Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Expanding Flexible Use of the 12.2-12.7 GHz Band	)	WT Docket No. 20-443
	)	
Expanding Flexible Use in Mid-Band Spectrum Between 3.7-24 GHz	)	GN Docket No. 17-183

REPLY COMMENTS OF RS ACCESS, LLC

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EXECUTIVE SUMMARY

A diverse array of commenters across industry sectors support the Commission's efforts to update its 12.2-12.7 GHz band ("12 GHz band") rules to unleash 500 megahertz of prime mid-band spectrum for 5G mobile broadband. Mobile broadband operators, public-interest groups, satellite companies, fixed-wireless operators, trade associations, spectrum-sharing experts, and Multichannel Video Distribution and Data Service ("MVDDS") operators agree that releasing more mid-band spectrum for terrestrial 5G serves the public interest by spurring billions of dollars in economic growth, fostering broadband equity, and promoting national security. The economic upside is enormous: according to economists from the Brattle Group, the value of the 12 GHz band for 5G could be as high as $54 billion and create more than a trillion dollars in benefits for society at large.

The 12 GHz band is a critical opportunity to accelerate U.S. 5G deployment. 5G proponents include New America's Open Technology Institute and Public Knowledge, which argue that opening the band for 5G will "promote the deployment of 5G services, promote competition . . . spur innovation, and help to address the digital divide in underserved communities." Competitive Carriers Association points out that current MVDDS rules are "ill suited to support two-way, high-power, Internet-based communications that are in demand and can simultaneously support a suite of applications, one of which may be video delivery." INCOMPAS and CCIA observe that this proceeding represents "an opportunity for the Commission to modernize decades-old rules while unlocking critical capacity in the 12 GHz spectrum." Two national mobile carriers have participated in this proceeding, and neither disputes the band's value for 5G. For its part, T-Mobile recently "urge[d] the Commission to consider making some or all of the [12 GHz] band available for terrestrial mobile operations."

Despite their diversity of interests, all 5G proponents agree that maintaining the regulatory *status quo* does not serve the public interest.

A technical report prepared by Roberson and Associates, LLC submitted with these reply comments ("Roberson Report") confirms that the 12 GHz band is ideal for 5G, with performance characteristics closer to the C-band and far superior to millimeter-wave bands. The report explains, for example, that the 12 GHz band's favorable propagation characteristics would allow 12 GHz base stations to provide the same coverage as five to fifteen millimeter-wave base stations. Moreover, the Roberson Report finds that, because the 12 GHz band attenuates less readily than millimeter-wave bands, it can better support higher-order modulation techniques, which enhance the relative spectral efficiency of the 12 GHz band. While spectral efficiency ultimately depends on the characteristics of a particular deployment and the channel quality between a base station and end-user device, the Roberson Report estimates that 500 megahertz in the 12 GHz band could support aggregate downlink throughput of 20.0 Gbps—a figure markedly higher than either the estimated 15.1 Gbps feasible using the 280 megahertz of spectrum in the C-band or the estimated 9.0 Gbps using the 850 megahertz of spectrum in the 28 GHz band. The differences in peak spectral efficiency are particularly stark when comparing the 12 GHz and 28 GHz bands: one megahertz of 12 GHz spectrum can carry 3.76 times as much data as one megahertz of 28 GHz spectrum (under peak throughput conditions). The Roberson Report also explains why, given the technologies being used for 5G, the practical deployment of 12 GHz should be straightforward, complementing current higher- and lower-frequency spectrum bands. In addition, the report finds that new consumer and network devices could be 12 GHz-compatible within one to two years of Commission adoption of a decision in this proceeding.

Coexistence among NGSO, DBS, and 5G is achievable. The key technical question before the Commission is whether 5G operations can coexist with non-geostationary satellite orbit Fixed-Satellite Service ("NGSO FSS") and Direct Broadcast Satellite ("DBS") licensees in the band. As the record makes clear, nationwide 5G operations can coexist with NGSO FSS and DBS. RKF Engineering Solutions, LLC's coexistence study, submitted with RS Access, LLC's initial comments, shows that 5G and NGSO FSS operations are complementary, not zero sum. Even if currently hypothetical NGSO services manage to develop sustainable business models, are deployed nationwide, and acquire subscribers well beyond current forecasts, the probability that an NGSO user terminal will experience an interference-to-noise ratio of -8.5 dB or greater (the ITU-prescribed limit) from co-channel 5G operations is less than 0.888%. Put differently, NGSO operators will experience a minimal likelihood of potential interference events, which mitigation techniques, good-faith coordination, and other time-tested measures can address. Indeed, rapid technical advances in antenna design and mobile network architectures have made coexistence among 5G and NGSO services more achievable now than when this proceeding began in 2016. The record also shows that DBS coexistence is achievable—a fact underscored by the support of DISH Network Corporation, one of two DBS operators in the United States. And given the many sharing advances since 2016 and the decline in satellite television subscribers, coexistence between 5G and DBS is similarly even more practical than it was half a decade ago.

The most efficient way to introduce flexible-use rights into the 12 GHz band is through incumbent MVDDS operators. This proceeding's twin goals are "putting spectrum to its highest-value and most efficient use while protecting incumbent operations in the band from harmful interference." In proceedings where the Commission has sought to intensify spectrum use while preserving incumbents' operations, the agency has opted to expedite time-to-market and reinforce existing incentives for reform by modernizing the service rules and modifying incumbent licenses.

By contrast, the clear-and-auction approach urged by some commenters is ill suited to the task of accelerating 5G investments. The Commission typically clears and auctions spectrum when the incumbents either do not use the spectrum or desire to vacate. Here, the Commission should maintain DBS and NGSO FSS licensees' ability to operate alongside terrestrial services, so seizing the geographic-area licenses the MVDDS operators won at auction would therefore not only represent an unprecedented exercise of Commission authority, but also fail to create unencumbered spectrum for 5G deployment.

The time to act is now. Even after scheduled and pending auctions conclude, the United States will remain behind other countries in deployed and licensed 5G spectrum, with no other mid-band spectrum in the pipeline to meet domestic demand. By taking swift action to modify the 500 megahertz of existing terrestrial licenses in the 12 GHz band, the Commission can achieve a "win-win-win" for industry and consumers while propelling the United States into a global leadership position in mid-band spectrum for next-generation broadband.

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REPLY COMMENTS OF RS ACCESS, LLC

I. INTRODUCTION

The record decisively supports RS Access, LLC's ("RS Access") call for modernizing the 12 GHz band by allowing MVDDS licensees to offer two-way, mobile 5G services. A diverse array of commenters across industry and public-interest organizations agree: releasing more mid-band spectrum for 5G will serve U.S. economic and national security interests. Wireless carriers agree that upper mid-band spectrum will need to play an important role for 5G and beyond.[1] The 12 GHz band's 500 megahertz of spectrum is particularly well suited to meet this need because it (1) is already licensed for terrestrial use and free from federal incumbents, so the Commission can enable 5G services without delay; (2) sits about one-third of the way between 3 GHz and 24 GHz, allowing operators to enhance their spectrum portfolios and optimize deployments from the 600 MHz band to the millimeter-wave frequencies; and (3) can allow high-capacity channel sizes of 100 megahertz or more. The economic benefits are substantial. Economists from the Brattle Group project that the value of 5G in the 12 GHz band ranges from

[1] *See, e.g.*, Comments of T-Mobile USA, Inc., WT Docket No. 20-443 and GN Docket No. 17-183 (filed May 7, 2021) ("T-Mobile Comments") ("Making available additional spectrum, particularly in higher mid-band frequencies, is important for the continued deployment of 5G.").

$27 billion to $54 billion and could create more than a ***trillion*** dollars in social welfare benefits for American consumers ("Brattle Group Study").[2]

The key technical question before the Commission is whether 5G operations can coexist with proposed non-geostationary satellite orbit Fixed-Satellite Service ("NGSO FSS") operations and authorized Direct Broadcast Satellite ("DBS") licensees in the band. The record's technical analyses establish that all incumbent services can coexist.[3] The 5G/NGSO FSS coexistence study by RKF Engineering Solutions, LLC ("RKF NGSO Study") shows that 5G and NGSO operations are complementary and can operate together.[4] The study finds that, even if NGSO services manage to develop a sustainable business model and acquire subscribers far beyond current forecasts,[5] the probability that an NGSO user terminal will experience an interference-to-noise ratio of -8.5 dB[6] or greater is less than 0.888%—a minimal likelihood that mitigation

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[2] *See* Comments of RS Access, LLC, WT Docket No. 20-443 and GN Docket No. 17-183, Appendix B at 18 (filed May 7, 2021) ("RS Access Comments").

[3] *Id.*, Appendix A ; Comments of MVDDS 5G Coalition, RM-11768, Attach. 1, MVDDS 12.2-12.7 GHz Co-Primary Service Coexistence, at 32-35 (filed June 8, 2016) ("Coexistence I); Tom Peters, MVDDS 12.2-12.7 GHz Co-Primary Service Coexistence II (filed June 23, 2016), Attachment I to Reply Comments of MVDDS 5G Coalition, RM-11768 (filed June 23, 2016) ("Coexistence II") (revalidating the original coexistence study in different topological use cases); Tom Peters, MVDDS 12.2-12.7 GHz NGSO Coexistence Study (filed Aug. 15, 2016), Attachment I of Petition to Deny of MVDDS 5G Coalition, RM-11768 *et al.* (filed Aug. 15, 2016).

[4] RS Access Comments, Appendix A.

[5] RKF assumes an NGSO subscriber ecosystem of 2,500,000 subscribers, more than double the current authorization of NGSO operator Space Exploration, Inc. ("SpaceX"), and more than triple the estimated system capacity. *See* Craig Moffett *et al.*, *Is Starlink a Substitute for, or a Supplement to, Wired Broadband?*, MoffettNathanson, at 25 (Apr. 5, 2021) ("*Is Starlink a Substitute for, or a Supplement to, Wired Broadband?*").

[6] Recommendation ITU-R SF.1006, *Determination of the Interference Potential Between Earth Stations of the Fixed-Satellite Service and Stations in the Fixed Service*, ITU, Table 1 (2017), https://bit.ly/3eYqhew.

techniques, good-faith coordination, and other time-tested measures can address.[7]

The record also shows that DBS coexistence is achievable. In 2016, a series of technical reports showed that 5G base stations could be sited to avoid interference to DBS receivers even in ultra-conservative deployment scenarios in urban areas.[8] Given the many sharing advances since 2016 and the ongoing decline in linear television subscribers in general—and satellite television subscribers in particular[9]—coexistence is even more practical than it was half a decade ago. No party has presented technical evidence to suggest that 5G/DBS coexistence is infeasible. To the contrary, DISH Network Corporation ("DISH"), one of the two U.S. DBS providers, supports introducing 5G into the 12 GHz band and submitted a declaration reaffirming the conclusions drawn in the 2016 coexistence studies.[10]

The time to act is now. Given the band's potential role for U.S. 5G leadership without undermining NGSO FSS or DBS, the upside is too great to ignore. Updating the rules for the 12 GHz band to allow 5G will stimulate billions of dollars in economic growth, produce immense consumer benefits, and promote national security.

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[7] *Id.* at 51.

[8] *See supra* note 3.

[9] *See, e.g.,* Lee Rainie, *Cable and satellite TV use has dropped dramatically in the U.S. since 2015*, Pew Research Center (Mar. 27, 2021), https://pewrsr.ch/3d9Pl2a ("The share of Americans who say they watch television via cable or satellite has plunged from 76% in 2015 to 56% this year, according to a new Pew Research Center survey of U.S. adults.").

[10] Comments of DISH Network Corporation, WT Docket No. 20-443 and GN Docket No. 17-183, at 3-4 (filed May 7, 2021) ("DISH Comments"); *id.* at Ex. 1.

II. BRINGING 5G TO THE 12 GHZ BAND SERVES THE PUBLIC INTEREST.

A. Commenters Widely Agree that the United States Needs More Mid-Band Spectrum to Ensure Its Global 5G Leadership.

Mobile broadband operators,[11] public-interest groups,[12] satellite companies,[13] fixed-wireless operators,[14] trade associations,[15] spectrum-sharing experts,[16] and MVDDS licensees[17] with diverse interests and perspectives agree that releasing more mid-band spectrum for terrestrial 5G serves the public interest by promoting national security, propelling economic growth, and fostering broadband equity.[18] Consumer demand for mobile broadband has exploded in recent years. As CTIA recently said, "With the right policies in place, 5G will be transformative—making our lives better, our communities safer, and our nation more prosperous. The key is spectrum, particularly mid-band spectrum."[19] Other commenters agree. As one group of 12 GHz licensees explained, public demand for wireless products and services shows

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[11] T-Mobile Comments.

[12] Comments of the Public Interest Organizations, WT Docket No. 20-443 *et al.* (filed May 7, 2021) ("PIO Comments").

[13] DISH Comments.

