# Valuing the 12 GHz Spectrum Band with Flexible Use Rights

**THE BRATTLE GROUP**

**PREPARED BY**

Coleman Bazelon
Paroma Sanyal

**PREPARED FOR**

RS Access LLC

**MAY 7, 2021**

Brattle

NOTICE

- This report was prepared for RS Access LLC in accordance with The Brattle Group's engagement terms, and is intended to be read and used as a whole and not in parts.
- The report reflects the analyses and opinions of the authors and does not necessarily reflect those of The Brattle Group's clients or other consultants.
- There are no third party beneficiaries with respect to this report, and The Brattle Group does not accept any liability to any third party in respect of the contents of this report or any actions taken or decisions made as a consequence of the information set forth herein.

TABLE OF CONTENTS

# Executive Summary

The new platform for wireless connectivity, 5G, is a game-changer in terms of its capabilities, its ability to maximize the potential of previously unusable spectrum, and the significant technological and economic growth it is expected to stimulate in the world economy. The economic value of 5G spectrum to the US economy is in the trillions of dollars. The FCC shares this view and appreciates the need for making spectrum available to support the 5G ecosystem. Mid-band spectrum is the key ingredient among the portfolio of frequencies suitable to support 5G networks. And the 12 GHz band is unique among mid-band frequencies because it alone offers 500 megahertz of contiguous mid-band spectrum that allow for wide channelization, international use, and will drive 5G deployments.

Recognizing the criticality of the 12 GHz band for 5G, the Federal Communications Commission (FCC or Commission) adopted a Notice of Proposed Rulemaking (NPRM) on January 12, 2021 to solicit comments on how to maximize efficient use of this band. For the Commission's purposes of promoting the public interest, the primary economic issue under consideration is whether authorizing terrestrial mobile services, including 5G applications, in the 12 GHz band improves consumer welfare relative to the regulatory status quo, which prohibits terrestrial mobile operations.

To measure the economic value of allowing terrestrial mobile operations in the 12 GHz band, we examine three scenarios:

**Scenario A (The Baseline): The current set of allocations and rules governing the 12 GHz Band.** Current rules prevent two-way, mobile operations in the 12 GHz band and restrict terrestrial operations to lower power limits that are out of sync with 5G deployments in the other bands. The regulatory status quo represents the baseline against which we measure the economic value and consumer welfare of future rules that allow for more intensive 5G deployments. We measure changes in economic value against this baseline.

**Scenario B (Sharing without interference): A sharing scenario in which DBS and NGSO systems continue to operate, coexisting with 5G terrestrial broadband services.** We find that if all services can share the band without interference the incremental economic value created by mobile services in the 12 GHz band over Scenario A is likely $40.6 billion within a potential range of $27.1 - $54.1 billion and total societal benefits with a range of $270 billion - $1,082 billion.

**Scenario C** (**Sharing with limited interference): A sharing scenario with limited interference in which DBS and NGSO systems continue to operate, coexisting with 5G terrestrial broadband services**. Technical analysis from RKF Engineering show limited (at most 1%), if any, potential for interference with NGSO fixed satellite services (FSS). This would mean at most minimal reductions in the value of either 5G services, NGSO services, or both. We do not yet have enough detailed information to quantify what that reduction in value of either 5G mobile services or NGSO services would be, but at 1% interference, we would expect the values of DBS, NGSO, and 5G services to be reduced by a minimal amount compared to the absolute value of enabling the band's use for 5G. As a result, even with limited interference in the range found by engineering studies, compared to Scenario A, we expect the incremental value of allowing mobile 5G services into the 12 GHz to be all or nearly all of $27.1 - $54.1 billion and the incremental total societal benefits to be all or nearly all of $270 billion - $1,082 billion.

The federal government has adopted a national policy to support and accelerate the development of 5G in the United States. By enabling the 12 GHz band to be put to its highest-valued use – terrestrial mobile 5G coexisting with satellite services – the FCC has a unique chance to serve the public interest in pursuit of this goal.

# I. Introduction

Technological change brought about by 5G networks is transforming the wireless space. 5G is not just faster or better than 4G but a technological leap forward. At the core of the new network is architecture that rests on seamlessly integrating spectrum from different bands, as appropriate, depending on frequency advantages, network characteristics, demand profiles and other relevant factors, and deploying massive MIMO and beamforming technologies.[1] Dramatically fast speeds, ultra-low latency, ultra-reliability and increased connections are the result. Download speeds are predicted to reach 1.4 Gbps for the median 5G user, a 2,000% gain compared to 71 Mbps for the median 4G user, and – a 96% reduction.[2] On top of faster data speeds and ultra-low latency, increased density of throughput and increased connection density (as high as one million devices per square kilometer compared to 0.1 million for 4G) makes 5G significantly different from its predecessor.[3]

Demand for mobile data continues to explode. In 2015 global mobile traffic totaled 5 exabytes per month; by 2020, global mobile traffic exploded to 60 exabytes per month, a 12-fold increase in 5 years.[4] North America (US and Canada) data demand almost quadrupled between 2015 and 2020—in 2015, the monthly demand for data was 1 exabyte; by 2020, that number spiked to 3.9 exabytes. By 2026, the data demand in North America is projected to be 17.2 exabytes per

---

1 GSMA, "5G Spectrum," GSMA Public Policy Position, March 2021, p. 5, https://www.gsma.com/spectrum/wp-content/uploads/2020/03/5G-Spectrum-Positions.pdf.

2 Qualcomm, "Qualcomm Network Simulation Shows Significant 5G User Experience Gains," February 25, 2018, accessed December 8, 2020, https://www.qualcomm.com/news/releases/2018/02/25/qualcomm-network-simulation-shows-significant-5g-user-experience-gains.

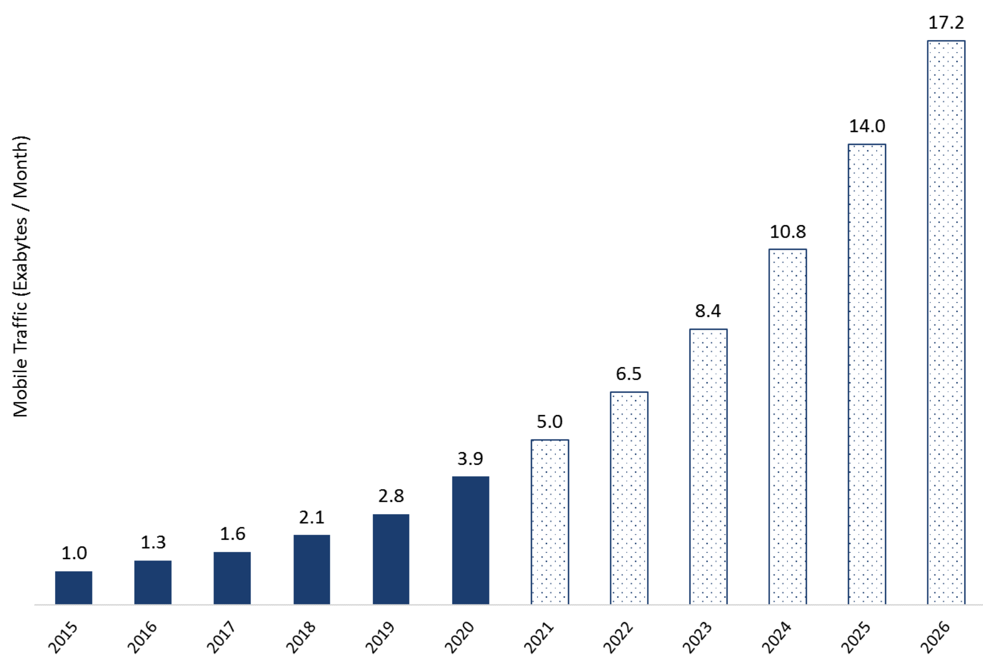
3 The other three key 5G capabilities listed by the ITU are: increased spectrum efficiency; increasing mobility; and increased network energy efficiency. *See* ITU, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and Beyond," Figure 3, p. 14, September 2015, https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf. *See also*, Robin Chataut and Robert Akl, "Massive MIMO Systems for 5G and Beyond Networks—Overview, Recent Trends, Challenges, and Future Research Direction," Sensors (Basel), MDPI, NIH, Table 1, May 12, 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7284607/, ("Massive MIMO for 5G and Beyond Networks").

4 The mobile data traffic in 2014-2015 was around 3 exabytes per months. Ericsson, "Ericsson Mobility Report," p. 4, February 2021, accessed March 24, 2021, https://www.ericsson.com/49220c/assets/local/mobility-report/documents/2020/emr-q4-2020-update.pdf.

Continued on next page

month, as seen from the figure below, which shows the data demand for all available years.[5] Between 2020 and 2026, Ericsson predicts that global mobile traffic will continue to grow at an annual rate of 24%, and for North America, the growth rate is around 27%.[6] During the pandemic, consumers have used mobile broadband networks at an unprecedented clip for a variety of applications, including schoolwork and telemedicine.[7]

**FIGURE 1: MOBILE TRAFFIC IN NORTH AMERICA, 2015 – 2026**




Source: Ericson Mobility Visualizer, accessed April 14, 2021, https://www.ericsson.com/en/mobility-report/mobility-visualizer?f=8&ft=2&r=4&t=8&s=4&u=3&y=2011,2026&c=1

5 Ericson reports the mobile traffic number for North America and not just the US. However a majority of the traffic is US-based.

6 Ericsson, "Ericsson Mobility Report," p. 14, February 2021, accessed March 24, 2021, https://www.ericsson.com/4adc87/assets/local/mobility-report/documents/2020/november-2020-ericsson-mobility-report.pdf. Calculation of Annual Data Growth Rate : Data Growth Percentage = (Difference between Current and Previous years*100) /Previous Data Demand = Data Growth in that Year. This is then averaged over the period 2021-2026.

7 Karthikeyan Iyengar, Gaurav K. Upadhyaya, Raju Vaishya, and Vijay Jain, "COVID-19 and Applications of Smartphone Technology in the Current Pandemic," Diabetes & Metabolic Syndrome: Clinical Research & Reviews, Vol. 14(5), September-October, 2020. https://www.sciencedirect.com/science/article/abs/pii/S1871402120301521?via%3Dihub.

Continued on next page

Deploying new frequencies and innovative technology under the 5G umbrella will help meet this increasing demand for mobile data and other real-time communication needs. Reallocating spectrum from lower-valued uses to more efficient, flexible and higher valued uses has been the hallmark of the FCC's spectrum policy in the recent past. The FCC's Broadcast Incentive Auction and the more recent C-band auction provide examples of this type of reallocation.[8]

While estimates vary, the potential value of 5G to the American economy is indisputably enormous. According to a report by the World Economic Forum, the faster than expected 5G deployment worldwide is expected to create an extra $13.2 trillion in economic impact.[9] The transformative nature of 5G technology and its potential to create a significant positive economic impact are well established by now. Therefore, as the demand for data continues to grow, any increase in 5G spectrum availability that allows the faster, less costly and more ubiquitous deployment of 5G services is of significant value.

