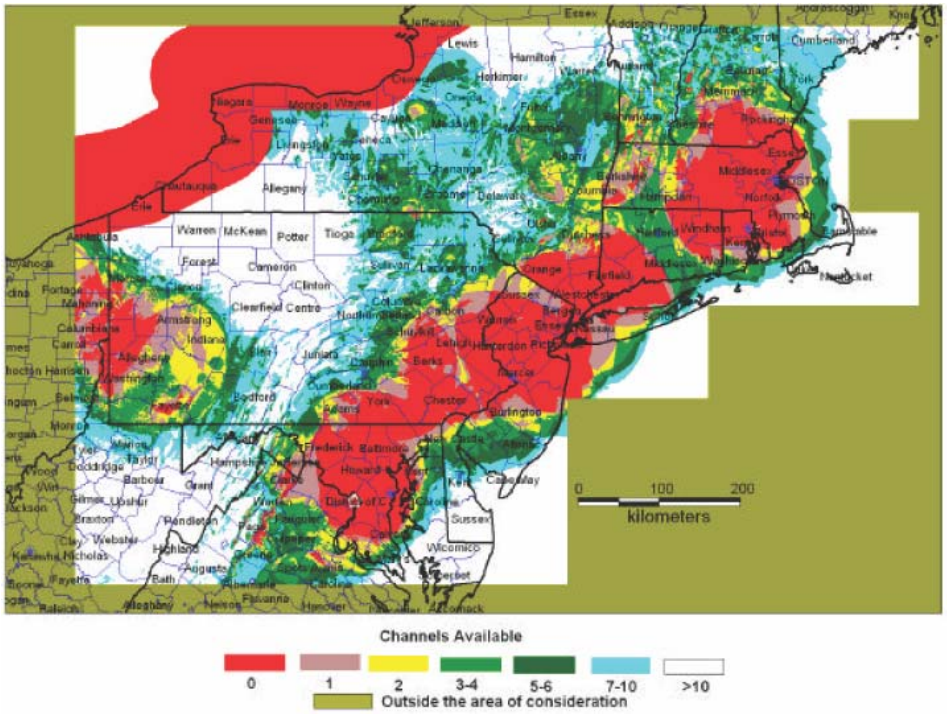
Appendix Contents

- Methodology
- Results
- General Observations

A few caveats …our results are approximate. We believe that the overall national figures are reasonably accurate. However the results for any one MTA will exhibit greater variability around the actual values than do the national results. A variety of factors limit our ability to predict with more accuracy.

- Whereas MSTV calculated interference effects using data on actual terrain along the propagation path, as a short cut, we used height above average terrain as listed in the FCC records.
- The list of post-transition licensees is still in flux.
- The post-transition operation of translators is necessarily speculative—the FCC is in the process of licensing translators for post-transition operation. We have estimated the future operation of translators based on current practices.
- Uncertainty about the FCC's interference rules is another limiting factor, although we have taken account of that by estimating white space under alternative interference rules (our five different scenarios).

MSTV Study Approach - MSTV filed an engineering study in January 2005 in FCC Docket 04-186.

MSTV White Space Estimate

- MSTV's study did an enormous computation in order to identify those locations where an unlicensed device could operate without being likely to cause interference to DTV reception. The study found few free channels in urban areas in the Northeast. Figure 6 from the study is reproduced here. It shows the white space in the North Eastern United States.
- The MSTV study differed from ours in several respects — perhaps the largest difference is that it assumes that an unlicensed device would operate as the FCC proposed — with radiated power (EIRP) of up to 4 watts in the direction of a DTV receiver.
- In contrast, we assumed that a licensee would engineer applications to efficiently use the white space; using directional antennas, lowered power, and terrain shielding in order to expand the service area as close the edge of the station's protected contour without causing interference.