[14] Comments of Starry, Inc., WT Docket No. 20-443 and GN Docket No. 17-183 (filed May 7, 2021) ("Starry Comments").

[15] Comments of Competitive Carriers Association, WT Docket No. 20-443 and GN Docket No. 17-183 (filed May 7, 2021) ("CCA Comments"); Joint Comments of INCOMPAS and CCIA, WT Docket No. 20-443 and GN Docket No. 17-183 (filed May 7, 2021) ("INCOMPAS/CCIA Comments").

[16] Comments of Federated Wireless, Inc., WT Docket No. 20-443 and GN Docket No. 17-183, at 1 (filed May 7, 2021); Comments of the Dynamic Spectrum Alliance, WT Docket No. 20-443 and GN Docket No. 17-183, at 9-10 (filed May 7, 2021) ("DSA Comments").

[17] Comments of the Go Long Wireless, Ltd. *et al.*, WT Docket No. 20-443 and GN Docket No. 17-183, at 8 (filed May 7, 2021) ("Go Long Wireless Comments").

[18] *See, e.g.*, RS Access Comments at 5-9.

[19] Letter from Meredith Baker, President & CEO, CTIA, to Marlene H. Dortch, Secretary, FCC, WT Docket No. 19-348 *et al.*, at 3 (filed Jan. 20, 2021).

no signs of abating and "has consistently driven an ever-increasing demand for additional spectrum resources."[20]

While the Commission has had meaningful success in allocating mid-band spectrum for 5G, including in the 3.70-3.98 GHz band ("C-band") and 3.45-3.55 GHz band ("3.45 GHz band"), mobile broadband operators continue to urge the Commission to expand that allocation.[21] Adding together all low- and mid-band spectrum currently assigned or in the FCC's spectrum pipeline,[22] the Commission has designated about 1,200 megahertz for 5G.[23] The 12 GHz band would—by itself—increase this spectrum pool by more than 40%—a massive boost to 5G spectrum between 3 GHz and 24 GHz. T-Mobile, for example, agrees that "[m]aking available additional spectrum, particularly in higher mid-band frequencies, is important for the continued deployment of 5G."[24] Competitive Carriers Association, which represents smaller rural and regional mobile operators, likewise observes that "[m]id-band spectrum will play a critical role in enabling network deployments that meet commercial demands in a 5G world."[25] According to a study from the Brattle Group, the 12 GHz band's value when employed for terrestrial 5G use ranges from *$27 billion to $54 billion*.[26] The Brattle Group Study estimates that modernizing the

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[20] Go Long Wireless Comments at 8-9.

[21] *See* CCA Comments at 2; T-Mobile Comments at 5; DISH Comments at 14.

[22] This figure includes the C-band, 70 megahertz of CBRS spectrum, and the 3.45 band.

[23] RS Access Comments, Appendix B at 39.

[24] T-Mobile Comments at 5; *see also* Reply Comments of T-Mobile USA, Inc., AU Docket No. 20-429, at 2 (filed May 27, 2021) ("As recent auctions demonstrate, there remains a strong demand for mid-band spectrum to meet expanding communications requirements. Consumer-driven need for increased network capacity has accelerated during the pandemic and will not be reversed even after the pandemic abates.").

[25] CCA Comments at 2.

[26] RS Access Comments, Appendix B at 35.

12 GHz band rules could create more than a trillion dollars in social welfare benefits for the American people.[27]

Economic prosperity goes hand in hand with national security, and as RS Access explained in its initial comments, more mid-band spectrum is necessary for the United States to keep pace with 5G competitors like China.[28] DISH agrees, citing the Congressional Research Service ("CRS"), which recently found that "China is the current leader in [low-band and mid-band] technologies and is likely to deploy the world's first 5G wide-area network."[29] The CRS Report explains that 5G technologies are expected to lead to improved military intelligence and efficiency and myriad other practical applications.[30] Similarly, the Department of Homeland Security has concluded that 5G is vital to other national security strategies, including promoting open and transparent international standards and working closely with the private sector to identify and mitigate risks, among other things.[31]

Virtually no commenter disputes the need for more 5G-ready mid-band spectrum. The recently released 2021 Ericsson Mobility Report finds,[32] for example, that 5G remains on track to become the fastest adopted mobile generation in history,[33] North American per-user mobile

[27] *See* RS Access Comments, Appendix B at 36.

[28] RS Access Comments at 8.

[29] DISH Comments at 16-18 (internal quotations omitted).

[30] John R. Hoehn & Kelley M. Sayler, *National Security Implications of Fifth Generation (5G Mobile Technologies)*, CRS, at 2 (updated Apr. 23, 2021), https://bit.ly/3vItw0Z ("CRS Report").

[31] *5G Introduces New Benefits, Cybersecurity Risks*, Department of Homeland Security (Oct. 15, 2020), https://bit.ly/2SOxhDg.

[32] *Ericsson Mobility Report*, Ericsson (June 2021), https://bit.ly/2SLs5Rj.

[33] *Id.* at 2 ("The speed of 5G uptake is far higher than it was for 4G, let alone 3G, and it is one more sign of an industry that tirelessly continues to drive innovation and bring new technology to the market.").

data traffic will increase from 11 GB in 2020 to 48 GB by 2026,[34] and year-over-year mobile data traffic increased 46%.[35]

To avoid the inescapable conclusion that more spectrum is needed to meet the exploding demand for mobile data, some participants in this proceeding have conflated the unique roles that low-band, mid-band, and millimeter-wave spectrum play, seeking to put the 12 GHz band in the wrong category. OneWeb argues, on the one hand, that different spectrum bands have different performance characteristics[36] and, on the other, that "the 12 GHz band represents only 10% of the 5000 MHz of high band spectrum."[37] OneWeb is correct that not all spectrum bands perform equally, but it is wrong to include the 12 GHz band with "high band spectrum" ranging up to 47 GHz. Spectrum like the 12 GHz band offers in-building penetration and coverage far superior to millimeter-wave bands and more capacity than lower-frequency bands.[38] The attached study from engineering consultancy Roberson and Associates, LLC ("Roberson Report") finds that the "12 GHz band's similarities to lower mid-band spectrum dramatically enhance the band's utility for mobile broadband networks."[39] The practical significance of this finding cannot be

[34] *Id.* at 14.

[35] *Id.* at 12.

[36] Comments of OneWeb, WT Docket. No. 20-443 and GN Docket No. 17-183, at 20 (filed May 7, 2021) ("OneWeb Comments") ("[T]he inter-site distance at these [12 GHz] frequencies will be much smaller than typical inter-site distances of mid-band spectrum at 2.5 GHz or 3.5 GHz . . . .").

[37] *Id.* at 16 ("[T]he 12 GHz band represents only 10% of the 5000 MHz of high band spectrum already available to 5G operators in the United States and only 6% of the total high band spectrum expected to be available in the medium-term in light of the Commission's expansion of flexible-use allocations to the 26 GHz and 42 GHz bands . . . .").

[38] *See* RS Access Comments at 14-20.

[39] Roberson Report at 4.

overstated. For example, 12 GHz base stations could provide the same coverage as five to fifteen millimeter-wave base stations.[40]

In contrast to the detailed and well documented analysis provided by the Roberson Report, OneWeb offers only undocumented assertions for its claim that the 12 GHz band is just another millimeter-wave band. The haphazard lumping together of spectrum bands with different performance characteristics is anathema to Commission policy and the wireless industry's approach to spectrum use.[41] For example, the Commission's spectrum screens distinguish between millimeter-wave spectrum and low- and mid-band spectrum.[42] As Verizon Executive Vice President Ronan Dunne recently explained, millimeter-wave bands are playing a *supplemental* role in Verizon's mobile broadband deployment strategy, "Millimeter wave . . . was always, always deployed on the basis of an *augmentation* of capacity in the mobility network . . . . [W]e're delivering millimeter wave as a fundamental *enhancement* of experience and capacity in the areas that have the densest demand for traffic."[43] And again, as the Roberson

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[40] *Id.*

[41] *Communications Marketplace Report*, 2020 Communications Marketplace Report, 36 FCC Rcd 2945 ¶ 32 (2020) ("*2020 Communications Marketplace Report*") ("The Commission adopted a separate threshold for mmW spectrum holdings, with an associated trigger of 1850 megahertz, as an initial analytical tool to aid in identifying certain markets for further review in proposed secondary market transactions.").

[42] *See, e.g.*, *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services et al.*, Report and Order and Further Notice of Proposed Rulemaking, 31 FCC Rcd 8014 ¶ 185 (2016) ("*Spectrum Frontiers R&O*") ("Historically, mmW frequencies have been considered unsuitable for mobile applications because of propagation losses at such high frequencies and the inability of mmW signals to propagate around obstacles. . . . bands above 24 GHz were not typically considered for standalone mobile services but rather as supplementary channels to deliver ultra-high speed data in specific places.").

[43] Verizon Communications Inc. (VZ) Management Presents at Annual Bernstein Strategic Decisions Conference (Transcript), Seeking Alpha (June 2, 2021), https://bit.ly/3wX9gZA (emphasis added).

Report extensively details, the performance of the 12 GHz band is far closer to the C-band than to the millimeter-wave bands.

RS Access has repeatedly emphasized that the FCC need not treat the 12 GHz band as a zero-sum choice between different use cases. Coexistence between 5G, DBS, and NGSO systems offers a win-win-win for the American public, which would reap the benefits of greater 5G capacity without losing access to DBS or NGSO offerings. Releasing 500 megahertz of prime mid-band spectrum in the 12 GHz band for 5G would materially strengthen the nation's mobile broadband spectrum inventory and allow the United States to leap to the front of the pack in global 5G leadership.

B. Commenters Widely Agree the 12 GHz Band Can Help Meet the United States' Burgeoning 5G Spectrum Needs.

Many technical factors make the 12 GHz band uniquely suited for 5G. The size of the 12 GHz band—500 megahertz—allows large contiguous channel blocks of at least 100 megahertz, which operators have recognized are vital to realizing the potential of 5G. Despite the 380 megahertz of spectrum between 3 GHz and 24 GHz becoming available for 5G over the next four years, only the C-band can support 100-megahertz channels, and only two such channels could be supported if local conditions permit. The 12 GHz band, however, could support five 100-megahertz channels *simultaneously*.

Interested parties representing nearly every facet of the commercial wireless market, as well as those considering the future possibilities of 5G, agree that opening the 12 GHz band would create a vital asset for mobile operators trying to keep pace with consumer demand. T-Mobile supports adding a two-way mobile allocation to the 12 GHz band and correctly observes that the current MVDDS rules are anachronistic and were "adopted before there was an urgent national need to make more spectrum available for 5G mobile services."[44] While AT&T has questioned 5G and DBS coexistence, it does not dispute the 12 GHz band's suitability for 5G.[45] DISH, the other DBS-affiliated wireless operator, has emphasized that it is "the company with the most to lose if 5G in the 12 GHz band interferes with its own DBS service [but] is confident that the two services can coexist."[46]

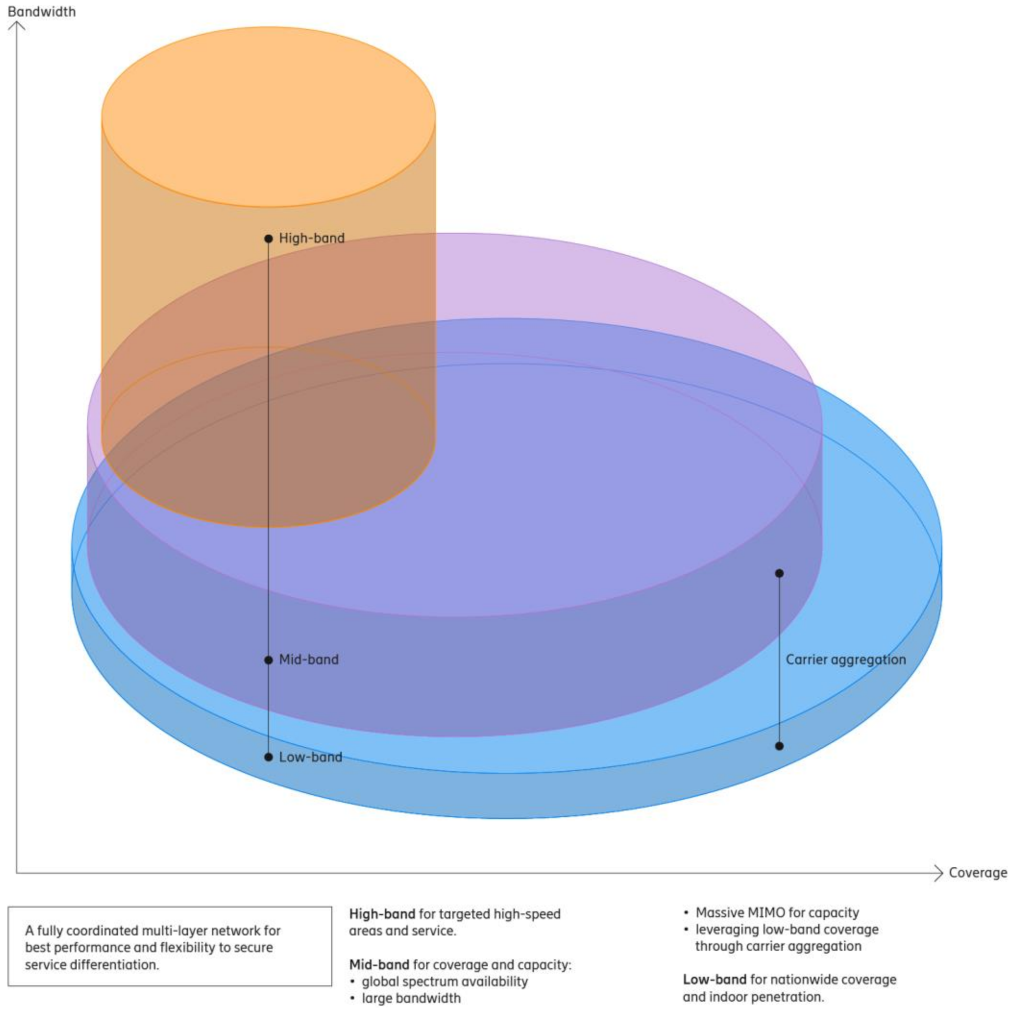
Integrating the 12 GHz band into the Commission's 5G plan would result in much more efficient use of existing spectrum, creating a "golden spike" that bridges lower mid-band and millimeter-wave bands into a seamless whole. By freeing up other bands and using each megahertz of scarce spectrum more efficiently, the 12 GHz band would permit carriers to maximize coverage and capacity. For example, mobile operators could assign 12 GHz capacity blocks to users who are closer to the cell center, allowing C-band, 2.5 GHz, and AWS spectrum to support the mid-range and freeing a greater portion of low-band spectrum for service to the cell's edge. Figure 1 illustrates a multi-band spectrum deployment strategy.