With burgeoning data demand, mobile networks have three primary options for adding network capacity: 1) increase spectral efficiency, 2) reuse existing spectrum by adding cell sites or nodes to the network, or 3) deploy additional spectrum. With respect to the first option, 5G has increased the efficiency of spectrum use by orders of magnitude greater than under 4G.[10] With respect to the second, mobile network operators have deployed additional cell sites in recent years as their networks have expanded and are continuing to plan and deploy more sites.[11] But these gains from spectral efficiency and infrastructure will not meet the exponentially increasing demand for mobile broadband data. Only with more spectrum can mobile network operators realize fully the promise of 5G.

5G represents a significant advance over its predecessor technologies in terms of its input, output and performance characteristics. On the input side, the technology has the ability to use low, medium, and high-band spectrum in a single network and to optimize their combined use based

---

8 FCC, "Auction 107: 3.7 GHz Service," accessed April 15, 2021, https://www.fcc.gov/auction/107. FCC, "Auction 1000," accessed April 15, 2021, https://www.fcc.gov/auction/1000.

9 World Economic Forum, "The Impact of 5G: Creating New Value Across Industries and Society," with PWC, January 2020, https://www.pwc.com/gx/en/about/contribution-to-debate/world-economic-forum/the-impact-of-5g.html.

10 CTIA, "Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum," July 9, 2019, p. 6, https://www.ctia.org/news/smarter-and-more-efficient-how-americas-wireless-industry-maximizes-its-spectrum ("Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum").

11 CTIA, "Background on CTIA's Wireless Industry Survey," for CTIA's "Wireless Industry Indices: 1985 – 2018," see Figure "Cell Sites in Service," p. 5, accessed May 1 2021, https://api.ctia.org/wp-content/uploads/2019/06/Background_on_CTIA_Wireless_Industry_Survey_2019.pdf.

Continued on next page

on propagation and capacity characteristics of each band of spectrum. Using a "multi-layer" spectrum portfolio, 5G will incorporate the millimeter wave (mmW) spectrum, along with mid and low-band spectrum, and a combination of small cells and macro cells.[12] Particularly important to 5G is mid-band spectrum as it offers an optimal combination of coverage and capacity necessary for the next generation of applications to flourish.[13] The U.S. C-band auction speaks to the value of such spectrum. It netted about $81 billion for the US Treasury, with a total cost of around $94 - $96 billion to the wireless providers after acceleration and clearing costs were factored in[14] (an all-in price of $1.10 per MHz-Pop).[15] The proceeds were significantly greater than analyst expectations and appear to suggest some fundamental shift in spectrum value in the 5G era.[16]

This paper focuses on the 12 GHz band, which offers 500 megahertz of contiguous spectrum that can support 5G and other terrestrial flexible use wireless services.[17] This band lies between 12.2 GHz and 12.7 GHz and, along with existing terrestrial licensees, has incumbent users such as DirecTV and Dish Network, and nascent users such as SpaceX, which have economic interests in the outcome of the FCC's ongoing review of the band for 5G. We find that the FCC can accelerate

---

12 OmniSci, "5G's Data Science Challenge," White Paper, p. 4, 2021, accessed March 7, 2021, https://www2.omnisci.com/resources/whitepaper/5g-data-science-challenge/lp.

13 Stein Gudbjørgsrud, "Mid-band Spectrum is Important for 5G Networks," Analysys Mason, June 25, 2020, https://www.analysysmason.com/research/content/comments/midband-5g-spectrum-rdts0/.

14 The acceleration payments are $9.7 billion and clearing cost estimate ranges from about $3.3 billion to $5.2 billion. $94-$96 billion = $81 billion auction proceeds + $9.7 billion in acceleration payments + ($3.3 - $5.2 billion in clearing cost). For the net auction proceeds see, FCC, "Auction 107 – 3.7 GHz," Public Reporting System, https://auctiondata.fcc.gov/public/projects/auction107. For the other costs see, FCC, "Expanding Flexible Use of the 3.7 to 4.2 GHz Band," GN Docket No. 18-122, adopted February 28, 2020, ¶¶ 210, 232, https://docs.fcc.gov/public/attachments/FCC-20-22A1.pdf. The acceleration payments are $9.7 billion and clearing cost estimate ranges from about $3.3 billion to $5.2 billion.

15 Sasha Javid, "Post-Auction Analysis for Auction 107 (3700 – 3980 MHz Band): Nationwide Price Per MHz-POP Statistics at End of Assignment Stage," Bitpath Data, accessed April 15, 2021, https://sashajavid.com/FCC_Auction107.php.

16 Analysts from Morgan Stanley Research had predicted a value between $26 - $35.2 billion, New Street Research analysts predicted around $51 billion and Sasha Javid, of Bitpath had a range of $19 - $38 billion for the C-band auction. *See* Monica, Alleven, "Analysts Beef up C-band Auction Forecast to $26B - $35.2B Range," Fierce Wireless, September 25, 2020, https://www.fiercewireless.com/regulatory/analysts-beef-up-C-band-auction-forecast-to-26b-35-2b-range. *See also*, Sasha Javid, "C-band Auction Kicks Off Deep with $1.74 Billion in Bids," December 8, 2020, https://www.linkedin.com/pulse/C-band-auction-kicks-off-deep-174-billion-bids-sasha-javid/. Internal Brattle estimates had valued the band around $50 - $53 billion.

17 FCC, "Expanding Flexible Use of the 12.2-12.7 GHz Band," DA/FCC #: FCC-21-13, Docket/RM: 20-443, 17-183, RM-11768, ¶ 1, adopted Jan 12, 2021, https://www.fcc.gov/document/fcc-seeks-comment-maximizing-efficient-use-12-ghz-band, ("12 GHz NPRM"). Adopting FCC usage as in ¶ 1, we regard the 12 GHz band as "mid band" spectrum.

Continued on next page

5G development by putting the 12 GHz band to its highest value and enabling flexible terrestrial mobile uses in the band.

# II. Summary of the 12 GHz Band

## A. Background

Spectrum in the 12 GHz band is currently assigned on a co-primary basis to operators in three services - Direct Broadcast Satellite (DBS) operators, such as Dish Network and DirecTV; the Multi-Channel Video and Data Distribution Service (MVDDS) terrestrial licensees "operating on a non-harmful interference basis to DBS under the co-primary Fixed Service allocation"; and non-geostationary orbit (NGSO) satellite systems, such as SpaceX and One Web, "operating on a non-harmful interference basis to DBS under the co-primary NGSO FSS allocation."[18]

The DBS allocation and assignment of licenses in the 12 GHz band were granted in the early 1980s and early 1990s, and operations using the spectrum began in 1994.[19] DBS operators have "exclusive rights to transmit from each of their orbital slots" but, they do not have exclusive rights in terms of geographic coverage, i.e., each DBS provider can use the full 500 megahertz in the band "on a shared basis" with the other DBS providers.[20]

In 2000, the FCC allowed MVDDS to operate on a non-harmful interference basis with respect to incumbent DBS providers and allowed "one-way digital fixed non-broadcast service, including one-way direct-to-home/office wireless service."[21] The FCC auctioned MVDDS licenses in 2004 and 2005.[22] Currently, eight companies hold 191 of the 214 terrestrial fixed licenses.[23] Two companies have the largest share of the licenses – DISH and RS Access. DISH's licenses cover

---

[18] "12 GHz NPRM," ¶ 5.

[19] "12 GHz NPRM," ¶ 6.

[20] "12 GHz NPRM," ¶ 36.

[21] "12 GHz NPRM," ¶¶ 6 – 7.

[22] FCC. "Auction 63: Multichannel Video Distribution & Data Service (MVDDS)," https://www.fcc.gov/auction/53/factsheet, and FCC, "Auction 63: Multichannel Video Distribution & Data Service (MVDDS)," accessed May 1, 2021, https://www.fcc.gov/auction/63/factsheet.

[23] "12 GHz NPRM," ¶ 11.

Continued on next page

about 75% of the US population, and RS Access holds licenses covering about 15% of US population.[24]

In 2016, the MVDDS 5G Coalition petitioned the FCC to consider opening up the band for flexible terrestrial use. The coalition comprised legacy satellite and cable video operators—including DISH Network Corp., Cass Cable TV Inc. and Go Long Wireless Ltd.—which already held licenses in the 12 GHz band and "wanted to use those licenses to deliver wireless service."[25] MVDDS stakeholders argued that if two-way, 5G wireless services were allowed, then the 500 megahertz of spectrum in the band could be extremely valuable for deploying mobile broadband.[26]

In 2017, the Commission allowed the deployment of a new generation of NGSO FSS systems with hundreds of small satellites, and companies such as SpaceX, OneWeb and Kepler Communications have begun to launch Low Earth Orbit (LEO) NGSO satellite constellations.[27] In 2018, the FCC granted SpaceX the authorization to operate in 10.7 - 12.7 GHz, 13.85 - 14.5 GHz, 17.8 - 18.6 GHz, 18.8 - 9.3 GHz, 27.5 - 29.1 GHz, and 29.5 - 30 GHz frequency bands.[28] The assignments included 12 GHz spectrum, but only conditional on future Commission decisions that anticipated the current proceeding.[29] According to the Commission, "[e]ach grant is subject to modification to bring it into conformance with any rules or policies adopted by the Commission in the future" and the Commission also stated that "any investments made toward operations in the bands authorized in the United States assume the risk that operations may be subject to additional conditions or requirements as a result of any future Commission actions."[30] Furthermore, in its recent grant SpaceX's third modification, the Commission confirmed that NGSO operators like SpaceX proceed at their own risk with respect to the pending 12 GHz rulemaking.[31]

---

24 Monica Alleven, "Dish, RS Access Cheer FCC Move to Re-evaluate 12 GHz Band," Fierce Wireless, January 13, 2021, accessed April 2, 2021, https://www.fiercewireless.com/regulatory/dish-rs-access-glad-to-see-fcc-take-closer-look-at-12-ghz-band.

25 S&P Global, "FCC Eyeing More Satellite Spectrum for New 5G Wireless Band," December 29, 2020, accessed March 20, 2021, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/fcc-eyeing-more-satellite-spectrum-for-new-5g-wireless-band-61916771.

26 "12 GHz NPRM," ¶ 13.

27 "12 GHz NPRM," ¶ 10.

28 FCC, "In the Matter of Space Exploration Holdings, LLC Request for Modification of the Authorization for the SpaceX NGSO Satellite System," Order and Authorization and Order of Reconsideration, IBFS File No. SAT-MOD-20200417-00037, adopted April 23, 2021, ¶¶ 2, https://docs.fcc.gov/public/attachments/FCC-21-48A1.pdf ("SpaceX Mod 3 Order").

29 "12 GHz NPRM," ¶¶ 15, 17.

30 "12 GHz NPRM," ¶ 16.