[44] T-Mobile Comments at 2.

[45] Comments of AT&T Services, Inc., WT Docket No. 20-443 and GN Docket No. 17-183, at 1 (filed May 7, 2021) ("[P]rotection of DBS services must be the guiding star of this proceeding.").

[46] DISH Comments at 1. Although DISH is both a DBS operator and an MVDDS licensee, coexistence will also be successful if the DBS operator is independent of the MVDDS licensee.

Figure 1: Illustration of a Multi-Band Spectrum Deployment Strategy[47]



Modernizing the 12 GHz service rules would also offer mobile operators the option of allocating a portion of the band for high-capacity wireless backhaul. Using Integrated Access and Backhaul, a 3rd Generation Partnership Project ("3GPP") Release 16 feature in the 5G New

[47] *5G across three spectrum bands*, Ericsson, https://bit.ly/3qEIZgT (last visited July 2, 2021).

Radio (NR) standard,[48] the Roberson Report states that "operators could assign a small portion of the 12 GHz band for wireless backhaul while using the remainder for commercial access."[49]

The 12 GHz band's massive potential for next-generation terrestrial services is also apparent to the public-interest community. The Public Interest Organizations ("PIOs"),[50] for example, "urge the Commission to give considerable weight to how increasing the spectrum use rights for current terrestrial licensees in the 12 GHz band will positively enhance broadband competition."[51] "Increasing competition within the broadband space," they argue, "has profound public interest benefits ranging from better quality of service to more affordable broadband access."[52]

Industry trade associations have likewise encouraged the Commission to refresh the terrestrial service rules governing the band. In their joint comments, INCOMPAS and CCIA conclude that "[l]everaging the Commission's flexible use policies for the 12 GHz band will enhance U.S. leadership in 5G and strengthen key economic and national security interests."[53] INCOMPAS and CCIA also note that modernizing the 12 GHz band fosters competitive entry by smaller players: "Increased competition in broadband through the broader use of mid-band spectrum will also encourage more innovation, more choices, and greater opportunities for the

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[48] Henrik Ronkainen *et al.*, *Integrated access and backhaul – a new type of wireless backhaul in 5G*, Ericsson (June 23, 2020), https://bit.ly/2SsMZo4.

[49] Roberson Report 23.

[50] The PIO Comments were jointly submitted by New America's Open Technology Institute, Public Knowledge, Next Century Cities, Consumer Federation of America, Center for Rural Strategies, National Digital Inclusion Alliance, Tribal Digital Village, the Institute for Local Self-Reliance, Access Humboldt, and National Consumer Law Center.

[51] PIO Comments at 2.

[52] *Id.*

[53] INCOMPAS/CCIA Comments at 5.

customers that stand to benefit."[54] Similarly, CCA argues that "the Commission correctly has declared that spectrum policies must be 'forward-thinking'" to "maintain[] 'a vibrantly competitive mobile wireless services marketplace' and spur[] 'greater investment in the mobile wireless industry.'"[55]

Some NGSO licensees, however, misjudge the 12 GHz band's complementary propagation and technical characteristics and downplay the enormous potential innovation that the 12 GHz band can bring. OneWeb asserts that 12 GHz band transmissions suffer from higher free-space path loss, higher building penetration loss, and poorer outdoor-to-indoor coverage relative to lower frequencies.[56] The same could be said when comparing any two spectrum bands at higher and lower frequencies.

This argument also conveniently ignores how much free spectrum the Commission has devoted to NGSO FSS use without ever being able to put those resource assignments to a market test through competitive bidding due to statutory limits on satellite spectrum auctions. Figure 2 shows the staggering difference between current commercial mobile allocations and NGSO FSS allocations. *All* current commercial mobile spectrum allocations together amount to less than 40% of NGSO FSS allocations. All low- and mid-band spectrum, including the C-band and 3.45 GHz band, equal about 8% of NGSO allocations.[57]

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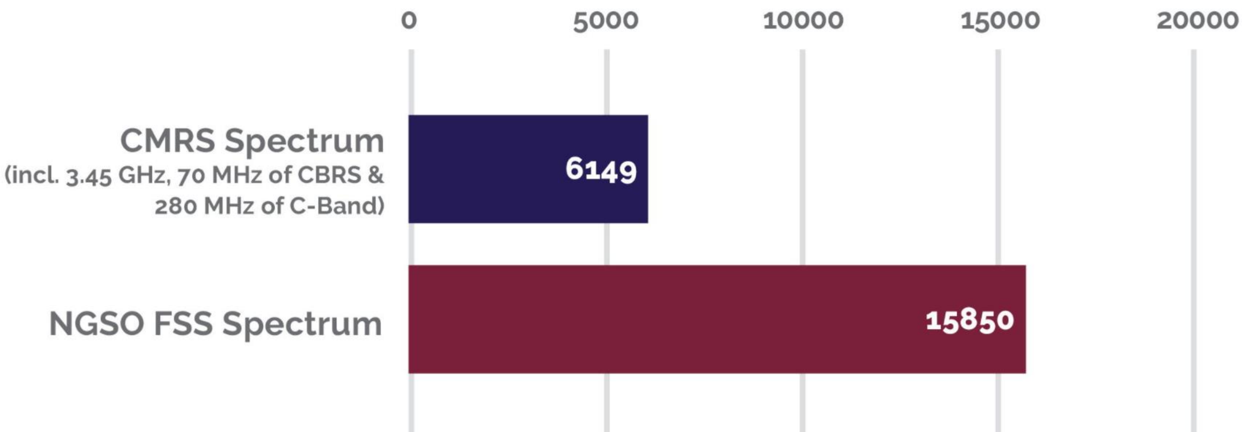
[54] *Id.* at 5.

[55] CCA Comments at 2 (quoting *Communications Marketplace Report et al.*, Report, 33 FCC Rcd 12558 ¶ 327 (2018)).

[56] OneWeb Comments at 20-21.

[57] *See* Letter from Jeffrey Blum Executive Vice President, External and Legislative Affairs, DISH Network Corporation, to Marlene H. Dortch, Secretary, FCC, RM-11768, at Attachment (filed July 14, 2020) (detailing the 15,500 megahertz of spectrum assigned to SpaceX for NGSO FSS operations).

Figure 2: Comparison of CMRS and NGSO Allocations[58]



As unambiguous as these figures are, tallying spectrum allocations for mobile or NGSO FSS misses the larger point about whether the United States has put any particular band to its highest and best use. The relevant question for any change in allocation or service rules is simply whether the spectrum has the coverage, capacity, and propagation characteristics to support more productive uses than it does today while enabling other incumbent services to continue to operate.[59] By this measure, the 12 GHz band holds significant promise for robust 5G deployments.[60]

Technical analysis reinforces this conclusion. For example, ITU studies examining the 5 GHz, 12 GHz, and various millimeter-wave bands show that the 12 GHz band propagates and attenuates much more like sub-6 GHz spectrum than millimeter-wave bands.[61] These

[58] *See* RS Access Comments, Appendix B at 39. The CMRS value excludes the 500 megahertz that the 12 GHz band could contribute.

[59] *See, e.g.*, *Expanding Flexible Use of the 3.7 to 4.2 GHz Band*, Report and Order and Order of Proposed Modification, 35 FCC Rcd 2343 ¶ 3 (2020) ("*C-Band R&O*") ("Mid-band spectrum is essential for 5G buildout due to its desirable coverage, capacity, and propagation characteristics. . . . The C-band will be critical mid-band spectrum for 5G services.").

[60] *See generally* Roberson Report.

[61] *See, e.g.*, *id.* at 4 ("[T]he 12 GHz band is more similar to lower mid-band spectrum than mmW spectrum in three key aspects: (1) path loss, including antenna characteristics, (2) building entry

performance distinctions are critical because they directly relate to how different spectrum can be deployed in a multi-band 5G network that maximizes both coverage and capacity. Not only does OneWeb conflate the 12 GHz band with millimeter-wave spectrum,[62] but also it ignores how the 12 GHz band offers a five-fold coverage advantage over millimeter-wave frequencies in the widely deployed 28 GHz band.[63] Further, OneWeb refers without citation to "3GPP specifications" and estimates penetration loss without offering any explanation or authority for how it arrived at its values.[64]

The Roberson Report puts OneWeb's misconceptions into sharp relief: the 12 GHz band performs far more like sub-6 GHz spectrum and far better than millimeter-wave bands in several key respects that define the band's potential for terrestrial mobile broadband. Based on a technical review of the characteristics of different spectrum bands, the Roberson Reports reaches several important conclusions,[65] including:

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loss, and (3) losses due to environmental effects (*e.g.*, foliage, human body, atmospheric absorption, and scattering)."); *see also* RS Access Comments at 19 ("The ITU's 2019 Report P.2346-3, which compiles measurement data, found that the 12 GHz band tracks closely with the performance of 5 GHz spectrum and performs markedly better than millimeter-wave bands.") (citing Report ITU-R P.2346-3, *Compilation of measurement data relating to building entry loss*, ITU, at 79 (May 2019), https://bit.ly/3uiGuBK.).

[62] One Web Comments at 21 ("Given the significant amounts of high-band spectrum MNOs currently have access to—spectrum that provides similar capabilities as the 12 GHz band—the value of the 12 GHz band to wireless carriers in the United States will not remotely approach the significant value this band currently provides to NGSO FSS operators.").

[63] Roberson Report at 4.

[64] OneWeb Comments at 20.

[65] Roberson Report at 1-3.

- ***The propagation characteristics of the 12 GHz band are highly favorable for 5G and resemble those of the lower mid-band frequencies.*** Lower mid-band spectrum, most notably the C-band, is regarded as including the prime frequency bands for 5G applications due to its radiofrequency ("RF") propagation and path-loss characteristics. In three key aspects of RF propagation—basic free-space path loss, building entry loss, and environmental effects (*e.g.*, foliage, human body, and atmospheric absorption, as well as scattering)—the 12 GHz band exhibits characteristics significantly closer to the C-band than the millimeter-wave bands. As one example, transmissions over the millimeter-wave bands exhibit free-space path losses that are 440% to 950% greater than can be expected in the 12 GHz band.

- ***The 12 GHz band promises significant capacity and throughput benefits, similar to those available in the millimeter-wave bands, but at lower cost.*** The 500 megahertz in the 12 GHz band is significantly greater than the bandwidth available in lower mid-band frequencies. This massive bandwidth allows large channels, supporting higher throughput and more capacity compared to frequencies in the lower mid-band. At the same time, 5G deployments in the 12 GHz band will require only between one-fifth and one-fifteenth the number of base stations that would be required for a similar millimeter-wave deployment, significantly reducing costs for 5G network operators. Likewise, semiconductors and other network elements can be produced at lower cost in the 12 GHz band than in millimeter-wave frequencies.

- ***The 12 GHz band supports greater aggregate throughput than either the C-band or 28 GHz band.*** When the many technological advantages the 12 GHz band can leverage are combined with its 500 megahertz of bandwidth, the band will be able to support higher values of aggregate throughput compared to either the C-band or 28 GHz band. While spectral efficiency ultimately depends on the characteristics of a particular deployment and the channel quality between a base station and end-user device, the Roberson Report estimates that 500 megahertz in the 12 GHz band could support aggregate downlink throughput of 20.0 Gbps—a figure markedly higher than either the estimated 15.1 Gbps feasible using the 280 megahertz of spectrum in the C-band or the estimated 9.0 Gbps using the 850 megahertz of spectrum in the 28 GHz band. The differences in peak spectral efficiency are particularly stark when comparing the 12 GHz and 28 GHz bands: one megahertz of 12 GHz spectrum can carry 3.76 times as much data as one megahertz of 28 GHz spectrum (under peak throughput conditions).

- ***Wireless network operators could use the 12 GHz band in multiple ways to add capacity and coverage to their networks.*** Because the 12 GHz band is uniquely positioned between lower mid-band and millimeter-wave spectrum, operators may use the 12 GHz band either as a resource to enhance throughput or to achieve more ubiquitous geographic 5G network coverage. For many operators, combining low-band or lower mid-band frequencies with the 12 GHz band is a natural next step in achieving significant increases in both capacity and coverage. A low- or lower mid-band carrier can be used on the uplink to achieve good coverage while the 12 GHz band is used for the downlink to increase capacity. For operators with millimeter-wave spectrum, the 12 GHz band can also be used in carrier aggregation mode to extend transmission distances of a millimeter-wave deployment. In this scenario, the millimeter-wave band can be used for the downlink and the 12 GHz band can be used for the uplink to achieve a larger coverage area for millimeter-wave band operations. Finally, the full set of frequencies can be used in a "layer cake" configuration at the base station to optimize both the coverage and the capacity provided by the base station.

- ***Significant technology advances over the past five years have unlocked the potential of 12 GHz and made 12 GHz deployments feasible in terms of cost and performance.*** Innovations in RF technologies and network design techniques have progressed from the laboratory to the field and are now embodied in both 3GPP 5G standards as well as devices and network equipment. These technologies include advanced antenna systems that enable Massive MIMO, beamforming, and adaptive antenna arrays; highly modular antenna structures; and low-cost efficient semiconductor devices supporting frequencies extending into the millimeter-wave range. The advanced antenna features, based on use of directional RF radiation patterns, are also conducive to facilitating coexistence with other systems operating in the same band. RF system design techniques and protocol capabilities such as small cells and carrier aggregation are coming into widescale use and can be readily applied to, and deployed, in the 12 GHz band.

- ***Global development of 5G-ready equipment in the 12 GHz band is commercially feasible in compressed timeframes and presents no major technical or cost impediments.*** The same technologies that already support 5G in other mid-band frequencies will readily allow for the production of 12 GHz band-compatible equipment. Leveraging RF design techniques and protocol advances that are now embedded in 5G standards, deployment in the 12 GHz band is likely to track the standards-settings decisions and equipment development milestones of other 5G bands. The 12 GHz band promises reduced design, manufacturing, and testing cost compared to the millimeter-wave bands.

Some parties also mischaracterize the role international and industry efforts play in setting the Commission's spectrum policy priorities. Microsoft, for example, treats the ITU and the 3GPP as gatekeepers to the Commission's spectrum policy decisions.[66] While prior consensus among intergovernmental bodies and standard-setting organizations may be desirable, it is certainly not a prerequisite to U.S. leadership on spectrum policy.[67] The Commission has repeatedly acted ahead of international standards-setting bodies, including the ITU, to support mobile broadband deployment in the United States. Examples abound, including the 600 MHz,[68] 700 MHz,[69] 2 GHz,[70] C-band,[71] and 28 GHz bands.[72] The Commission likewise adopted a reverse-band regime in 2000-2020 MHz even though no ITU agenda item had considered the issue.[73] Indeed, Microsoft itself strongly supported the Commission's global leadership in the 6 GHz proceeding,[74] where the Commission introduced unlicensed use into the 5.925-7.125 GHz band *despite* the dearth of global, standards-body consensus over the band's future use.[75] The

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[66] Comments of Microsoft Corporation, WT Docket No. 20-443 and GN Docket No. 17-183, at 9 (filed May 7, 2021) ("Microsoft Comments").

[67] *See, e.g.*, RS Access Comments at 68-69.

[68] *See Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, Report and Order, 29 FCC Rcd 6567 ¶ 319 (2014).

[69] *See Reallocation and Service Rules for the 698-746 MHz Spectrum Band (Television Channels 52-59)*, Report and Order, 17 FCC Rcd 1022 (2002) (relocating the lower 700 MHz for mobile use before the ITU designed the band for IMT at WRC-07) ("*700 MHz Reallocation R&O*").

[70] *See Redevelopment of Spectrum to Encourage Innovation in the Use of New Telecommunications Technologies*, First Report and Order and Order and Third Notice of Proposed Rulemaking, 7 FCC Rcd 6886 ¶ 3 (1992).

[71] *C-Band R&O*; *see also* ITU Resolution 811 (WRC-19) (creating WRC-23 agenda item 1.2 to "consider identification of the frequency band[] . . . 3600-3800 MHz . . . for International Mobile Telecommunications (IMT), including possible additional allocations to the mobile service on a primary basis").

[72] *See Spectrum Frontiers R&O* ¶ 25.

[73] *See DISH Network Corporation*, Memorandum Opinion and Order, 28 FCC Rcd 16787 (2013).

[74] *See, e.g.*, Comments of Microsoft Corporation, ET Docket No. 18-295 and GN Docket No. 17-183 (filed Feb. 15, 2019).

[75] *See, e.g.*, Brett Tarnutzer, *A balanced approach to 6 GHz is needed*, GSMA (Aug. 3, 2020), https://bit.ly/3v6yT94 ("The [6 GHz] plans so far split into different groups: China has supported

same record of U.S. leadership that Microsoft found desirable for unlicensed allocations holds true for other types of allocations. For example, the Commission will likely act on a new 17 GHz band allocation for the fixed-satellite service before the ITU does so at the 2023 World Radiocommunication Conference ("WRC").[76] In short, neither the United States, nor the FCC has a history of awaiting ITU spectrum designation decisions.

Microsoft's concern about the lack of international action is overstated in any case. As RS Access noted in its initial comments, in June 2020, 3GPP approved a technical report that considered how 3GPP standards should treat bands between 7.125 GHz and 24.25 GHz.[77] Based on the frequency range under consideration, this 3GPP report paves the way to develop a band class for 12.2-12.7 GHz in the United States and other countries seeking more mid-band spectrum to promote 5G deployment. The ITU's WP5D working group is studying the 10.0-10.5 GHz band for global use.[78] The ITU has examined the 12 GHz band's building entry loss characteristics and found its performance characteristics to be similar to the 5 GHz band.[79] As

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the use of this spectrum for licensed 5G while the US has gone in the opposite direction. Europe, reflecting on the current use of the band for backhaul systems, has limited the use for licence exempt applications to the bottom 500 MHz. This split point at 6425 MHz is being considered by other countries and this is also how WRC-23 splits the band, with 6425-7125 MHz under discussion in Region 1 as a whole for IMT.").

[76] *Amendment of Parts 2 and 25 of the Commission's Rules to Enable GSO Fixed-Satellite Service (Space-to-Earth) Operations in the 17.3-17.8 GHz Band, to Modernize Certain Rules Applicable to 17/24 GHz BSS Space Stations, and to Establish Off-Axis Uplink Power Limits for Extended Ka-Band FSS Operations*, Notice of Proposed Rulemaking, 35 FCC Rcd 13239 (2020).

[77] RS Access Comments at 21.

[78] *See, e.g.*, ITU-R Preparatory Studies for WRC-23, ITU, https://bit.ly/3gTwQQx (last visited June 22, 2021).

[79] Report ITU-R P.2346-3, *Compilation of measurement data relating to building entry loss*, ITU, at 70-79 (May 2019), https://bit.ly/3uiGuBK; *see also* RS Access Comments at 19.

the record shows, moreover, broad interest in the 12 GHz band exists among a host of different organizations, including major wireless service providers.[80]

Immediate action from the Commission would spur commercial development of 5G equipment in the band, a now well established process given the FCC's frequent leadership in global spectrum policy.[81] Because the United States is a market that, by itself, exercises considerable influence in the global supply chain for advanced communications equipment, authorizing 5G in the 12 GHz band would not only hasten similar action abroad, but also incentivize chipmakers and device manufacturers to incorporate the band into existing wireless equipment.[82] According to the Roberson Report, moreover, "components for 12 GHz operation will not require exotic semiconductor materials, sophisticated waveguide components, or cost-prohibitive development and testing equipment. . . . If commercial vendors can produce mmW components with limited constraints, they can do the same for 12 GHz."[83] The report also notes that "the underlying technologies to support 12 GHz components already exist in mass-

[80] T-Mobile Comments at 5 ("Making available additional spectrum, particularly in higher mid-band frequencies, is important for the continued deployment of 5G."); Starry Comments at 2 ("[A]dopting an approach that allows two-way communications in the 12 GHz band will optimize innovation in these frequencies, while encouraging private sector investment in a robust next-generation ecosystem."); INCOMPAS/CCIA Comments at 7 ("Eliminate overly-restrictive limits on MVDDS licensees use of the 12 GHz band by aligning federal regulations with today's spectrum-sharing realities to empower an ecosystem where mid-band spectrum drives innovation, new technologies, and next-generation connectivity for American businesses."). These comments as well as elements of the Roberson Report discussed above contradict Microsoft's unsupported assertion that device manufacturers may not invest in developing 12 GHz radio transmitters or implementing technology into consumer devices. *See* Microsoft Comments at 11.

[81] *See, e.g.*, Roberson Report at 32 ("The Commission's adoption of a report and order allocating the 12 GHz band for two-way mobile services will jump-start the 3GPP standards development process.").

[82] *Id.* at 32, 33-34 ("[B]roadband deployment will be commercially feasible in the 12 GHz band in a rapid timeframe if the FCC authorizes two-way 5G services in the band.").

[83] *Id.* at 34.

production and can transition to support operations in the band with minimal cost implications."[84] As a result, the Roberson Report concludes that "12 GHz service could be integrated in 5G equipment in 12-24 months."[85]

For its part, DISH summarizes the overwhelming consensus of commenters when it says that the 12 GHz band presents "a unique opportunity to propel the U.S. to undisputed leadership in the race to 5G. The band contains 500 megahertz of contiguous mid-band spectrum that, if allocated for terrestrial flexible use (including 5G wireless broadband), could help unlock the full potential of 5G in the U.S. for years to come."[86]

C. The Record Makes Clear that the Commission Must Act Now.

If the Commission is to accelerate 5G deployment and secure U.S. 5G leadership through flexible-use services in the 12 GHz band, now is the time to do so. As RS Access explained in its initial comments,[87] the 12 GHz band is in a transitional period: DBS service is declining as millions of subscribers switch to over-the-top video services; demand for 5G is skyrocketing; and NGSO FSS services remain undeployed or in a pre-commercial stage of development.[88]

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[84] *Id.*

[85] *Id*. at 36.

[86] DISH Comments at 7-8. *See also* INCOMPAS/CCIA Comments at 12-13 ("[T]he Commission should modify the existing terrestrial licenses by updating the MVDDS operational rules to permit MVDDS licensees to provide two-way mobile broadband service and updating the technical rules on transmit power and Equivalent Power Flux Density ('EPFD') levels to enable a 5G service while protecting other users from harmful interference.").

[87] RS Access Comments at 4.

[88] *See, e.g.*, Press Release, Leichtman Research Group, *Major Pay-TV Providers Lost About 5,120,000 Subscribers in 2020*, (Mar. 4, 2021), https://bit.ly/3ejOqNt ("Satellite TV services lost about 3,440,000 subscribers in 2020 – compared to a loss of about 3,700,000 subscribers in 2019"); *2020 Communications Marketplace Report* ¶ 156, Fig. II.D.1 (rel. Dec. 31, 2020) (citing S&P Global, *Multichannel Industry Benchmarks* (last visited Oct. 27, 2020)) (finding a year-over-year decrease in DBS subscribership of about 3.75 million).

During this transitional phase, the Commission has a unique chance to establish a new, forward-looking regulatory framework based on expected technology trajectories rather than outmoded 2G-era assumptions. Failure to act now would risk perpetuating costly and counterproductive operational constraints that frustrate investment without protecting against interference or serving any other public-interest benefit beyond bolstering the interests of a handful of satellite licensees who would rather not share "their" spectrum with any terrestrial wireless broadband operators regardless of the detrimental consequences for the nation.