31 "SpaceX Mod 3 Order," ¶ 50.

# B. FCC's NPRM on the 12 GHz Band

## 1. A Brief Summary

Since 1994, the FCC has had the authority to auction rights to licenses for "mutually exclusive applications." Changes in the "supply" of frequencies inevitably come from repurposing or expanding existing uses of spectrum. When repurposing privately licensed frequencies, the FCC has taken many paths from ordering incumbents out of the band to implementing a reverse auctions that reveal the incumbents' willingness to accept payment to relinquish their licenses, to hybrid formats such as Auction 103 where incumbents were given credits to be used in the auction. Outside the auction framework, the FCC also has allowed license modifications that increase the value created from a band of spectrum. The FCC can assure adequate spectrum supply to meet the needs for new spectrum-based technologies by continuing to evaluate spectrum allocations and assignments and by redirecting spectrum to its highest valued uses.

As part of these efforts, the FCC adopted the 12 GHz Notice of Proposed Rulemaking (NPRM) on January 12, 2021 to solicit comments on allowing terrestrial flexible use of the band.[32] The NPRM seeks comment on how to maximize efficient use of the 500 megahertz of mid-band spectrum in the 12 GHz band and asks if "terrestrial flexible use service is compatible with DBS service due to technological advances, such as targeted small-cell deployments and advanced antenna techniques like beamforming and beamsteering, which allow better control of transmitter energy and therefore can protect DBS."[33] The FCC seeks comment in three primary areas:

1. Can the band be used for terrestrial mobile services?

    The FCC is cognizant of the rights of all the users of the band and asks for comments on the costs and benefits of adding a mobile service allocation in the band.[34]

2. If it can be used for terrestrial mobile services, who should be granted the flexible use rights and what are the possible methods of granting such flexible use rights?

---

[32] "12 GHz NPRM."

[33] "12 GHz NPRM," ¶ 20.

[34] "12 GHz NPRM," ¶ 33.

Continued on next page

The FCC has solicited comments on three alternative methods of addition flexible use rights in the band. First, it could grant these to existing licensees in the band. Second, it could auction overlay licenses. Third, it could allow the underlay—that is, opportunistic unlicensed—use of the band.[35]

3. If sharing is feasible, how should the FCC facilitate such sharing?

   The Commission seeks comments on several alternative sharing schemes such as service rule sharing, geographic sharing, and dynamic sharing between full power terrestrial and satellite users.[36]

In this paper, we focus on the economic implications of the first question. Assuming that the FCC will modify the licenses of existing MVDDS licensees and allow for flexible-use rights, we explore the costs and benefits of sharing the band between DBS, NGSO and flexible use mobile services.

## 2. Establishing the Baseline

In this proceeding, the Commission asks whether new rules promote the public interest and improve consumer welfare relative to the regulatory status quo. The answer is "yes"—liberalizing terrestrial use of the 12 GHz band, as explained below, will significantly enhance consumer welfare compared to existing rules. As we have demonstrated in other reports, the increased economic value of spectrum due to regulatory reform leads to large increases in consumer welfare.[37] This paper shows allowing flexible terrestrial mobile use in the 12 GHz band will unlock substantial commercial value and drive accompanying consumer welfare gains.

We estimate the economic value of spectrum and consumer welfare of two scenarios (Scenarios B and C) compared against the baseline status quo (Scenario A):

**Scenario A** (Baseline): the current set of allocations and rules governing the 12 GHz Band;

**Scenario B** (Sharing without interference): a sharing scenario in which DBS and NGSO systems continue to operate, coexisting with 5G terrestrial broadband services; and

---

[35] "12 GHz NPRM," ¶¶ 37-39.

[36] "12 GHz NPRM," ¶¶ 41-50.

[37] Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the Economy," Prepared for CTIA, May 11, 2015, https://api.ctia.org/docs/default-source/default-document-library/brattle_spectrum_051115.pdf, ("Mobile Broadband Spectrum").

**Scenario C** (Sharing with limited interference): a sharing scenario with very limited interference in which DBS and NGSO systems continue to operate, coexisting with 5G terrestrial broadband services.

# III. Framework for Understanding the Consumer Welfare Value of the 12 GHz Band

To assess whether new 12 GHz rules would enhance consumer welfare, it is important to first assess the specific technological and commercial properties that might drive valuation. This section explores what makes spectrum valuable generally and then explains what makes the 12 GHz band valuable. We discuss how, in the face of exploding data demand, factors such as coverage and capacity characteristics drive spectrum value. Turning to the 12 GHz band specifically, we explain the characteristics that drive its value for today's emerging 5G networks.

## A. General Valuation Framework

Spectrum's worth is based on the value derived by and for the benefit of consumers and businesses over time. Various factors—such as propagation characteristics of the spectrum band, restrictions on its use, the relative supply and demand for the spectrum, the demand for and utilization of services transmitted via spectrum, various impairments, cost of relocation of incumbents, the timing and uncertainty over availability—affect spectrum value.[38] These factors can be divided into two broad groups: (1) elements that influence the value of *all* bands of spectrum, (2) elements that influence just a *specific* band.[39]

The first group includes factors such as the general macroeconomic condition of the economy, overall demand for wireless services, spectral efficiency, the overall supply of spectrum, and new

[38] Coleman Bazelon and Giulia McHenry, "Spectrum Value," Telecommunications Policy, October 2013, accessed June 17, 2019, https://www.sciencedirect.com/science/article/abs/pii/S0308596113001006. ("Spectrum Value").

[39] Coleman Bazelon, Paroma Sanyal, Jonathan Lee, Ezra Frankel and Ryan Taylor, " Network Value drivers in a 5G World," Conference Paper, Telecommunications Policy Research Conference 47, February 12, 2021, p.5, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3749891, ("Network Value drivers in a 5G World").

Continued on next page

technologies. The general condition of the economy—whether it is in a downturn, upswing, or in between—can affect customers' willingness to pay for services, and consequently can also affect the willingness and ability of firms to pay for spectrum. New technologies, such as 4G LTE and now 5G, increase the amount of information that can be transmitted using a given band of spectrum. These new technologies have generally increased the value of spectrum.[40]

The set of band-specific factors affecting valuation include the frequency's propagation and bandwidth characteristics, availability of a device ecosystem that can use the band, and restrictions on the use of the band. Low-band frequencies have greater potential coverage areas and require fewer cell sites for a given network footprint, making them less expensive to deploy to provide coverage over large areas. This fact is reflected in higher historical valuations for low-band frequencies compared to mid-band frequencies during the 3G and 4G eras, holding other differences constant. However, as networks have matured, the coverage advantage of low-band spectrum has decreased and now the focus has turned more to adding capacity and wider channels.[41] Regulations such as the geographic coverage of the license, potential pairings with other bands, incumbents that must be accommodated, and various use restrictions on licenses can also impact the relative value of a specific band of spectrum.[42]

As noted above, Ericsson projects an annual increase in demand of 24% for mobile broadband over the next five years, putting continued strain on existing networks and adding pressure for mobile operators to find new spectrum to ease capacity constraints. We have found in other research that a measure of spectrum deficit—the gap between how much spectrum is expected to be available compared to the demand over the coming five years—influences the value of a given band of spectrum.[43] This measure is based on traffic forecasts, increase in spectral efficiency, growth of cell towers, and the expected increase in spectrum supply. We have generally found that as the gap between the need for spectrum and its availability increases, so does spectrum value.[44] With the recently concluded C-band auction and the 3.45 GHz auction already in the works, some supply of spectrum will come online in the next several years. Yet the extent of future spectrum needs will be driven by just how large the increase in demand is, which,

---

[40] GSMA, "Study on Socio-Economic Benefits of 5G Services Provided in mmWave Bands," pp. 7- 15, December 2018, accessed July 15, 2019, https://www.gsma.com/spectrum/wp-content/uploads/2019/06/mmWave-5G-benefits.pdf.

[41] "Network Value drivers in a 5G World," p. 6.

[42] "Network Value drivers in a 5G World," p. 6.

[43] "Network Value Drivers in a 5G World."

[44] The deficit analysis is an updated version of the analysis in "Network Value Drivers in a 5G World". *See also* FCC, "Connecting America: The National Broadband Plan," Chapter 2, March 2010, https://transition.fcc.gov/national-broadband-plan/national-broadband-plan.pdf.

based on the Ericson forecasts, is significant. It is quite possible, that without the infusion of new spectrum sources, increasing mobile data demand will overwhelm the existing capacity.

The 12 GHz band is the only significant sub-mmW band that could be authorized for terrestrial mobile use in the near future. With its 500 megahertz of mid-band spectrum, it represents the largest swath of contiguous spectrum in this range that can be used for terrestrial mobile deployment, and no spectrum is licensed for terrestrial mobile use between the C-band (3.7 GHz) and the 24 GHz mmW band.

## B. The 12 GHz Band

The spectrum usability landscape has changed dramatically in the past few years with the advent of 5G. In a 2017 study, the NTIA had not discussed mobile terrestrial applications as one of the use cases for high mid-band spectrum such as 12 GHz.[45] However, since then, there have been significant strides in technical development, and the coverage characteristics that are associated with higher frequencies, such as the 12 GHz, have changed. The nearest band licensed to support mobile broadband services is the recently licensed C-band at 3.7-3.98 GHz.[46] Consequently, we will focus our discussion on comparability between 12 GHz and C-band. Below we discuss the characteristics of the band, and their evolution.

### i. Coverage

The current MVDDS licenses cover the continguous United States.[47] We therefore assume the terrestrial mobile operations in the 12 GHz band will be available ubiquitously, the deployment of which will be determined by economic and engineering considerations. We understand that 12 GHz would be deployable for both mobile and fixed 5G applications in ways similar to 3.7 GHz spectrum, only with a shorter reach resulting from the higher frequency of 12 GHz. Between

---

45 NTIA, "Identifying Key Characteristics of Bands for Commercial Deployments and Applications Subcommittee," Commerce Spectrum Management Advisory Committee, November 17, 2017, https://www.ntia.doc.gov/files/ntia/publications/key_characteristics_sub-committee_final_report_nov_17_2017.pdf.

46 The 12 GHz band's performance is similar to the C-band than other higher bands. *See* Comments of RS Access, "In the Matter of Expanding Flexible Use of the 12.2-12.7 GHz Band; Expanding Flexible Use in Mid-Band Spectrum Between 3.7-24 GHz," WT Docket No. 20-443, GN Docket No. 17-183, May 7, 2021, pp. 17, 20, 21. ("Comments of RS Access"). *See also*, ITU-R, "Technical Feasibility of IMT in Bands Above 6 GHz," Report ITU-R M.2376-0, July, 2015, https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2376-2015-PDF-E.pdf.

47 This is inclusive of the few authorizations currently held in FCC inventory..

Continued on next page

mobile, fixed and backhaul deployments, these frequencies can be usefully deployed across the entire country.