Commenters agree that failure to reform the rules for the 12 GHz band promptly could leave the band in regulatory limbo. Risk of regulatory inertia is why T-Mobile has urged "the Commission . . . not allow any action taken with respect to the SpaceX Third Modification Order or SpaceX's deployment to prejudice any aspects of this proceeding, particularly for terrestrial mobile use. And the Commission should refrain from entertaining any additional modifications or applications for use of the 12 GHz band at this time."[89]

Satellite operators openly acknowledge that they aim to preclude 5G services in the 12 GHz band. For example, SES contends that it remains philosophically opposed to sharing spectrum with next-generation 5G mobile operations. According to SES, any sharing regime, especially one that drives 5G deployment in the United States, might one day "constrain the growth and evolution of satellite service" and should be rejected.[90] Intelsat similarly argues that this proceeding must preserve the *status quo* for satellite services indefinitely and opposes any Commission action to streamline outmoded, twenty-year-old constraints on terrestrial deployments because doing so could "introduce uncertainty and complication into the NGSO

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[89] T-Mobile Comments at 6-7.

[90] Comments of SES S.A., WT Docket No. 20-443 *et al.*, at 9 (filed May 7, 2021) ("SES Comments").

FSS environment."[91] Of course, *any* change in the 12 GHz band introduces a measure of uncertainty and complexity. The Commission did not start this proceeding to avoid complexity or preserve free optionality for NGSO FSS operators just in case they feel like using the band in the future, but rather to explore whether the benefits of U.S. global leadership in 5G deployment outweigh any costs of change. Given the feasibility of coexistence between 5G, NGSO FSS, and DBS, any costs of modernizing the rules for the 12 GHz band are dwarfed by its benefits.

When viewed in the context of the vast expanse of spectrum already allocated to satellite use, moreover, the practical necessity for spectrum sharing in the 12 GHz band should take none of the satellite licensees by surprise. The Commission has repeatedly stated over the past four years[92] that NGSO authorizations to use the 12 GHz band remain conditioned on the then-pending, first-in-time 5G petition for rulemaking and any subsequent FCC action.[93] Beyond the Commission's explicit warnings to NGSO licensees against their reliance on the band, as well as the literal conditional allocation in the 12 GHz band, spectrum is simply too valuable and too limited for the NGSO licensees—who have yet to even deploy commercial services in the 12 GHz band—to expect the Commission to indefinitely hold terrestrial licensees to decades-old,

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[91] Comments of Intelsat License LLC, WT Docket No. 20-443 *et al.*, at 5, 6 (filed May 7, 2021).

[92] *See, e.g., Space Exploration Holdings, LLC Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System et al.*, Memorandum Opinion, Order and Authorization 33 FCC Rcd 3391, n.88 (2018); *WorldVu Satellites Limited, d/b/a OneWeb (OneWeb) Petition for a Declaratory Ruling Granting Access to the U.S. Market for the OneWeb NGSO FSS System*, Order and Declaratory Ruling, 32 FCC Rcd 5366 ¶ 6 (2017).

[93] *Space Exploration Holdings, LLC Request for Modification of the Authorization for the SpaceX NGSO Satellite System*, Order and Authorization and Order on Reconsideration, IBFS File No. SAT-MOD-20200417-00037, FCC 21-48, ¶ 50 (rel. Apr. 27, 2021) ("As with prior grants, we condition this grant, subject to any modification necessary to bring it into conformance with future actions in Commission rulemakings, including but not limited to the 12 GHz proceeding, which is expressly referenced in the ordering clauses below. Therefore, SpaceX proceeds at its own risk.").

command-and-control style rules that require fixed, low-power, one-way deployments in a world needing mobile, high-power, two-way spectrum.[94] In sum, the Commission must act now to reform the band to promote American 5G leadership and economic prosperity through equitable, shared use of the 12 GHz band.

III. COEXISTENCE AMONG 5G, NGSO, AND DBS USERS IS FEASIBLE.

A. This Proceeding Does Not Present an Either-Or Choice Between 5G and Other Co-Primary Services.

As RS Access explained in its initial comments, the Commission does not face a binary choice to either do nothing or sacrifice DBS and NGSO services in the 12 GHz band.[95] This zero-sum mode of thinking that pervades some comments is not only factually wrong, but also counterproductive. Prematurely declaring failure based on unsupported assertions of potential interference in a hypothetical, undefined future scenario does not signal substantive engagement to further the primary goal of this proceeding: determining whether and how the Commission can update the 12 GHz service rules to reach a win-win-win solution that maximizes use of the band is in the public interest. The facts and evidence should guide the Commission's decision-making, and so far, only one side has done the hard work to provide the technical details of how coexistence can work in practice.

The RKF NGSO Study, which simulates nationwide deployments of an NGSO system and a 5G system, shows that nationwide NGSO and 5G deployments can coexist with a less than 1% probability that an NGSO user terminal experiences an interference-to-noise ratio of -8.5 dB

[94] DISH Comments at n.5 (noting that SpaceX is exploring user downlinks spectrum in the Ka-band).

[95] RS Access Comments at 24.

or greater.[96] And in the unlikely scenario where an exceedance event does occur, standard coordination techniques the Commission has often encouraged can mitigate potential disruptions. Yet opponents of reforming the band assume their conclusion and merely assert without evidence that 5G and potential future satellite uses of the band are incompatible. By invoking the unproven specter of co-channel interference and claiming that the 12 GHz band is essential for their (largely hypothetical) operations, opponents would have the 12 GHz terrestrial regime frozen in place. The claims are implausible, at best.

Coexistence with NGSO is achievable and desirable. Just as 5G can stimulate broadband deployment across all geographies and topographies, NGSO licensees can play a "role in expanding coverage and adding competition in rural, Tribal, and other less densely-populated areas."[97] At the same time, the need for more terrestrial mobile spectrum shows no sign of abating and will continue to place pressure to reallocate bands used less intensively than terrestrial mobile bands. As the U.S. Department of Commerce recognized in its milestone report *Driving Space Commerce Through Effective Spectrum Policy*, learning to coexist may also offer the only viable long-term strategy for preserving the vast expanses of spectrum satellite licensees claim to need for providing service.[98] In this sense, sharing spectrum between satellite

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[96] *Id.*, Appendix A at 55.

[97] PIO Comments at 7; Jon Brodkin, *Elon Musk: Starlink latency will be good enough for competitive gaming*, ARS TECHNICA (Mar. 10, 2020 2:28 PM), https://bit.ly/3dUrbbu ("'The challenge for anything that is space-based is that the size of the cell is gigantic . . . it's not good for high-density situations,' Musk said. 'We'll have some small number of customers in LA. But we can't do a lot of customers in LA because the bandwidth per cell is simply not high enough.'").

[98] Wilbur L. Ross and David J. Redl, *Driving Space Commerce Through Effective Spectrum Policy*, Dept. of Commerce, at 15 (Mar. 2019), https://bit.ly/3g2cxzZ ("[S]pace systems should leverage innovative technologies, to the extent feasible, to tolerate certain levels of interference, increasing resiliency and maximizing the potential for spectrum sharing with other communications services.").

and terrestrial users—rather than a quixotic effort to preclude anything other than 2000-era, ultra-low power, one-way, point-to-multipoint terrestrial services—may offer the best opportunity to ensure satellite services can continue to access spectrum resources over time.

B. Terrestrial 5G Services Can Coexist with NGSO.

NGSO operators devoted much of their comments to complaining that proponents of modernizing the band somehow did not meet their burden to show the feasibility of coexistence.[99] SpaceX, for example, claims that "[t]he ubiquity of 12 GHz Band incumbent services thus belies DISH's and RS Access's unsupported claims that co-channel sharing with mobile 5G service is feasible."[100]

To begin, there is nothing ubiquitous about SpaceX's or any 12 GHz NGSO operator's current services; indeed, NGSO licensees are not even offering commercial services to the public.[101] And the NGSO operators' criticisms are moot in any case. Proponents of modernizing the band have met their burden to show 5G services in the 12 GHz band are not only possible but also readily feasible at scale and under real-world deployment conditions with minimal, if any, disruption to NGSO services. The RKF NGSO Study shows that 5G can coexist with a widespread deployment of hypothetical Starlink subscribers, generously assuming 2.5 million

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[99] *See, e.g.*, OneWeb Comments at 10 ("The technical record currently before the Commission is unanimous: the studies in the existing record conclusively demonstrate that sharing between flexible-use, high-powered terrestrial services and NGSO FSS systems is entirely incompatible with the existing, co-primary NGSO FSS allocation in the band and, critically, no MVDDS party has submitted any study or analysis into the record demonstrating otherwise, despite repeated requests by satellite operators to do so.").

[100] Comments of Space Exploration Holdings, LLC, WT Docket No. 20-443 and GN Docket No. 17-183, at 22 (filed May 7, 2021) ("SpaceX Comments").

[101] Starlink is offering a "Public Beta Service," with a "[f]ocus on remote, rural communities with un/underserved households." Letter from David Goldman, Director of Satellite Policy, SpaceX, to Marlene H. Dortch, Secretary, FCC, WT Docket No. 20-133, Attachment at 7 (filed May 3, 2021).

Starlink terminals might be deployed throughout the contiguous United States—two-and-a-half times as many terminals as the Commission has authorized SpaceX to operate and more than three times the medium-term deployment estimates of respected industry analysts.[102] Even in that case, the study finds that coexistence between *uncoordinated* 5G operations and NGSO operations is readily achievable.

The RKF NGSO Study also addresses OneWeb's concerns that NGSO systems cannot coexist with 5G operations in adjacent bands. OneWeb says that "introducing two-way terrestrial mobile services in the 12 GHz band would also significantly impact NGSO FSS operations in the adjacent 10.7-12.2 GHz frequency range" due to "a significant difference between the power level of the emissions of 5G devices and the low power transmissions received by the user terminal from satellites (such as OneWeb's) at an altitude of 1200 km."[103] OneWeb also asserts that 5G mobile devices would produce out-of-band emissions due to signal leakage, and these emissions would interfere with NGSO signals in the 10.7-12.2 GHz band.[104] The probability of adjacent-channel interference is bounded by the probability of co-channel interference. The simulation shows that the probability that a co-channel Starlink user terminal experiences an exceedance event above -8.5 dB is less than 1%. Of course, the severity, and thus the probability of co-channel interference, is far greater than adjacent channel issues. While

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[102] *Compare* RS Access Comments, Appendix A at 16 *with* Application of SpaceX Services, Inc., Call Sign E190066, IBFS File No. SES-LIC-20190211-00151 (granted Mar. 13, 2020), *with Is Starlink a Substitute for, or a Supplement to, Wired Broadband?* at 25. SpaceX later filed an application for 5,000,000 terminals and another application for unlimited terminals, neither of which has been granted. *See* Application of SpaceX Services, Inc., IBFS File No. SES-MOD-20200731-00807 (filed July 31, 2020); Application of SpaceX Services, Inc., IBFS File No. SES-LIC-INTR2021-02141 (filed June 8, 2021).

[103] OneWeb Comments at 14.

[104] *Id.*

uncoordinated operations could also result in receiver overload, that would only occur if an NGSO user terminal and 5G base station were sited very close to one another—much closer than the distance necessary to cause a co-channel I/N greater than -8.5 dB—and thus the risk is extremely small relative to the probability of a -8.5 dB exceedance event occurring, which is already minimal.

The RKF NGSO Study shows that co-primary sharing that maximizes both NGSO FSS and 5G use is readily attainable. SpaceX entirely misses the point in accusing RS Access of not identifying "suitable and available alternative spectrum for SpaceX and other NGSO FSS operators to use for consumer downlinks or how such a relocation could possibly work."[105] RS Access supports coexistence and has shown the band's feasibility to support co-primary services. RS Access does not propose that the Commission require NGSO FSS licensees to exit the 12 GHz band. Thus, the parade of horribles SpaceX associates with identifying replacement spectrum for NGSO FSS is irrelevant.

Even if alternative NGSO FSS spectrum were a relevant factor, satellite services already hold some 5.3 *gigahertz* of additional Ku-, Ka-, and V-band spectrum available for NGSO FSS user downlinks in the United States.[106] In SpaceX's case, for example, DISH calculates that the 12 GHz band accounts for a mere 2% of SpaceX's total spectrum allotment, 3% of its already licensed spectrum, and only 6% of its licensed downlink spectrum.[107] And, as T-Mobile observes,

> [O]ne of the reasons the Commission granted OneWeb's request to operate an NGSO system in the 12 GHz band despite the then-pending MVDDS 5G

[105] SpaceX Comments at 26.

[106] This figure includes the 10.7-12.2 GHz, 17.8-18.3 GHz, 18.3-18.6 GHz, 18.8-19.3 GHz, 19.7-20.2 GHz, and 40.0-42.0 GHz bands.

[107] DISH Comments at 5, 46.

> Coalition Petition for Rulemaking that requested, among other things, the Commission permit expanded, flexible terrestrial use of the band, was because OneWeb's request included several other frequency bands. The Commission observed that OneWeb would still have flexibility to provide its services on those other bands "even if NGSO FSS systems were precluded entirely from the 12.2-12.7 GHz band."[108]

INCOMPAS and CCIA likewise conclude that "given that NGSO FSS operators seeking to use the 12 GHz band also have access to spectrum in multiple other bands, sharing appears to be a workable solution."[109] Indeed, SES acknowledges that NGSO FSS operators do not exclusively rely on the 12 GHz band for their user downlinks.[110] And Mr. Elon Musk recently claimed that SpaceX will be able to provide "global connectivity for everywhere except the poles" beginning in August 2021,[111] despite Starlink's inability to receive transmissions in the 12 GHz band in much of Australia[112] or any part of India[113] or Brazil.[114] And in Canada, SpaceX ostensibly may operate under an interim authorization, but operating conditions are not publicly available.[115] Despite the limits on 12 GHz operations, SpaceX still appears to be moving forward with

[108] T-Mobile Comments at 8-9; *see also id.* ("NGSO operators have been authorized to use the entire 10.7-12.7 GHz band and others for downlink operations, meaning that they may continue providing service without using the 12 GHz band. . . . And there is no evidence in the record that those other bands are insufficient to meet NGSOs' business plans.").

[109] INCOMPAS/CCIA Comments at 14.

[110] SES Comments at 4-5 ("A number of NGSO constellations with which O3b must share Ka-band spectrum also rely on the Ku-band, including the 12 GHz band, to support their operations. Constraining these systems' ability to fully utilize the 12 GHz frequencies will increase the pressure on Ka-band spectrum used by O3b and others.").

[111] *WATCH: Elon Musk discuss Starlink Internet at MWC 2021 - Livestream*, YouTube (June 29, 2021), https://bit.ly/2SURXtX.

[112] Pantelis Michalopoulos and Andrew Golodny, Counsel, DISH Network Corporation, to Marlene H. Dortch, Secretary, FCC, WT Docket No. 20-443 *et al.*, at 3 (filed Apr. 23, 2021).

[113] *Id.* at 5.

[114] *Id.* at 6.

[115] *Id.* at 7.

offering service in each of these countries, proving that existing resources outside the 12 GHz band can support the NGSO FSS aspirations of SpaceX and other licensees.

C. Terrestrial 5G Services Can Coexist with DBS.

To date, all credible evidence in the record shows coexistence between 5G and DBS is feasible, and no evidence filed in response to the notice of proposed rulemaking purports to show otherwise. The overwhelming weight of record evidence establishes that the Commission can and should authorize 5G operations in the band while lifting unnecessarily onerous restrictions intended to protect DBS operations.

Two technical studies prepared in 2016 show the feasibility of sharing between DBS and 5G.[116] The studies examined the effects on DBS dishes from 5G base stations and mobile devices in three configurations—point-to-point, outdoor small cell (the "urban canyon" scenario), and indoor small cell—in the areas of Indianapolis, Indiana, and Washington, D.C. The studies were intended to establish the feasibility of sharing even under unrealistically intensive DBS deployment scenarios. The studies thus relied on worst-case siting assumptions by placing hypothetical DBS antennas within *every square meter* of every suitable rooftop site in urban areas and *every two square meters* of every suitable rooftop site in rural areas. The studies did not seek to identify real-world interference conditions because there are not—and never will be—hundreds of millions of DBS receivers in a community or even across the United States. Instead, the studies set out to establish that, even in the presence of what amounted to an improbably large deployment of DBS receivers, factors such as antenna discrimination and clutter would act as natural shields sufficient to allow for coexistence between co-frequency DBS and 5G operations. In a declaration accompanying DISH's comments, the author of the

[116] *See* Coexistence I; Coexistence II.

2016 DBS coexistence studies affirmed those results and noted that subsequent technical advances have "further facilitated coexistence between terrestrial 5G networks and DBS receivers."[117] Indeed, one of the main proponents of the feasibility of arm's-length coexistence between DBS and 5G is DISH, one of two DBS operators in the 12 GHz band.

The likelihood of coexistence between DBS and 5G is even more realistic now than in 2016. First, the 2016 studies were developed during a pre-5G era when spectrum sharing technologies were comparatively primitive by today's standards—before beamforming,[118] beamsteering, Massive MIMO, and other innovations in terrestrial wireless services were commercially viable. Second, the last five years have witnessed a rapid and accelerating decline in satellite television subscribership as consumers have moved to video streaming delivered by fixed and mobile broadband. Given the precipitous decline in DBS since the 2016 coexistence studies (at least 7 million fewer subscribers and associated receiver-dish antennas in just the past two years[119]), the likelihood of interference is now even smaller and will continue to diminish. Thus, the Commission has more flexibility to address DBS coexistence than it did when it adopted the original MVDDS rules, or even compared to just a few years ago.[120]

The record contains no evidence questioning the validity of these findings. AT&T—the only DBS operator to express concerns with 5G operations in the band—has presented no technical evidence showing that coexistence is infeasible based on the state of technology in 2021. Instead, AT&T rehashes the Commission's outdated technical findings from the early

[117] *See* DISH Comments, Peters Decl. at 1.

[118] While DBS antennas likely do not utilize modern beamforming technology, 5G antennas are not similarly constrained.

[119] *See supra* note 88.

[120] *See* DISH Comments at 3 (stating that DirecTV "has moved most of its direct-to-home service to Ka-band satellites, with only one fully used satellite in the 12 GHz band").

2000s and cites older letters that posit the possibility of 5G interference with DBS systems.[121] Never in this proceeding has AT&T made any affirmative showing that 5G systems would affect DirecTV customers. Rather than present its own studies, AT&T exclusively sought to cast doubt on the 2016 studies, relying heavily on corner cases, such as the existence of an undefined number of mobile DirecTV receivers and DirecTV dishes at the ground level. Likewise, in its discussion of the 2016 studies' extensive engineering modeling, AT&T claimed that the studies use "cherry-picked" assumptions about the location of DBS antennas and 5G deployments.[122] For example, AT&T criticizes the studies for considering "one deployment scenario [that] involved a section of downtown Washington, D.C. near Capital One Arena," which has "not be[en] considered heavily residential compared to other areas of the city where there are likely many more DBS receivers and, therefore, much more challenging conditions."[123]

These criticisms were wrong when first raised, and they are even more misplaced in 2021. In 2016, the relevant study locations were chosen precisely *because* they show that 5G base stations could be sited in a manner that poses little risk of interference with DBS—even when an improbably large number of DBS receivers are located within the vicinity of mobile operations. Contrary to AT&T's claims, the studies showed how 5G operators can avoid interference to DBS through geographic separation, absorption in the clutter, transmitter power reductions if needed, and other careful radio-frequency engineering techniques. None of these

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[121] *See* Comments of AT&T Services, Inc., WT Docket No. 20-443 and GN Docket No. 17-183 (filed May 7, 2021) ("AT&T Comments").

[122] Letter from Michael Goggin, Assistant Vice President & Senior Legal Counsel, AT&T, to Marlene H. Dortch, Secretary, FCC, RM-11768, Appendix A at 1 (filed June 14, 2018).

[123] *Id.* at 1-2.

constraints may be required, but all of them are available to support coexistence and help establish confidence in the viability of sharing between DBS and 5G services.

IV. TARGETED CHANGES TO THE 12 GHZ SERVICE RULES REMAIN THE MOST EFFICIENT AND LEGALLY DEFENSIBLE WAY TO INTRODUCE TERRESTRIAL 5G IN THE 12 GHZ BAND.

The record shows strong support for introducing flexible-use rights in the 12 GHz band. The most efficient path to do so is by updating the terrestrial service rules that govern existing, geographically exclusive MVDDS terrestrial authorizations. By contrast, a clear-and-auction approach under the *Emerging Technologies* framework is poorly suited to the 12 GHz band and the Commission's goal of maintaining existing services in the band.

A. The *Emerging Technologies* Framework Has No Precedential Basis In this Proceeding and Would Frustrate Efforts to Maximize Use of the 12 GHz Band.

If the Commission determines that the public interest supports introducing flexible-use rights in the band, the *Emerging Technologies* framework is inapt and legally dubious. T-Mobile correctly notes that the Commission has relied on the *Emerging Technologies* framework in several proceedings, including most recently the C-band. The Commission has employed the *Emerging Technologies* approach when it needs to clear spectrum of one use to make room for another. Bands subject to an *Emerging Technologies* approach involve a fundamental repurposing of spectrum, such as from broadcasting or satellite services to terrestrial wireless operations.[124] Here, the Commission aims to determine whether and how to increase terrestrial

[124] *C-Band R&O* ¶ 27 ("The Commission has used an auction of overlay licenses on a number of occasions to repurpose spectrum for a new service, by requiring incoming licensees to clear the band (typically by funding the relocation of incumbent licensees) in order to fully deploy the new service in a manner that meets the goals and requirements that the Commission had established under section 303 for providing that service."); *id.* ¶ 322 ("[T]he Commission's *Emerging Technologies* framework has largely involved the relocation of fixed services to allow for mobile operations under new, flexible-use licenses.").

uses in a band where satellite operators will remain *and* terrestrial authorizations ***already exist***—after terrestrial operators acquired their geographic-area licenses through a competitive bidding process.[125] For the reasons discussed below, T-Mobile errs when it proposes that the Commission shoehorn the inapposite *Emerging Technologies* framework into the 12 GHz proceeding and simply relocate incumbent MVDDS operators (and potentially others) to some other, unnamed band.[126]

First, the Commission has never before applied a clear-and-auction approach to spectrum previously bought and assigned through competitive bidding, such as the terrestrial MVDDS licenses.[127] This limitation on the *Emerging Technologies* framework represented a key analytical point in the *C-Band R&O*'s distinguishing satellite authorizations, which the Commission modified under the *Emerging Technologies* framework, from terrestrial licenses.[128] The *C-Band R&O* emphasized that, unlike satellite authorizations, "the exclusive geographic terrestrial licenses that the Commission issues through competitive bidding [differ] both in the rights conferred to the licensees and the method by which they are issued."[129] Amplifying this

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[125] *NPRM* ¶ 19 ("[W]e seek comment on two potential approaches to future use of the 12 GHz band: increasing terrestrial use of the shared band or continuing with the current framework.").

[126] T-Mobile Comments at 11-12 ("Similar to the approach implemented in the C-band proceeding, the Commission may use its authority under Section 316 of the Act to modify MVDDS licensees' authorizations and relocate them to other bands if they can provide the same service as they currently do.").

[127] *Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range et al.*, Memorandum Opinion and Order and Second Report and Order, 17 FCC Rcd 9614 ¶ 130 (2002) ("*Second MVDDS R&O*") ("We believe the initial services that will be provided by MVDDS licensees — multichannel distribution of local television programs and high-speed internet access — require ubiquitous coverage. Thus, deployment of this service will be more efficient by using a geographic licensing scheme that supports ubiquitous service.").

[128] *See* RS Access Comments at 54-58.

[129] *C-Band R&O* ¶ 143.

point during the later litigation, CTIA, AT&T, and Verizon said, "The [*C-Band R&O*] thus does not support the proposition that the Commission could alter licenses, in the guise of a 'modification,' in a way that materially undermines a licensee's investment-backed expectations in its future operations."[130] In other words, if the Commission were to alter or impair MVDDS licensees' paid-for rights, holders of other licenses assigned by competitive bidding may reasonably ask whether their authorizations could be next. As the Commission has recognized time and again, when licensees acquire their spectrum rights, they have reasonable, investment-backed expectations that the agency will not arbitrarily arrogate their licenses at some future point. Relocation is costly and operationally disruptive—and it forces operators to postpone their investments and deployment timetables. Re-auctioning terrestrial licenses would undercut MVDDS operators' rights as winners of auctioned, exclusive-use licenses and undermine their investment-backed expectations that paid-for spectrum rights will be protected.

Second, the present notice of proposed rulemaking rightly does not seek to clear the 12 GHz band of all incumbents as band-clearing efforts under the *Emerging Technologies* framework have done.[131] At the same time, the detour in pursuit of the first-ever application of the *Emerging Technologies* clear-and-auction approach to licenses bought at auction would almost certainly result in years of delay as courts resolve the scope of the FCC's authority under Section 316 of the Communications Act to introduce new terrestrial rights on top of already auctioned licenses.[132] In particular, courts have never addressed whether an impairment of paid-

[130] Final Brief of Intervenors CTIA — The Wireless Association, AT&T, and Verizon in Support of Appellees, at 14, *PSSI Global Services, L.L.C. v. FCC*, 983 F.3d 1 (D.C. Cir. 2020) (No. 20-1142).

[131] *See generally NPRM* ¶¶ 22-32 (seeking comment on the protection of DBS and NGSO FSS operations).