New technologies like massive MIMO allow higher mid-band frequencies like the 12 GHz to behave more like the lower mid-band spectrum, such as the 3.7 GHz.[48] Massive MIMO combines hundreds and even thousands of antennas at a base station. These antennas serve multiple users simultaneously and can significantly improve spectral efficiency by focusing narrow beams towards a user.[49] MIMO improves cell edge performance and would allow 12 GHz spectrum to reach larger coverage areas than would otherwise have been possible. We understand the 12 GHz band to have a coverage radius of around 200 meters for mobile applications in dense urban areas and longer ranges outside these urban centers and for fixed applications.[50] According to the RKF study, in a rural environment, a 12 GHz application would have a range of 1,732 meters.[51]

### ii. Capacity

The 12 GHz band is like the C-band in many respects (but with a more limited reach) and can be deployed as capacity spectrum on existing macro cells for mobile 5G applications and also for fixed 5G applications. When those macro cells are sufficiently small or spectrum is deployed in mesh configurations, 12 GHz can reach the entire coverage area of the deployment and provide capacity substitutable for 3.7 GHz spectrum for both mobile and fixed applications. When the macro cells are larger, the 12 GHz frequencies will only cover a portion of the area of the cell for mobile 5G applications. These technological drivers provide significant additional coverage for fixed applications. Providing capacity to areas near the macro-cell node frees up other resources that will be available to provide additional capacity to the rest of the macro cell.

---

48 We do not use the 3.5 GHz as a comparison as the reduced power and sharing feature of the band make the band characteristics different. *See*, FCC, "Promoting Investment in the 3550-3700 MHz Band," Report and Order, adopted October 23, 2018, ¶¶ 65-67, https://docs.fcc.gov/public/attachments/FCC-18-149A1.pdf.

49 Massive MIMO involves "using hundreds and even thousands of antennas attached to a base station to improve spectral efficiency and throughput. This technology is about bringing together antennas, radios, and spectrum together to enable higher capacity and speed for the incoming 5G." "Beamforming helps the base station to find a suitable route to deliver data to the user, and it also reduces interference with nearby users along the route." *See* "Massive MIMO Systems for 5G and Beyond Networks."

50 According to a RFK technical study, urban inter-site distances vary from 200 – 300 meters, which approximately translate to a coverage radius of 177 – 200 meters. Given this, we assume a minimum reach of 200 meters for 12 GHz signals. *See* RKF Engineering Solutions, LLC, "Assessment of Feasibility of Coexistence between NGSO FSS Earth Stations and 5G Operations in the 12.2 – 12.7 GHz Band," WT Docket No. 20-443, GN Docket No. 17-183, May 7, 2021, p. 27, ("RKF Technical Study").

51 "RKF Technical Study," p. 27.

Continued on next page

### iii. License Size

The 12 GHz band has 500 megahertz of spectrum and will allow for large license sizes. The mmW licenses allow for 100 megahertz channels whereas the 3.7 GHz band only permits individualized channels of 20 megahertz.[52] In general, larger license sizes are associated with greater value, holding all else equal. Larger bandwidth increases the efficiency of the channel capacity. A 20 megahertz channel is more efficient than two 10 megahertz channels and will accommodate increased speed and lower latencies compared to the latter.[53] The 12 GHz band can accommodate license sizes of 50 – 100 megahertz or even larger, and that would be very valuable in 5G deployments.[54]

# IV. 12 GHz Valuation

Having established the technical and economic properties that drive spectrum valuation generally, we now use a "market-comparables" approach to establish a value for terrestrial use of the 12 GHz band. This method uses prior auctions or secondary market transactions for similar spectrum as a baseline to value a given spectrum band. We then adjust for differences between the spectrum band used in those transactions and the band being valued.[55] We begin by summarizing our findings. We then explain the methodology, which rests on establishing a base value of spectrum—the recently auctioned C-band—and then establish the value of the 12 GHz Band relative to that band by accounting for differences between the two bands. We then compute the dollar value of the 12 GHz band based on this relative value.

## A. Summarizing the Range of Values for the Use of the 12 GHz Band for Mobile Broadband Services

Table 1 shows our calculations of prices per MHz pop for the 12 GHz spectrum band. As explained in subsequent sub-sections, we use the C-band fully loaded national average auction price as the base for valuing the 12 GHz band. We then calculate the share of the US population expected to be covered by the C-band for mobile 5G applications. We estimate that for mobile 5G applications, the C-band can be used to cover urban populations entirely, and a large fraction of the population

---

52 FCC, "Auction 107: 3.7 GHz Service," accessed April 15, 2021, https://www.fcc.gov/auction/107.

53 "Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum,", p. 7.

54 "Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum."

55 Coleman Bazelon and Giulia McHenry, "Spectrum Value," p. 2.

in non-urban areas where cell towers are more spaced out. Together, for mobile 5G applications, the C-band covers 74.5% of the total US population.

We then conduct a similar exercise for the 12 GHz band. The urban area coverage for mobile 5G applications is identical to the C-band, but the reach of non-urban population is lower. In total we estimate that the 12 GHz band mobile 5G broadband deployments that are spread out over the US will be expected to reach 23.8% of the US population. Fixed wireless applications could reach substantially all of the population. Mobile deployments in the 12 GHz band, therefore, are expected to cover 32.0% of the population covered by C-band deployments.[56] This yields an interim value of the 12 GHz band at $0.35/ MHz-pop.[57]

As discussed later, we could discount this value because the 12 GHz band is not internationally harmonized as yet, and due to its propagation characteristics will not be deployed to reach the entire US population. When we apply a 25% discount for these considerations, we estimate a value of $0.26/MHz-pop, with sensitivities reported at 0% and 50% for estimates of $0.18 - $0.35/MHz-pop. Given the 500 megahertz of spectrum that is available and 308 million people in the United States,[58] these calculations result in a total dollar value of $27.1 - $54.1 billion.

56 Calculation: 12 GHz pops as a share of C-band pops = (23.8%/74.5%) = 32.0%.

57 Calculation: 12 GHz Value = 12 GHz pops as a share of C-band pops * C-band $/MHz-pop = 32.0% of $1.10/MHz-pop = $0.35 MHz-pop.

58 Populations figures are based on the 2010 Census and projections for 2024.

TABLE 1: VALUE OF 12 GHZ BAND FOR MOBILE 5G APPLICATIONS

| | | |
|---|---|---|
| C-Band Fully Loaded Price ($ / MHz-Pop) | [1] | $1.10 |
| Share of US Population Expected To Be Covered by C-Band | [2] | 74.5% |
| Covered Urban Population (% of US Total Population) | [3] | 15.6% |
| Covered Non-Urban Population (% of US Total Population) | [4] | 58.9% |
| Share of US Population Expected To Be Reached by 12 GHz | [5] | 23.8% |
| Reached Urban Population (% of US Total Population) | [6] | 15.6% |
| Reached Non-Urban Population (% of US Total Population) | [7] | 8.2% |
| Implied Percentage, 12 GHz to C-Band | [8] | 32.0% |
| Pop-Adjusted National Average Price ($ / MHz-Pop) | [9] | $0.35 |
| **Value of the 12 GHz Band** | | |
| ***At 0% Dissimilarity Discount*** | | |
| **National Average Price ($ / MHz-Pop)** | [10] | **$0.35** |
| **Value of Band ($ bn)** | [11] | **$54.1** |
| ***At 25% Dissimilarity Discount*** | | |
| **National Average Price ($ / MHz-Pop)** | [12] | **$0.26** |
| **Value of Band ($ bn)** | [13] | **$40.6** |
| ***At 50% Dissimilarity Discount*** | | |
| **National Average Price ($ / MHz-Pop)** | [14] | **$0.18** |
| **Value of Band ($ bn)** | [15] | **$27.1** |

Sources: FCC Auction 107, American Tower, "US Technology and 5G Update," April 2018, https://www.americantower.com/Assets/uploads/files/PDFs/vendor-relations/investor-relations/2018/us-technology-and-5g-update-april-2018.pdf. Bevin Fletcher, "Verizon defends C-band plans," *Fierce Wireless*, March 29, 2021, https://www.fiercewireless.com/operators/verizon-defends-C-band-plans. ZTE, "APT 700 MHz: Best Choice for Nationwide Coverage," June 2013, https://www.gsma.com/spectrum/wp-content/uploads/2013/07/ZTE-LTE-APT-700MHz-Network-White-Paper-ZTE-June-2013.pdf.

[1]: National average price for Auction 107 after assignment phase including estimated clearing payments and relocation costs.

[2]: Sum of [3] - [4]. Note that we remove PEAs not covered by the C-band.

[3]: Urban population calculated as population in census tracts with a population density of at least 7,500 pops per square mile. See American Tower presentation.

[4]: Non-urban population calculated as population in census tracts with a population density less than 7,500 pops per square mile

[5]: Sum of [6] - [7]. Note that we remove PEAs not covered by the C-band.

[6]: Urban population calculated as population in census tracts with a population density of at least 7,500 pops per square mile. See American Tower presentation. We assume that 12 GHz will cover all urban population.

[7]: Non-urban population calculated as population in census tracts with a population density less than 7,500 pops per square mile. See American Tower presentation. We assume that 12 GHz will be placed on all macro cells on which C-band is deployed in these areas, but will only cover the area within the larger of one-quarter the C-band radius implied by the C-band tower deployment or 200 M of the cell.

[8]: [5] / [2].

[9]: [1] x [8].

[10]: [9].

[11]: [10] x 308 M pops x 500 megahertz.

[12]: [9] x 75%.

[13]: [12] x 308 M pops x 500 megahertz.

[14]: [9] x 50%.

[15]: [14] x 308 M pops x 500 megahertz.

## B. Explaining The Value of the 12 GHz Band Relative to the C-band

Having summarized the 12 GHz value estimates earlier, this section does a deeper dive into the methodology behind the estimates. As an initial matter, we recognize that the value of a band of spectrum is based on the expected profits that can be earned by deploying it. Thus, similar spectrum bands can be expected to have similar profit expectations and thus similar value. It is often difficult to find a band with all of the same relevant characteristics. But as explained earlier, the C-band is a good reference for assessing the value of the 12 GHz band.

The C-band auction was more complex than some past auctions given its spectrum availability, the existence of geostationary satellite incumbents that needed to be vacated, acceleration timelines, and incentive and relocation payments.[59] The 280 megahertz of spectrum was divided into three (unpaired) blocks, each with 20 megahertz sub-blocks. Without comparable information on the phasing of availability of 12 GHz spectrum, the baseline comparable value of the C-band we use is $1.10/MHz-Pop national average price.[60]

The next step is to establish the value of the 12 GHz band relative to the C-band. This requires analyzing the difference between the two bands on various dimensions discussed in Section III and applying appropriate adjustments that reflect differences between C-band and the 12 GHz Band, such as differences in propagation characteristics, capacity and so on. We will base our relative value calculation on the difference between C-band and 12 GHz for expected mobile population deployments. We recognize that both bands will also be used for fixed deployments, but abstract from those differences for the current analysis.[61]

---

59 FCC, "Auction of Flexible Use Service Licenses in the 3.7-3.89 GHz Band for Next Generation Wireless Services, Comment Sought On Competitive Bidding Procedures For Auction 107," Public Notice, AU Docket No. 20-25, FCC 20-110, released March 3, 2020, https://www.fcc.gov/document/fcc-proposes-C-band-auction-procedures-0, ("Auction 107 Procedures PN").

60 Sasha Javid, "Post Auction Analysis for Auction 107 (3700 – 3980 MHz)," BitPath, accessed May 4, 2021, https://sashajavid.com/FCC_Auction107.php.

61 This abstraction is conservative because the ratio of 12 GHz to C-band expected population deployments for fixed applications is likely higher than the ratio of 12 GHz to C-band expected population deployments for mobile applications. Also the share of total value from fixed deployment is likely only a fraction of the value created from mobile deployments.

## 3. 12 GHz Band's Near-Term Mobile Population Reach Based on a C-Band Overlay

For mobile applications, we model the 12 GHz band as deployed as a capacity overlay on a C-band network. That is, we model that terrestrial 12 GHz deployments will generally exist wherever C-band is deployed, but given the expected architecture of a C-band network, the 12 GHz frequencies will not reach all of the population reached by the C-band network. To be clear, wireless carriers could choose to build out the 12 GHz coverage with new tower and infrastructure for more complete coverage, but our assumption herein is that the 12 GHz deployment is an overlay of a C-band network.

### i. Key Variables Required to Calculate the 12 GHz Near-Term Mobile Population Reach

To estimate the difference in coverage of a 12 GHz and C-band deployment, we consider three factors:

- *Near-Term C-band Coverage Expectations*

  We rely upon Verizon's expectation for how C-band will be deployed for mobile 5G applications to form our basis for C-band coverage. Verizon expects that by 2024, 250 million people will be covered by their recently acquired C-band spectrum.[62] These 250 million people served is not the final expected reach of their network. They will likely continue to build out their mobile network beyond 2024. Verizon also expects that C-band will share similar propagation characteristics to 2.5 GHz spectrum, and additional evidence also suggests that given the C-band relatively higher power levels, its coverage is similar to 2.5 GHz spectrum.[63] We then rely upon an engineering study that reports spectrum propagation characteristics for bands near 2.5 GHz at various terrain types, i.e. coverage radii for urban areas, suburban areas and rural areas.[64] For mobile 5G applications in urban areas, for example, we expect C-band to travel 0.45 kilometers, and in rural areas, it could travel as far

[62] Bevin Fletcher, "Verizon Defends C-band Plans," *Fierce Wireless*, March 29, 2021, https://www.fiercewireless.com/operators/verizon-defends-C-band-plans, ("Verizon Defends C-band Plans").

[63] Bevin Fletcher, "Verizon Defends C-band Plans,"

[64] ZTE, "APT 700 MHz: Best Choice for Nationwide Coverage," June 2013, https://www.gsma.com/spectrum/wp-content/uploads/2013/07/ZTE-LTE-APT-700MHz-Network-White-Paper-ZTE-June-2013.pdf, ("APT 700 MHz: Best Choice for Nationwide Coverage").

Continued on next page

as 3.04 kilometers.[65] Given these propagation characteristics, we estimate the number of C-band towers required to meet the population covered expectation of 250 million people.

- *Near-Term 12 GHz Reach Expectations*

  Given a set of towers for mobile applications identified for C-band, we need to estimate the share of population that would be reached by the same towers using 12 GHz spectrum for mobile applications. To do this, we use a conservative estimate of coverage radii for the 12 GHz Band based on only mobile applications. We assume that the reach of the band is the larger of one-quarter of the coverage radius implied by the C-band tower deployment or 0.2 kilometers (the dense urban coverage radii) from each cell tower independent of the terrain.[66] The reach of 12 GHz could extend beyond this population if wireless carriers choose to expand the cell towers available for the network beyond the C-band overlay, but we do not assume an infrastructure expansion here.

- *Defining Urban and Non-Urban Population*

  We treat urban and non-urban population differently in our analysis (100% 12 GHz reach of urban population, fractional 12 GHz reach of non-urban population.) We define the urban population as population in tracts with a population density of at least 7,500 pops per square mile.[67] The remaining population, comprised of suburban and rural population, is the non-urban population set.[68]

---

65 "APT 700 MHz: Best Choice for Nationwide Coverage," p. 9, Table 3-1.

66 The RFK analysis reports suburban and rural inter-site distances of 500 to 1,732 meters, which translates to an approximate coverage radius of 260 meters to 1,040 meters. With a maximum C-Band radius of about 3,000 meters, and assuming terrain impacts are similar on a proportional basis between C-Band and 12 GHz, we assume in less dense areas a 12 GHz signal will reach about one-quarter the distance of a C-Band signal, which corresponds to the rounded-up average of of the suburban and rural radii (650 meters rounded to 750 meters). *See* "APT 700 MHz: Best Choice for Nationwide Coverage," p. 9, for the rural cell range of 2.6 GHz which we use as a proxy for the C-Band range sue to reasons discussed in the body of this report. For the intersite distances *see* "RKF Technical Study," p. 27.

67 American Tower, "U.S. Technology 5G Update," p. 22, April 2018, https://www.americantower.com/Assets/uploads/files/PDFs/vendor-relations/investor-relations/2018/us-technology-and-5g-update-april-2018.pdf.

68 For contextualizing results, suburban tracts are those that fall within a population density of at least 600 pops per square mile but less than 7,500 pops per square mile. Rural tracts have a population density below 600 pops per square mile. This characterization of urban/suburban/rural differs from one that categorizes geographies at the county level.

## ii. Calculating the Near-Term Population for Mobile 5G Applications Reachable by 12 GHz

As noted, we assume a network overlay of the 12 GHz band using the same macro towers that would be used for C-band to derive the near-term reach for 12 GHz, as described below; wireless carriers could choose to expand the reach of 12 GHz by adding additional infrastructure to their networks, but that is not our assumption here. To estimate the ratio of population reached by 12 GHz versus C-band for mobile applications, we first identify C-band coverage areas for mobile applications and then segment them into urban and non-urban areas. We assume all urban population is covered for mobile 5G applications by both C-band and 12 GHz, given their coverage radii and the inter-site distance between urban towers. For the non-urban areas, we then estimate the number and coverage areas of C-band towers for mobile 5G applications. Finally we calculate the share of covered population of those towers that would be reached for mobile 5G applications by a 12 GHz deployment on those towers. We describe this in detail below.

- *Near-Term Population Covered by C-band in Urban and Non-Urban Areas for Mobile 5G Applications*

  To model C-band population coverage by urban and non-urban area, we assume that the most population-dense areas are built out first and networks progressively deployed to less dense areas until a 250 million population threshold is reached, which is Verizon's target for its C-band coverage. We rank census tracts by population density and count the cumulative population until we reach the set of tracts whose population totals Verizon's population coverage expectation of 250 million people. Based on this, the C-band will cover 74.5% of the U.S. population for mobile 5G applications. The C-band licences are nationwide and the modeled deployments reach throughout the country. Not every person in the U.S. will be covered in initial deployments. Even so, these deployments will reach well into rural areas to serve pockets of populations in small towns and villages. Every single C-band license sold at auction indicated demand even in less populated markets.[69]

  To contextualize, in Table 2 below, we see that 15.6% of the US population is in urban areas (i.e., in tracts with greater that 7,500 population per square mile). We assume that this population will be covered by the C-band for mobile 5G applications, since in urban areas the inter-site distances of towers are such that the C-band coverage radii will cover all of the

[69] FCC, "Auction 107 - 3.7 GHz: Assignment Phase Results," accessed April 25, 2021, https://auctiondata.fcc.gov/public/projects/auction107/reports/results.

Continued on next page

population. In general the inter-site distance in dense urban areas is between 0.1 to 0.3 kilometers, while the reach of a C-band site in these areas is assumed to be up to 0.45 kilometers.[70] Additionally, 84.4% of the U.S. population is in non-urban areas, and we calculate that based on a target of covering 250 million people, about 70% of these populations (58.9% of the total U.S. population) will also be fully covered by the C-band for mobile 5G applications.

- *Near-Term Population Reached by the 12 GHz Band for Mobile 5G applications*

    - *Near-Term Urban Population Reached by 12 GHz*

Given the dense morphology of networks and ubiquity of cell sites in urban settings, 12 GHz frequencies are expected to cover the same population for mobile 5G applications as C-band deployed on these networks. As discussed earlier, the urban inter-site distances are between 0.1 to 0.3 kilometers whereas the 12 GHz coverage radii in these areas is about 0.2 kilometers. Thus, if the 12 GHz spectrum is deployed exclusively on the urban towers, we expect it to cover the entire urban population. Thus, all of the 15.6% of urban pops covered by C-band deployments can also be covered by the 12 GHz band.

    - *Near-Term Non-Urban Population Reached by 12 GHz for Mobile 5G applications*

The potential radius of 12 GHz spectrum deployments is less than that of C-band spectrum deployments. Thus, in non-urban areas, the more limited radius of 12 GHz spectrum becomes the limiting factor in reaching population. Focusing on the 70% of the non-urban population that C-band will cover, we estimate the share of this population that would be reached by 12 GHz mobile deployments. The analysis below shows that 8.2% of the U.S. non-urban population is reached by the 12 GHz band. To calculate this, we first estimate the number of C-band towers required for the non-urban C-band mobile coverage.

To calculate the number of C-band towers in non-urban areas, we rely on the average number of subscribers covered by a C-band tower and the maximum reach of a tower. We assume the total population served by a tower in a non-urban setting can be as high as the population served by the least dense urban deployment, i.e., it is equal to the number of population per tower in the marginal urban tract.[71] However, the area covered by that tower cannot exceed

---

70 For the intersite distances see “RKF Technical Study,” p. 27.

71 We calculate the pops per tower by estimating the population covered in an area with the population density of the marginal urban tract given the C-band coverage radii. This yields approximately 1,150 pops per tower.

Continued on next page

the maximum reach of a C-band signal. Using this population per tower figure plus the information on the maximum reach of a C-band signal, we calculate the number and coverage of towers required to reach the anticipated C-band coverage areas.[72]

The number and coverage area of towers allows us to calculate the implied C-band coverage radius for each tract. We then calculate the implied population reached by a 12 GHz cell based on the radii of a 12 GHz cell assuming the 12 GHz radii is the larger of one-quarter of the coverage radius implied by the C-band tower deployment or 0.2 kilometers. We then calculate the population in the covered area assuming that population is uniformly distributed in the tract. These pops will be the target to be reached by potential 12 GHz deployments for mobile 5G applications. Summing up these target population, we find that 8.2% of the US population living in non-urban areas would be covered by 12 GHz. These 8.2% of population are spread throughout the US, including in rural areas, wherever some clustering of population justifies a C-band deployment. Combining this with the urban population, we find that the 12 GHz spectrum is expected to reach 23.8% of the U.S. population at the very least when integrated into 5G mobile networks, based on a 12 GHz overlay on current towers that will deploy the C-band spectrum. Operators could expand their reach by expanding their tower networks available for 12 GHz deployments. Fixed wireless applications could reach substantially all of the population but, as noted above, we have conservatively excluded this calculation from our analysis.