[132] *See generally* 47 U.S.C. § 316.

for rights to geographically exclusive use of spectrum would effect a "fundamental change."[133] Forcing terrestrial licensees out of spectrum assigned through competitive bidding would be readily distinguishable from *Community Television*, which upheld an FCC order allowing broadcasters to use a digital channel for ten years and to retain access to their analog channels over that same period because broadcasters would "begin and end the transition . . . under very similar terms."[134] MVDDS licensees paid for co-primary, geographically exclusive rights to 500 megahertz of spectrum between 12.2 and 12.7 GHz. Introducing new terrestrial operations, relocating MVDDS licenses, or reducing MVDDS licensees' authorized frequencies would not be "very similar terms" to the rights MVDDS licenses currently convey. While *PSSI Global Services, LLC* affirmed the FCC's reduction in C-band satellite operators' authorized frequencies,[135] those operators possessed no paid-for rights to geographically exclusive spectrum use, a point the Commission emphasized in the *C-Band R&O*:

> [B]y their very nature, these incumbent space station licenses are fundamentally distinct, and easily distinguishable, from the exclusive geographic terrestrial licenses that the Commission issues through competitive bidding both in the rights conferred to the licensees and the method by which they are issued.[136] . . . [U]nlike terrestrial licensees, incumbent space station operators have no

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[133] *See, e.g.*, *MCI Telecommunications Corp. v. AT&T*, 512 U.S. 218, 228 (1994) (holding that statutory "authority to 'modify' does not contemplate fundamental changes") ("*MCI v. AT&T*").

[134] *Cmty. Television, Inc. v. FCC*, 216 F.3d 1133, 1140-41 (D.C. Cir. 2000) (applying *MCI v. AT&T's* reasoning to Section 316 of the Communications Act and suggesting that impairing the ability of a licensee to provide the same services as those enabled by the original license might be considered a fundamental change), *cert. denied*, 531 U.S. 1071 (2001). *Cellco Partnership* is also inapt. There, the court affirmed the FCC's data roaming rule (*i.e.*, a service rule), which did not alter the basic licensing terms of mobile licenses. *Cellco P'ship v. FCC*, 700 F.3d 534, 543-44 (D.C. Cir. 2012).

[135] *PSSI Glob. Servs., LLC v. FCC*, 983 F.3d 1 (D.C. Cir. 2020).

[136] In allocating the 12 GHz band for MVDDS operations, the Commission rejected requests to provide DBS operators with spectrum set-asides, even for those "DBS licenses [acquired] through auction," concluding that "DBS licenses do not include an authorization to use the 12.2-12.7 GHz band for terrestrial services." *Second MVDDS R&O* ¶ 154.

> expectation of exclusive access to a particular spectrum band and incurred no appreciable costs for use of this valuable public resource beyond investment in their own network.[137]

The MVDDS licensees' exclusive geographic area terrestrial licenses purchased at auction wholly distinguish them from other licenses that have been subject to the *Emerging Technologies* framework.

Third, the *Emerging Technologies* framework requires relocating incumbents to comparable facilities. Often that relocation has meant moving terrestrial operators from one spectrum band to another.[138] In the C-band proceeding, for example, that approach meant providing reimbursement costs so satellite operators could retain sufficient capacity in the upper 200 megahertz "to provide substantially the same or better service to incumbent earth station operators."[139] Here, however, that requirement would mean moving geographically exclusive MVDDS licensees into another high-capacity band, which is simply unavailable. No commenter provided a suggestion of an alternative contiguous 500-megahertz swath of terrestrial spectrum with performance characteristics similar to the 12 GHz band.

Fourth, moving MVDDS licensees to another band would simply transpose the anachronistic MVDDS service rules into another band, rather than refreshing those rules to reflect current technologies. In other words, the MVDDS rules result in an inefficient terrestrial

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[137] *C-Band R&O* ¶ 143.

[138] *See, e.g.*, *Amendment to the Commission's Rules, Regarding a Plan for Sharing the Costs of Microwave Relocation*, First Report and Order and Further Notice of Proposed Rulemaking, 11 FCC Rcd 8825 ¶ 3 (1996) ("We also established procedures for 2 GHz microwave incumbents to be relocated to available frequencies in higher bands or to other media . . . .").

[139] *C-Band R&O* ¶ 194; *id.* ¶ 199 ("[F]lexible-use licensees will be required to reimburse eligible space station operators for their actual relocation costs . . . . [W]e expect that procuring and launching new satellites may be reasonably necessary to complete the transition. These new satellites will support more intensive use of the 4.0-4.2 GHz band after the transition.").

use of critical mid-band spectrum, but—even if possible—moving MVDDS service rules and licensees to a different swath of spectrum would create an entirely new coordination problem in another band merely to preserve those outdated rules. Given the Commission's longstanding preference for flexible-use licensing when expanding or introducing terrestrial rights in a band, relocating the MVDDS licensing regime into another band would stray far from Commission policy.

Finally, the Communications Act does not require an auction. T-Mobile, citing AT&T, asserts that the Communications Act requires an auction to introduce flexible-use rights into the 12 GHz band.[140] But as AT&T itself correctly noted in 2019 during the C-band proceeding, "[b]ecause Section 309(j)'s auction regime applies only to the issuance of *initial* licenses," a license modification "would not implicate the Section 309(j) auction regime at all."[141] In other words, the Commission possesses "broad authority under the Communications Act to 'consider the public interest in deciding whether to forgo an auction.'"[142] The public interest is particularly

[140] T-Mobile Comments at 10 ("And, as AT&T notes, '[t]o bestow new flexible use rights on MVDDS licensees . . . would merely deprive the U.S. Treasury of revenue and violate Section 309 of the Telecommunications Act,' which requires a public auction whenever mutually exclusive applications are filed. Moreover, the Commission should not assume that only existing terrestrial licensees should be permitted to offer mobile service because only a single licensee can coordinate both forms of terrestrial use or terrestrial/satellite use.").

[141] Reply Comments of AT&T, GN Docket No. 18-122 *et al.*, at 2 (filed July 18, 2019) (emphasis added); *see also* Joint Opposition of AT&T Mobility Spectrum LLC and FiberTower Corporation, ULS File Nos. 0007652635 and 0007652637, at n.50 (filed Apr. 6, 2017) ("Section 309(j) of the Communications Act does not compel an auction of FiberTower's licenses. . . . The Commission has already determined that, in the interest of expedited deployment, it is more important to convert incumbent licenses to UMFUS than to re-auction them.").

[142] *Service Rules for Advanced Wireless Servs. in the 2000-2020 MHz & 2180-2200 MHz Bands*, Order on Reconsideration, 33 FCC Rcd 8435 (2018) (quoting *M2Z Networks, Inc. v. FCC*, 558 F.3d 554, 563 (D.C. Cir. 2009)).

evident here: the 12 GHz band is already exhaustively licensed for terrestrial use, and the modifications needed to unlock 5G services are relatively minor compared to an auction.

Although AT&T has persuasively explained in past proceedings why a spectrum auction is unnecessary to modify existing licenses and update service rules, it has taken an entirely different position here. In this proceeding, where AT&T is an incumbent, the company now claims that the FCC only has the straw-man choice of either maintaining the regulatory *status quo* or stripping the band of all uses and starting over.[143] Of course this is not true: exhaustively licensed, geographically exclusive terrestrial authorizations for the full 500 megahertz of contiguous spectrum already exist in the band and provide a ready-made foundation for rapid investment and 5G deployment.

B. Expanding MVDDS Rights in the Band Is Consistent with Section 303(y) of the Communications Act.

The Commission has broad authority to authorize 5G operations by existing terrestrial licensees. The Commission may add a flexible-use allocation to a band "if . . . the Commission finds . . . that . . . such use would not result in harmful interference among users."[144] Despite

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[143] AT&T Comments at 10 ("In the absence of a sharing regime that could enable the meaningful deployment of two-way, mobile service while protecting incumbent services from interference, the Commission is left with two options: (1) uphold the existing, carefully balanced framework with co-primary sharing among three diverse services, or (2) clear all incumbent services from the 12 GHz band with adequate compensation and auction greenfield terrestrial spectrum rights in the band.").

[144] 47 U.S.C. § 303(y)(2)(C); *see also Flexibility for Delivery of Communications by Mobile Satellite Service Providers in the 2 GHz Band, the L-Band, and the 1.6/2.4 GHz Bands; Review of the Spectrum Sharing Plan Among Non-Geostationary Satellite Orbit Mobile Satellite Service Systems in the 1.6/2.4 GHz Bands*, Report and Order and Notice of Proposed Rulemaking, 18 FCC Rcd 1962 ¶ 207 (2003) ("Section 303(y) of the Act gives the Commission additional authority to allocate spectrum to provide flexibility of use, provided that the use is consistent with international agreements to which the United States is a party; and, if after notice and comment, the Commission finds that such an allocation would be in the public interest; would not deter investment in communications services and systems, or technology development; and would not result in harmful interference among users.").

TechFreedom's claims to the contrary,[145] assessing 5G/DBS/NGSO FSS coexistence feasibility is a principal purpose of this proceeding.[146] If the Commission determines that coexistence is achievable and adopts rules accordingly, that finding should also suffice for Section 303(y)'s "harmful interference" criterion.[147] TechFreedom and Microsoft argue that Section 303(y) does not permit adding flexible-use operations to the 12 GHz band.[148] But this argument puts the cart before the horse. If coexistence is feasible, as the evidence shows it is, Section 303(y) does not pose a legally binding constraint on the Commission's ability to adopt rules with the flexibility necessary to introduce 5G into the 12 GHz band.

The *Spectrum Frontiers* proceeding makes clear that the Commission can introduce flexible-use operations into bands allocated for satellite services.[149] Here, the RKF NGSO Study

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[145] Comments of TechFreedom, WT Docket No. 20-443, at 12 (filed May 7, 2021) ("TechFreedom Comments") ("The 12 GHz NPRM Ignores the Fundamental Incompatibility of NGSO Operations and Mobile 5G Uses of the Same Spectrum").

[146] *NPRM* ¶ 20 ("[W]e seek comment on adding a mobile service allocation throughout the 12 GHz band, whether *coexistence between and among these competing services is technically achievable* and, if so, what mechanisms the Commission might consider in facilitating such coexistence.") (emphasis added).

[147] *See 700 MHz Reallocation R&O* ¶ 19 ("We find that, by adopting power limits and other technical rules that limit interference between service types, a broadcast and wireless allocation would not result in harmful interference among users."). The Commission then determined that introducing flexible-use operations in the 698-746 MHz band "would not deter investment in communications services and systems, or technology development," 47 U.S.C. § 303(y)(2)(B), "because [it took] steps to mitigate possible interference between the two distinct services." *700 MHz Reallocation R&O* ¶ 19.

[148] TechFreedom Comments at 18 ("There is a heavy burden, therefore, on both the MVDDS advocates and the FCC to demonstrate how the proposed reallocation is consistent with Section 303(y)."); Microsoft Comments at 3 ("Section 303(y) of the Communications Act requires the Commission to adopt rules that serve the public interest and protect existing licensees from harmful interference before allocating a new mobile service. Unfortunately, none of the regulatory approaches outlined in the NPRM would adequately address the twin challenges of protecting existing NGSO FSS operators from harmful interference while facilitating a meaningful 12 GHz terrestrial service.").

[149] *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services et al.*, Second Report and Order, Second Further Notice of Proposed Rulemaking, Order on Reconsideration, and

shows a minimal probability of an exceedance event of greater than -8.5 dB to an NGSO FSS receiver when co-channel 5G base stations are *randomly* sited and without coordination.[150] The 2016 5G/DBS coexistence studies showed co-channel 5G operations can coexist near an improbably high density of DBS receivers. Because 5G deployment remains compatible with legacy DBS and NGSO services and there is no conflict with any international treaty,[151] the Commission could reasonably conclude that modifying the MVDDS service rules to allow for two-way, flexible-use services complies with Section 303(y). And while TechFreedom argues that "a reviewing court would be required under Section 303(y) to review the record *de novo*,"[152] the Commission's technical judgments on spectrum policy receive great deference.[153]

C. Some Commenters' Arguments Are Irrelevant.

NGSO FSS licensees raise a host of spurious and immaterial claims that require correction. For example, they claim RS Access and other MVDDS operators have sat on their

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Memorandum Opinion and Order, 32 FCC Rcd 10988 ¶ 22 (2017) ("[W]e find 24 GHz suitable for mobile and flexible use, and therefore add the proposed mobile and fixed allocations. . . . We also conclude . . . that mobile and BSS feeder links can coexist.").

[150] RKF NGSO Study at ii.

[151] *See* RS Access Comments at 68-71.

[152] TechFreedom Comments at n.40.