**TABLE 2: POPULATION FOR MOBILE 5G APPLICATIONS COVERED BY C-BAND AND REACHED BY 12 GHz OVERLAY**

| Population Category | Share of U.S. Population | Share of U.S. Population Covered by C-Band | Share of U.S. Population Expected to be Reached 12 GHz | Share of Population Category Covered by C-Band | Share of Population Category Expected to be Reached by 12 GHz |
|---|---:|---:|---:|---:|---:|
| [a] | [b] | [c] | [d] | [e] | [f] |
| Urban Population | 15.6% | 15.6% | 15.6% | 100.0% | 100.0% |
| Non-Urban Population | 84.4% | 58.9% | 8.2% | 69.8% | 9.8% |
| Total | 100.0% | 74.5% | 23.8% | - | - |

Sources: See Table 1.

Notes:

[e]: [c] / [b].

[72] We identify population at the Census Tract level. We do not perform an engineering analysis and do not model an actual build. Instead, we take the Census Tract's identified as non-urban C-band coverage areas (identified as those Tracts needed to meet the C-band total population coverage target) and calculate the fractional tower needed to cover the area represented by each tract. Although this is both a simplification and abstraction, we find any errors in such an analysis tend to be offsetting.

[f]: [d] / [b].

## 4. Additional Adjustments for Valuing 12 GHz Spectrum for Mobile 5G Applications

Additional differences between the C-band and 12 GHz could require further potential price adjustments even based on mobile 5G applications alone. We discuss three potential factors. First, we recognize that the effective reach of 12 GHz is smaller than for C-band, which could lead to a discount on the unit value of spectrum beyond the discount calculated above for the fewer people the deployment is expected to reach. This would lead to a fragmentation discount, which could lower the price of the band. Second, the 12 GHz band is not internationally harmonized, which could impact the costs of developing an equipment ecosystem, and lead to a further discount. The third, is an offsetting factor. The 12 GHz band offers 500 megahertz of spectrum that could be used in larger bandwidths and larger channelizations than in the C-band, which would put upward pressure on the prices. Below we discuss these factors.

### i. Fragmentation

Empirical evidence suggests that in some cases larger geographic licenses can be more valuable. For example, the FCC used a 5% aggregation premium in estimating the value of a nationwide license over the value of a collection of smaller licenses that cover the country.[73] In addition, researchers have found an aggregation premium of about 13% between regional economic area licenses and the substantially smaller economic area licenses.[74] Although not directly comparable to evaluating the difference between two bands of spectrum that have different shares of population that are effectively covered, these examples do illustrate that the value of reaching a larger pool of customers is more valuable than the sum of reaching smaller pools of customers. Similar effects are seen in the advertising markets, where the value of reaching an eyeball can be higher per eyeball when the advertising medium has a farther reach. Because the band has been exhaustively licensed, the licensees could organize any geographic service area or lease areas in an economically logical fashion, including PEAs. Consequently, the 12 GHz band could be organized at least as valuably as the C-band, which was licensed on a PEA basis. That said, there

---

73 FCC, "Improving Public Safety Communications in the 800 MHz Band," Report and Order, Fifth Report and Order, Fourth Memorandom Opinion and Order, and Order, WT Docket 02-55, ¶ 297, adopted July 8, 2004, https://www.fcc.gov/release-fcc-04-168.

74 Jean Pierre De Vries and Cheng-Yu Chan, "Edge License Discounts in Cellular Auctions," TPRC 2010, January 20, 2012, p. 18, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1988429.

is likely some discount for 12 GHz for not expecting to reach the same set of population as the C-band deployments.

Another potential driver of a fragmentation discount relates to equipment costs. The functionality built into a handset to enable 12 GHz based 5G services will most likely be built into all handsets. This is for two reasons. First, any mobile network customer will likely come into the 12 GHz service area, even if they do not have that service at their home. Second, it would not be practical to build that functionality into only a subset of handsets. Given that the cost of including 12 GHz bands into handsets will apply to all users, but the capacity benefits are more limited than other bands such as the C-band, the effective cost of that functionality will be higher per customer. This added cost, albeit likely not very large, puts additional downward pressure on the $/MHz-pop value of 12 GHz spectrum.

### ii. Lack of International Harmonization

The global harmonization of a band and the related availability of the equipment ecosystem increase the value of a band.[75] The 12 GHz band is allocated internationally for multiple uses, including mobile, but it is not harmonized.[76] Spectrum harmonization drives economies of scale, and is essential for 5G to succeed.[77] This implies that if spectrum is not harmonized, its value will be lower. On a related note, when bands are newly allocated, it may take time for a band to be cleared, suggesting some portion of value will only be realized in the future. If new equipment ecosystems are needed, it can take time and expense before the band is deployed. Delay in availability is a potential risk if the Commission adopts complex rules subject to protracted interpretation and litigation. This too can lower the price of a band.

---

[75] Spectrum harmonization is a worldwide effort led by of the ITU to encourage governments and regulators to allocate radio spectrum consistently across borders, "thereby enabling global roaming, interoperability and global markets for telecom equipment". *See* https://www.gartner.com/en/information-technology/glossary/spectrum-harmonization. *See also*, GSMA, "5G Spectrum," GSMA Public Policy Position, March 2021, p. 6, https://www.gsma.com/spectrum/wp-content/uploads/2021/03/5G-Spectrum-Positions.pdf.

[76] 12 GHz is not one of the frequency bands in the revision to ITU Recommendation M.1036-6, which specifies all frequency bands for the Terrestrial component of IMT (including IMT 2020), and is thus not harmonized internationally. *See*, Alan Weissberger, "Big Names Clash over 12 GHz for 5G despite it NOT being included in ITU M.1036 – Frequency Arrangements for IMT," IEEE Communications Soceity, October 28, 2020, https://techblog.comsoc.org/tag/12-ghz/.

[77] Saad Asif, "Need for harmonized Spectrum," MTN Consulting, October 4, 2019, https://www.mtnconsulting.biz/5g-need-for-harmonized-spectrum/.

Continued on next page

### iii. Larger Channel Sizes

The C-band licenses are 20 megahertz. The 12 GHz licenses could easily be configured for multiple 100 megahertz or larger channels.[78] As explained earlier, larger license sizes can allow for wider channels that enhance spectral efficiency, increase data speeds and lower latency. In fact in the mmW auction context the FCC has stated that the 100 megahertz license size it adopted was "consistent with developing industry standards that maximize spectral efficiency."[79]

### iv. Resulting Dissimilarity Discount

Above, we have reviewed factors that likely would affect the value of 12 GHz spectrum for 5G mobile applications, both positively and negatively. Taking them into account and using our professional judgement, we believe that taken all together a reasonable discount is an additional 25% reduction in value. Recognizing there is uncertainty around this estimate, we also present estimates based on a 0% and 50% reduction in value for these factors.

# C. Other Factors Influencing Value

There are two further adjustments to the value of the 12 GHz band that need to be considered: the first is an adjustment to the overall value spectrum, and the second is specific to the 12 GHz band. As discussed below these, in our opinion, are offsetting factors in the near-term, and require no additional adjustment.

## 1. Sea-Level Change in Spectrum Value and Supply Adjustment

The first additional adjustment to consider is that with an increase in the supply of frequencies available for supporting 5G networks, the baseline values we are using will be reduced by the addition of the 12 GHz bands. Following the method we have used in prior work, we estimate the overall value of the inventory of spectrum and then calculate the impact on spectrum prices from an increase in supply, here from the addition of the 12 GHz band. The details are provided in Appendix A. We find that adding 500 MHz of 12 GHz spectrum to the overall inventory of spectrum would reduce spectrum prices, by approximately 5%.

---

[78] "Comments of RS Access," pp. 2, 14.

[79] "Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum,", p. 7.

Continued on next page

We note that even after adding the 280 megahertz from the C-band auction, looking at a five-year horizon, there is still an expected spectrum deficit, despite the increase in spectral efficiency and growth in towers.[80] The expected exponential traffic growth of mobile broadband discussed earlier will only increase such deficit which will put a downward pressure on the growth in 5G services. Making more spectrum available is the most effective way to alleviate this deficit.

## 2. Using the 12 GHz for Fixed 5G and Backhaul Services

The second additional adjustment is for an increase in value resulting from 12 GHz being useful for fixed 5G and backhaul services in those areas where it may be less useful for mobile 5G capacity on C-band macro cells. Many 5G applications involve distribution of fixed services to residential and enterprise customers. Transmission distances for fixed applications typically are longer than for mobile applications, and the engineering estimates indicate distances of at least 1.7 kilometers in rural areas.[81] Much as the C-band can be used for fixed 5G applications, so too can the 12 GHz band. Although fixed applications typically have lower values than mobile applications, these 5G applications may still have substantial value particularly in non-urban areas.

The economics of value creation in providing fixed 5G services is very different from creating value for mobile 5G services, so the value of spectrum in the two uses is not comparable without further empirical evidence. Wireline infrastructure competes with fixed wireless and provides a backstop on price, while wireline infrastructure does not compete with mobile applications. Even so, both C-band and 12 GHz spectrum has value for fixed applications.

For the population that would have mobile 5G applications in the 12 GHz band as well as the C-band, the C-band comparable we use incorporates the value of fixed applications. To the extent the covered population for fixed deployments only is larger for 12 GHz than for C-band, we are underestimating the value 12 GHz by scaling its value for expected mobile reach compared to the C-band. This is likely the case, although we have not quantified this underestimate.

Increased demand for both mobile and fixed 5G applications should put upward pressure on pricing for backhaul services and the inputs—including spectrum—needed to provide those

80 This is a measure of demand 5 years out that will not be met with the expected supply of spectrum. This measure is calculated based on traffic forecasts, increase in spectral efficiency, growth of cell towers, and the increase in spectrum supply. The deficit analysis is an updated version of the analysis in "Network Value Drivers in a 5G World".

81 "RKF Technical Study," p. 27.

services. However, because backhaul can in many instances be provided through wireline infrastructure, the amount spectrum-based backhaul can charge is limited by the backstop of this alternative.

We do not have good comparables for the value of these non-mobile services in the 12 GHz Band. As one extreme lower bound on the value of spectrum for fixed services, Verizon recently sold some of its mmW frequencies (generally assumed to be worth around $0.01/MHz-pop) for fixed wireless uses.[82] The same 12 GHz spectrum would likely be worth more in fixed uses than the equivalent amount of mmW spectrum. Consequently these fixed and backhaul services would be worth more than the 3% of the value of the 12 GHz band suggested by $0.01/MHz-pop.[83]

Taken together, we assume the net impact of the price-depressing effect of an increased spectrum supply and the price-increasing effect of these bands being attractive for fixed 5G applications and backhaul when not used in mobile networks is roughly offsetting. The balance of these considerations may be more likely to put upward pressure on our estimate of 12 GHz value—especially considering the potential for expanded fixed uses—but without estimating these effects we do not make any further adjustment to the value of the 12 GHz band for these factors.

# V. Consumer Welfare Benefits of Allocating the 12 GHz Band for Flexible Terrestrial 5G Applications

Based on the valuations estimated above, we discuss the benefits of authorizing terrestrial mobile 5G services in the 12 GHz band. We compare first discuss the baseline scenario (Scenario

[82] Mike Dano, "Verizon Sells Some 5G Spectrum to GeoLinks," March 25, 2021, https://www.lightreading.com/5g/verizon-sells-some-5g-spectrum-to-geolinks/d/d-id/768346.

$0.01 / MHz-Pop reflects a rounded average observed auction price for millimeter wave spectrum based on Auction 102. See Sasha Javid, "Auction 102 Summary," Bit Path, accessed May 6, 2021, https://sashajavid.com/FCC_Auction102.php.

[83] We apply $0.01/MHz-pop to the subset of 12 GHz population not reached by macro cell towers (e.g. 76.2% of US population). We then compare this value to our estimated value of the 12 GHz band to arrive at approximately 3% of value using the value of the 12 GHz spectrum under a 25% dissimilarity discount.

A), and then discuss the incremental value that would be created by the mobile 5G authorization in the 12 GHz band under two interference scenarios (Scenario B and C).

**Scenario A – The Baseline – the current set of allocations and rules governing the 12 GHz Band**

As discussed earlier, there are two existing satellite-based services in the 12 GHz band – the DBS and the NGSO services. Typical DBS services offer digital programming and audio services. With the increasing popularity of Over-the-Top programming, video providers such as DirecTV and DISH have been losing customers in the past few years.[84] They are using the 12 GHz band for linear television programming and standard-definition broadcasting. In the case of DirecTV, its high-definition programming is in the Ka band at the 26.5 to 40 GHz range.[85] DBS is an important, but declining, service due to the trend of migration to streaming platforms over the last few years.[86] In fact, Direct TV stopped buying satellites several years ago is pivoting towards streaming services, and is in the process of being divested by AT&T.[87] Utilization of DBS services by consumers continues to decline, and thus the potential for loss in consumer welfare for losing access to some of these services will decrease as well.

NGSOs are non-geostationary satellite systems such as Low Earth orbits (LEO) that move across the sky during their orbit around the Earth, and "must deploy a fleet of several satellites, generally called "constellations," to provide continuous broadband connectivity from 400 to

[84] Statista, "Number of Dish Network video subscribers in the United States from 1st quarter 2014 to 4th quarter 2020 (in millions)," https://www.statista.com/statistics/497299/dish-network-number-subscribers-usa/; and "Number of DirecTV video subscribers in the United States from 1st quarter 2014 to 4th quarter 2020," https://www.statista.com/statistics/497288/directv-number-video-subscribers-usa/.

[85] Ku-band uses frequencies in the 12 to 18 GHz range, while Ka-band uses frequencies in the 26.5 to 40 GHz range. The Ku Band has 6 GHz and the Ka band has 13.5 GHz (in the mmW range) for use. The Ku-band can cover an entire continent with a single beam, whereas the Ka-band has a smaller range and has to use multiple beams for country-wide coverage, but has greater bandwidth and faster speeds. *See* Aid & International Development Forum, "Ka vs Ku Band: Which is the Best for Satellite Broadband?," September 24, 2019 , http://www.aidforum.org/Topics/technology-data/ka-vs-ku-band-which-is-the-best-for-satellite-broadband/. Direct TV uses "B-Band" (250 Mhz – 750 MHz), "Coax" (475 Mhz – 625 MHz), satellite bands (1600 MHz – 1840 MHz), the L-Band (1650 – 2150 MHz), Ku-Band (12 GHz – 18 GHz) and the Ka-Band (26.5 GHz – 40 GHz). See Solid Signal, "Frequency Bands In Use," accessed March 23, 2021, https://blog.solidsignal.com/docs/Frequency%20Bands%20in%20Use.pdf. For DirectTV also see Darrin Meyer, "Satellite TV, Simplified: How Does Satellite TV Work?," accessed April 15, 2021, https://itstillworks.com/satellite-tv-simplified-satellite-tv-work-13233.html.

[86] Eric Anderson, "DISH vs. DIRECTV – Satellite TV Showdown," CATV, March 18, 2020, accessed April 14, 2021, https://www.catv.org/dish-vs-directv/.

[87] Eric Anderson, "DISH vs. DIRECTV – Satellite TV Showdown," CATV, March 18, 2020, accessed April 14, 2021, https://www.catv.org/dish-vs-directv/.

Continued on next page

2,000 kilometers above the Earth[88] Currently, there are six authorized LEO providers with access to spectrum in the 12 GHz band including Space X with its Starlink constellation, OneWeb and Kepler.[89] These operations currently serve a limited number mostly invited users in remote and rural areas.[90]

**Scenario B – Sharing without interference – a sharing scenario in which DBS and NGSO systems continue to operate, coexisting with 5G terrestrial broadband services**

Under this scenario, the opportunity cost of the reallocation is zero. Thus, the MVDDS users could deploy terrestrial mobile services without interfering with either the DBS services or the NGSO satellite services.

No transition costs imply that all three services would maximize the value created. In this scenario, there is no tradeoff between the current services and the 5G allocation in this band unlike, say, in the 600 MHz Band or the C-band, where existing services had to vacate the spectrum after reallocation.[91] The net welfare impact of the reallocation is the value of adding the terrestrial uses to the band. The economic value of this is primarily estimated to be $40.6 billion within a range of $27.1 billion - $54.1 billion (see Table 1). If past estimates of the total value of spectrum to consumers hold at 10 to 20 times the spectrum's economic value, this suggests total net expected welfare increase of $270 - $1,082 billion.[92]

**Scenario C – Sharing with limited interference – a sharing scenario with limited interference in which DBS and NGSO systems continue to operate, coexisting with 5G terrestrial broadband services**

[88] ITU, "Non-geostationary satellite systems," accessed April 14, 2021, https://www.itu.int/en/mediacentre/backgrounders/Pages/Non-geostationary-satellite-systems.aspx.

[89] "12 GHz NPRM," ¶¶ 16-17.

[90] Michael Sheetz, "What Early Users of SpaceX's Starlink Satellite Internet Think About the Service, Speed and More," CNBC, ASpril 16, 2021, https://www.cnbc.com/2021/04/15/spacexs-starlink-early-users-review-service-internet-speed-price.html.

[91] For C-band see, Inside Towers, "Here are C-Band Move Cost Estimates," July 31, 2020, https://insidetowers.com/cell-tower-news-here-are-c-band-move-cost-estimates/. For the 600 MHz auction see, S&P Global Market Intelligence, "More Than 99% of TV Stations Moved off 600 MHz Wireless Spectrum – FCC," July 14, 2020, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/more-than-99-of-tv-stations-moved-off-600-mhz-wireless-spectrum-8211-fcc-59415231.

[92] In addition to the direct economic value generated by the spectrum (as reflected in the value), i.e. the producer's surplus, there are welfare benefits to consumers of the services enabled by the spectrum. "For mobile wireless services, economists estimated that the total social benefits from licensed spectrum are at least 10 to 20 times the direct economic value of the spectrum." *See* "Mobile Broadband Spectrum,", p. 1.

It may be the case that a new use will diminish services in the 12 GHz Band. Our understanding is that engineering studies find limited (under 1%), if any, interference, but we examine in this subsection how the Commission should evaluate 5G applications in the 12 GHz even in the presence of some limited interference. Even in the presence of new interference, authorizing 12 GHz spectrum to be used in mobile 5G broadband networks is consumer welfare enhancing if the incremental value of the 12 GHz band in the new use exceeds the costs of modifying the existing uses of the band. This is not a straightforward calculation for at least three reasons:

1. Based on the engineering considerations, there may be tradeoffs in future service among DBS, NGSO, and 5G (e.g., as DBS continues to decline, NGSO viability becomes more apparent, and 5G continues to grow in importance). These tradeoffs would depend on specific engineering parameters that have not yet been determined.

2. Even if the engineering parameters were precisely known, there can be substantial differences between (a) the value of lost services caused by interference; and (b) the cost of remediation to restore service to the level that would have been obtained without interference.

3. NGSO authorizations were conditioned on the outcome of this proceeding. NGSOs that chose to operate in the 12 GHz Band, a choice that other NGSO FSS aspirants did not make, were on notice of the risk they were taking when 15 GHz or more of other spectrum was also authorized.

Our expectation is that the costs from harmful interference would be extremely low, and such interference can possibly be mitigated by cost-effective technical solutions.[93] DISH, one of the two DBS providers supports allowing terrestrial mobile 5G operations in the 12 GHz band, strongly suggesting the benefits outweigh the costs. For the NGSOs, their target markets tend to be complementary to the most valuable uses of 12 GHz. The proporition of NGSO subscribers who would potentially receive interference is exceedlingly small, and the nature of the interference itself may not even materially impact their user experience. So long as any costs from potential interference are only a fraction of the value of consumer welfare added in the band—which is highly likely given the relatively large values created by terrestrial use of

93 For e.g, *see* "12 GHz NPRM," ¶¶ 41-51.

Continued on next page

spectrum—significant value will be created by adding 12 GHz to the arsenal of spectrum available for 5G.[94]

# VI. Conclusion

The value of radio spectrum is derived from using it – and any delay in allowing the 12 GHz band to support 5G services will create an unrecoverable costs. The largest of these losses will be suffered by consumers, who will have to wait to benefit from the new services that the 12 GHz frequencies will enable. Jerry Hausman, in his 1997 paper on the cost of delay in mobile phones in the U.S., showed that regulatory delays often lead to large losses in consumer surplus that "cannot be regained in subsequent periods" and there can be persistent "consumer welfare losses from past regulatory delays."[95] Thus authorizing mobile terrestrial use in the 12 GHz band without delay is of utmost importance.

We find that without interference associated with new 5G applications in the 12 GHz band the incremental economic benefit of authorizing terrestrial mobile services in the band is likely $40.6 billion, within a range of $27.1 - $54.1 billion. The annual consumer welfare gains are expected to equal this increase in spectrum value.[96] On a present value basis, this suggests a total net consumer welfare increase of $270 - $1,082 billion. It also highlights the costs of delaying putting this spectrum to its highest valued uses – $27.1 - $54.1 billion per year. Interference and opportunity costs associated with the 5G authorization in the 12 GHz band are likely small so DBS and NGSO services should be able to share the band without significant loss of the services they provide. This would be a welfare increasing expansion of use as long as the economic value given up by other users is less than $27.1 billion.[97]

94 In fact, given how much value is created by allowing terrestrial mobile 5G uses in the 12 GHz band, the losses in value to services from potential interference can be equally as high before allowing such expanded uses of the band would no longer be value creating.

95 Jerry A. Hausman, "Valuing the Effect of Regulation on New Services in Telecommunications," Brookings Papers: Microeconomics, 1997, pp. 35-36. https://pdfs.semanticscholar.org/c0b0/675b01bd38e14ec3deeaeda8e797a2df148e.pdf. ("Valuing the Effect of New Regulation").

96 Thomas W. Hazlett and Roberto E. Muñoz, "A Welfare Analysis of Spectrum Allocation Policies," RAND Journal of Economics. Vol.40(3), 2009, pp. 424-454, https://ideas.repec.org/a/bla/randje/v40y2009i3p424-454.html.

97 Of course, if the value of the 12 GHz frequencies was higher, this threshold would be higher.

There are *currently* over 400 million mobile subsribers in the U.S. who are exhibiting sustained increasing demand for 5G services, in contrast to the declining pool of current DBS users and the relatively limited pool of theoretical NGSO subscribers years in the future if proven economically viable. Given the overwhelming weight of terrestrial subsribers in the U.S. relative to other users, both today and in the future, allowing terrestrial mobile uses of the 12 GHz band is almost surely the welfare-maximizing path for the FCC to take. Consequently, even with limited interference we expect the incremental value of allowing mobile 5G services into the 12 GHz to be all or nearly all of $27.1 - $54.1 billion and the incremental total societal benefits to be all or nearly all of $270 billion - $1,082 billion.

# Appendix A: Impact of Increased Supply on Spectrum Price

Spectrum's market value is derived from the profits that can be made from deploying it. The overall sea level of spectrum value is set by macro factors such as overall levels of demand for spectrum-based services, the total supply of spectrum available to provide those services, and the type of technology. Individual license valuations, and therefore the relative value of spectrum, can be affected by many factors including frequency, regulatory restrictions, and the maturity of technological ecosystems.[98]

To estimate the effect of adding 12 GHz frequencies to the stock of spectrum available for mobile broadband uses we first establish the value of the existing stock of spectrum and then update prices based on the increased supply.

## 1. Spectrum Baseline

Below we briefly describe these current licensed frequencies.[99] These frequencies are ones available to be integrated in mobile broadband networks. Many of these frequencies are also used for fixed applications; we do not include frequencies that are only useful for fixed services on a stand-alone basis.

- *Sub-1 GHz (Low Band)*: Currently, the licensed sub-1 GHz frequencies – 600 MHz, 700 MHz and 800 MHz (cellular and SMR) bands – have a total of 204 megahertz licensed.
- *Between 1 GHz and 3 GHz (Low-Mid Band)*: The licensed frequencies in this band are the AWS-1, AWS-3, AWS-4, PCS, H-Block, WCS, BRS/EBS bands and the new

---

98 For a more lengthy explanation of the value of radio spectrum, see "Spectrum Value," pp. 737–747.

99 In the near term, another 100 megahertz in the 3.45 GHz – 3.55 GHz is becoming available in late 2021. In the medium and longer term, other allocations being considered include 1300 – 1350 MHz, 3.1 – 3.45 GHz, the 42 GHz bands. We do not include this in our inventory as we do not know what the encumbrances will be on these bands and when they will be available for commercial use. See, FCC, "Facilitating Shared Use in the 3100-3550 MHz Band," report and Order, DA/ FCC No. FCC-21-32, Docket No. 19-348, adopted March 17, 2021, https://www.fcc.gov/document/fcc-opens-100-megahertz-mid-band-spectrum-5g-0.

Continued on next page

2.5 GHz spectrum, which on total comprise 511.5 megahertz of licensed spectrum.[100] There are two possible additions to this band expected in the near-term: 10 megahertz of spectrum from the NOAA/Ligado band (1670 MHz – 1680 MHz band) and an additional 23.5 megahertz of 2.5 GHz band spectrum that was previously unlicensed will be licensed.[101] The total then is 545 megahertz of spectrum.

- *3 GHz – 24 GHz (Mid-Band)*: The recently auctioned 70 megahertz in the 3.5 GHz band and the 280 megahertz from the C-band auction.[102]
- *Above 24 GHz (mmW Bands)*: The total mmW spectrum licensed for use through Auctions 101 – 103 is 4,950 megahertz, which includes 850 megahertz of the 28 GHz band, 700 megahertz of the 24 GHz band, along with 2,400 megahertz in the Upper 37 GHz and 39 GHz spectrum bands, and 1,000 megahertz in the 47 GHz band.
- Adding spectrum from each of the buckets show the totals by each group.
    - The low and low-mid band spectrum inventory, which makes up the traditional CMRS frequencies, totals 749 megahertz.[103]
    - Adding the 3 GHz - 24 GHz spectrum brings this total of low and mid band spectrum to 1,099 megahertz.
- After adding the mmW spectrum, the total licensed spectrum inventory stands at 6,149 megahertz.
- 500 megahertz of 12 GHz will be added to this inventory for a total of 6,649 megahertz.

---

[100] We use 156.5 megahertz for the BRS/EBS spectrum to match the bands excluded from the FCC's updated spectrum screen. *See*, FCC, "Policies Regarding Mobile Spectrum Holdings," Report and Order, WT Docket No. 12-269, June 2, 2014, at ¶¶ 107-125, https://apps.fcc.gov/edocs_public/attachmatch/FCC-14-63A1.pdf. *See also*, "Mobile Broadband Spectrum," p. 7.

[101] The 23.5 megahertz of 2.5 GHz band spectrum is added since the Commission has made EBS white space spectrum available for commercial use, See FCC, " Transforming the 2.5 GHz Band," Report and Order, WT Docket No. 18-120, ¶¶ 98-100, https://docs.fcc.gov/public/attachments/DOC-358065A1.pdf.

[102] FCC, "Auction of Priority Access Licenses for the 3550-3650 Band; Notice and Filing Requirements, Minimum Opening Bids, Upfront Payments, and Other Procedures for Auction 105; Bidding in Auction 105 Scheduled to Begin June 25, 2020," Public Notice, Docket/RM: 19-244, DA/FCC #: FCC-20-18, adopted February 28, 2020, https://www.fcc.gov/document/fcc-establishes-procedures-35-ghz-band-auction-0. *See also*, FCC, "FCC Acts To Free Up C-band Spectrum For 5G Services," News Release, GN Docket # 18-122, adopted February 28, 2020, https://www.fcc.gov/document/fcc-expands-flexible-use-C-band-5g and Coleman Bazelon and Paroma Sanyal, "Mobile Broadband Spectrum: A Revaluation in a 5G World," CTIA, May 20, 2019, ("Mobile Broadband Spectrum: A Revaluation in a 5G World").

[103] The inventory currently available is 715.5 megahertz. *See* FCC, "Communications Marketplace Report", November 21, 2018, GN Docket No. 18-231, Figure A-23, p. 30, https://docs.fcc.gov/public/attachments/DOC-355217A1.pdf.

APPENDIX TABLE 1: SPECTRUM BASELINE

| | Band Name | Location | Potential Spectrum Supply (MHz) |
|---|---|---|---|
| | [a] | [b] | [c] |
| [1] | 600 MHz | 600 MHz | 70 |
| [2] | 700 MHz | | |
| [3] | Paired | 700 MHz | 58 |
| [4] | Unpaired | 700 MHz | 12 |
| [5] | Cellular | 800 MHz | 50 |
| [6] | SMR | 800 MHz / 900 MHz | 14 |
| [7] | NOAA/Ligado | 1670 - 1680 MHz | 10 |
| [8] | AWS-1 | 1.7 GHz / 2.1 GHz | 90 |
| [9] | PCS | 1.9 GHz | 120 |
| [10] | G-Block | 1.9 GHz | 10 |
| [11] | H-Block | 1.9 GHz /2.0 GHz | 10 |
| [12] | AWS-3 | | |
| [13] | Paired | 1.7 GHz / 2.1 GHz | 50 |
| [14] | Unpaired | 1.7 GHz | 15 |
| [15] | AWS-4 | 2.0 GHz / 2.2 GHz | 40 |
| [16] | WCS | 2.3 GHz | 20 |
| [17] | BRS/EBS | 2.5 GHz | 156.5 |
| [18] | EBS New | 2.5 GHz | 23.5 |
| [19] | 3.45 - 3.55 GHz | 3.45 - 3.55 GHz | 100 |
| [20] | CBRS | 3.5 GHz | 70 |
| [21] | C-Band | 3.7 GHz / 4.2 GHz | 280 |
| [22] | 12 GHz | 12 GHz | 500 |
| [23] | 24 GHz | 24 GHz | 700 |
| [24] | 28 GHz | 28 GHz | 850 |
| [25] | 37 GHz | 37 GHz | 1,000 |
| [26] | 39 GHz | 39 GHz | 1,400 |
| [27] | 47 GHz | 47 GHz | 1,000 |
| **[28]** | **Total** | | **6,649** |

## 2. Valuation

To establish the value the spectrum inventory baseline, we use a generic mid-band around 2GHz as the anchor and then use estimates of the relative value of all bands vis-à-vis the anchor band, to estimate the value of the baseline inventory.[104] We then estimate the effect of adding 500 megahertz of 12 GHz spectrum to this inventory. Based on our experience and past practices, we assume that adding a single band to the existing inventory of spectrum does not change the total profits that can be earned from the wireless sector. This may be a conservative assumption, but it is likely true to a large degree as any services provided on a new band will cannibalize services provided on existing bands to some degree. The efficiency of wireless services will increase, leading to an expansion of the value created by the industry, but this expansion will be less than the gross value created by the new spectrum. Furthermore, this expansion in value likely does not lead to a one-for-one expansion in profits and, therefore, does not lead to a similar expansion in spectrum value.

Adding a band of spectrum to the inventory has two, offsetting effects. First, the additional frequencies add to the total stock of spectrum, increasing the quantity of spectrum being valued. Second, the increased supply is expected to reduce the value of the bands already in the inventory. Again based on prior research, we assume an elasticity of -1, which implies that a 1% increase in the base supply of spectrum should result in a 1% decrease in its price. Consequently, the expected price decreasing effects of adding 500 MHz of 12 GHz spectrum will be about equal to the percentage increase in (relative value weighted) supply the 12 GHz frequencies represent. Our analysis suggests that after taking into account the relataive values of different bands, the 500 megahertz of 12 GHz spectrum represents an increase of approximately 5% of the total mobile broadband spectrum inventory. As a result, we expect the price decreasing effect of this increase supply to also be about 5%.

[104] See, for example, Coleman Bazelon and Paroma Sanyal, "Mobile Broadband Spectrum: A Revaluation in a 5G World," CTIA, May 20, 2019.