[153] *See, e.g.*, *Teledesic LLC v. FCC*, 275 F.3d 75, 84 (D.C. Cir. 2001) ("The Commission is therefore entitled to the deference traditionally accorded decisions regarding spectrum management.") (citing *Telocator Network of Am. v. FCC*, 691 F.2d 525, 538 (D.C. Cir. 1982) (finding when it is fostering innovative methods of exploiting the spectrum, the Commission "functions as a policymaker and, inevitably, a seer—roles in which it will be accorded the greatest deference by a reviewing court")); *FCC v. WNCN Listeners Guild*, 450 U.S. 582, 596 (1981) ("[T]he Commission's judgment regarding how the public interest is best served is entitled to substantial judicial deference."). More generally, federal courts defer to agencies' reasoned policy choices and predictive judgments within the scope of the agency's expertise. *See, e.g.*, *Motor Vehicle Mfrs. Ass'n of the U.S., Inc. v. State Farm Mut. Auto. Ins. Co.*, 463 U.S. 29, 43 (1983) ("The scope of review under the 'arbitrary and capricious' standard is narrow and a court is not to substitute its judgment for that of the agency.").

licenses and violated their substantial service obligations, a baseless claim that is not even at issue in this proceeding.[154] Irrelevancy aside, these assertions ignore detailed and unchallenged demonstrations showing that RS Access has met and, indeed, greatly exceeded the Commission's substantial service requirement for MVDDS licensees required to establish a renewal expectancy.[155] RS Access satisfied the safe harbor requirements through meaningful MVDDS investments and deployments, delivering a variety of data-intensive applications (despite the current regulatory constraints) to a diverse set of users—including rural and underserved communities, anchor institutions, and public-safety organizations. RS Access has deployed hundreds of links constructed for Wi-Fi extension, video, and first-responder services at various academic, commercial, veterans' service organizations, and other institutions.[156] As the notice of proposed rulemaking notes, RS Access has also deployed a "wide-area commercial MVDDS deployment, in Albuquerque, New Mexico,"[157] although that deployment required a waiver of the MVDDS power limits and other constraints that apply throughout the rest of the country.[158]

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[154] OneWeb Comments at 9 ("[T]he MVDDS parties have squatted on their licenses in the 12 GHz band for the better part of twenty years . . . .").

[155] *See* 47 C.F.R. § 101.1413; *Second MVDDS R&O* ¶ 177.

[156] *See, e.g.*, ULS File No. 0008742311, RSA/MDS Substantial Service Showing Supplement, 26-30 (filed July 26, 2019) (deploying MVDDS transmitter locations and receive-site equipment to connect the Emergency Operations Training Center and other training field stations at Texas A&M University's Disaster City, a 52-acre mock community that offers customized training to first responders); ULS File Nos. 0009264045 and 0009264048, RS Access, LLC Pending Request for Emergency Special Temporary Authority in Batesville, Mississippi (filed Oct. 16, 2020) (requesting special temporary authority to provide two-way connectivity to a transportable remote telehealth hub that will treat patients in rural Mississippi during the COVID-19 pandemic).

[157] *NPRM* ¶ 40 (citing RS Access, LLC, ULS File No. 0008742312, Required Notification for Call Sign WQAR 561, Substantial Service Showing Supplement at 43-49 (filed July 26, 2019)).

[158] RS Access has not received a single complaint of harmful interference since the Commission allowed higher power limits in Albuquerque.

RS Access's deployments and service offerings comply with, and are constrained by, MVDDS rules as they currently exist, and RS Access is not free to violate those regulations even if NGSO FSS licensees seem to believe it should have.

Before having even read the RKF NGSO Study, SpaceX sought to discredit the study by launching *ad hominem* attacks about the "financial motivations"[159] of MVDDS licensees, even going as far as to suggest that the Commission should view skeptically or simply discount the technical analysis of a party with a "pecuniary benefit"[160] in the outcome of the rulemaking. Baselessly impugning the integrity of highly respected engineering firms, particularly firms that have assisted the Commission in numerous spectrum proceedings, has no place in this or any proceeding.[161] Surely the Commission would not have hired RKF to assist in the C-band transition if the firm could not be counted on to produce reliable engineering data and assessments. In any event, NGSO FSS interests have their own "financial motivations" in this proceeding, and Microsoft has financial interests as a partner of SpaceX. Nevertheless, the Commission should evaluate each party's claims on their merits,[162] and SpaceX's attempt to discredit the RKF NGSO Study before reading it conflicts with the purpose of a rulemaking proceeding where an agency "must consider and respond to significant comments received

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[159] SpaceX Comments at 5.

[160] SpaceX Comments at 17.

[161] *See, e.g.*, *Expanding Flexible Use of the 3.7 to 4.2 GHz Band*, Order Denying Stay Petition, 35 FCC Rcd 10118 ¶ 4 (2020) ("The Commission engaged a third-party contractor, RKF Engineering Solutions, LLC (RKF), to assist FCC staff in identifying the costs that incumbents might incur, developing a cost category schedule, and calculating the lump sum payment amounts.").

[162] Jennifer Sokolowsky, *Azure Space partners bring deep expertise to new venture*, Microsoft (Oct 20, 2020), https://bit.ly/35JYNoY.

during the period for public comment."[163] The D.C. Circuit and the FCC have both concluded that the "self-interested character" of the evidence a party brings before the Commission when it crafts policy does "not bar the Commission from giving it substantial weight."[164] Any other rule of evidence—such as the one SpaceX has invented—would upend the entire public comment process by rendering the analysis and insight of the most motivated stakeholders irrelevant to the outcome.[165]

Further, OneWeb and SpaceX charge MVDDS licensees with spectrum warehousing, but NGSO FSS systems have a history of delay and failure. As shown in Figure 3, the history of NGSO FSS in the 12 GHz band is essentially a decade of failure from 1997 until 2007 followed by nearly a decade of stasis and inactivity from 2007 until 2016. Indeed, the recent resurrection of NGSO FSS interest in the 12 GHz band came *after* the MVDDS 5G Coalition filed its petition for rulemaking: OneWeb did not file its first application to operate an NGSO FSS system in the

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[163] *Perez v. Mortg. Bankers Ass'n*, 575 U.S. 92, 96 (2015) (citing *Citizens to Pres. Overton Park, Inc. v. Volpe*, 401 U.S. 402, 416 (1971). *See also Home Box Off., Inc. v. FCC*, 567 F.2d 9, 35 (D.C. Cir. 1977) ("[A] dialogue is a two-way street: the opportunity to comment is meaningless unless the agency responds to significant points . . . ."); 5 U.S.C. § 553(c).

[164] *See Syracuse Peace Council v. FCC*, 867 F.2d 654, 662 (D.C. Cir. 1989) (upholding the FCC's decision to eliminate the Fairness Doctrine, finding that it was proper for the FCC to consider evidence from broadcasters affected by the rule) (citing *Inquiry into Section 73.1910 of the Commission's Rules & Reguls. Concerning the Gen. Fairness Doctrine Obligations of Broad. Licensees*, 102 F.C.C.2d 142 ¶ 58 (1985)).

[165] As the Commission has noted, if a "self-serving" commenter is one that "ha[s] a direct interest in the outcome of [a] proceeding, the identical charge could be leveled against every statement of every commenting party. [The Commission has] never held that the evidence of interested parties lack probity; indeed, were [it] to adopt such a rule it would be virtually impossible for us to come to any conclusions about any issue raised in this proceeding." *Inquiry into Section 73.1910 of the Commission's Rules & Reguls. Concerning the Gen. Fairness Doctrine Obligations of Broad. Licensees*, 102 F.C.C.2d 142 ¶ 58 (1985).

band until April 2016,[166] and SpaceX waited until the end of 2016 to file the *first draft* of its *first application* to the Commission for such authority.[167] Before then, NGSO FSS applications for operations in the band were rare,[168] and actual deployment even rarer.[169]

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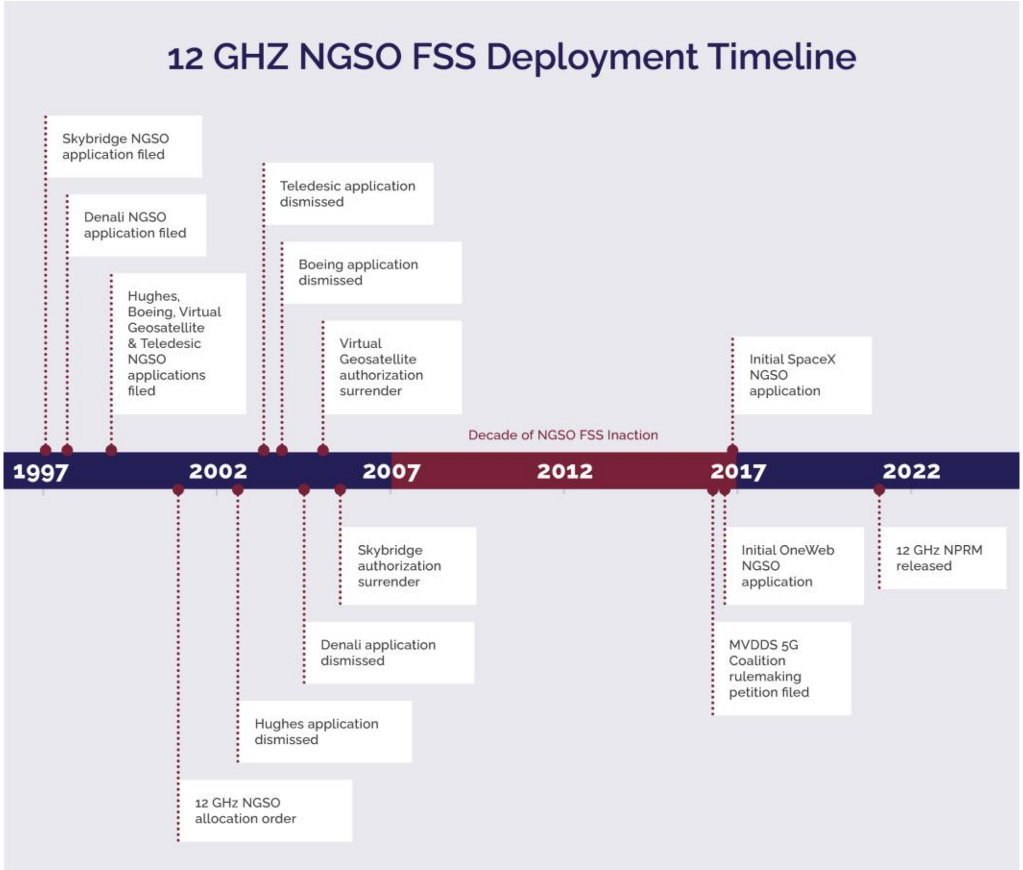
[166] *See, e.g.*, *WorldVu Satellites Limited, Petition for a Declaratory Ruling Granting Access to the U.S. Market for the OneWeb System*, IBFS File No. SAT-LOI-20160428-00041 (filed April 28, 2016).

[167] Space Exploration Holdings, LLC, Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System, IBFS File No. SAT-LOA-20161115-00118 (filed Nov. 15, 2016); Letter from William M. Wiltshire, Counsel, SpaceX, to Marlene H. Dortch, Secretary, FCC (Nov. 22, 2016) (submitting corrected technical information).

[168] *See Cut-Off Established for Additional Application and Letters of Intent in the 12.75-13.25 GHz, 13.75-14.5 GHz, 17.3-17.8 GHz and 10.7-12.7 GHz Frequency Bands*, Public Notice, Report No. SPB-141 (Nov. 2, 1998), https://bit.ly/3bmr4Fm; *Satellite Applications Accepted For Filing in the 12.75-13.25 GHz, 13.75-14.5 GHz, 17.3-17.8 GHz and 10.7-12.7 GHz Frequency Bands, Public Notice*, Report No. SAT-00013 (March 23, 1999), https://bit.ly/2SDxaKL; *Establishment of Policies and Service Rules for the Non-Geostationary Satellite Orbit, Fixed Satellite Service in the Ku-Band, Notice of Proposed Rulemaking*, 16 FCC Rcd 9680, Appendix D: NGSO FSS System Applications (2001).

[169] *See, e.g.*, Application of Denali Telecom, IBFS File No. SAT-LOA-19970926-00127, as amended (application dismissed by the Commission); Applications of Hughes Communications Inc., IBFS File Nos. SAT-LOA-19990108-00002, SAT-LOA-19990108-00003 (dismissed at Applicant's request); Application of Teledesic, L.L.C., IBFS File No. SAT-LOA-19990108-00005, as amended (dismissed at Applicant's request); Application of The Boeing Company, IBFS File No. SAT-LOA-19990108-00006, as amended (dismissed at Applicant's request); SkyBridge L.L.C., SAT-LOA-19970228-00021 (authorization surrendered); Virtual Geosatellite LLC, SAT-LOA-19990108-00007 (authorization surrendered).

Figure 3: Timeline of NGSO FSS Deployments



As SpaceX CEO Elon Musk noted in February 2021, "SpaceX needs to pass through a deep chasm of negative cash flow over the next year or so to make Starlink financially viable. Every new satellite constellation in history has gone bankrupt."[170] Likewise, since filing its market access request in 2016 and making grandiose claims about its near-term deployment, OneWeb had entered and exited bankruptcy once, gaining a new foreign government owner in the process.[171] Intelsat's bankruptcy remains underway and in litigation.[172]

[170] Elon Musk (@elonmusk), Twitter (Feb. 9, 2021, 1:20 AM), https://bit.ly/3tYa5Q9.

[171] British satellite firm OneWeb emerges from bankruptcy, REUTERS (Nov. 20, 2020), https://reut.rs/3hzZBDY.

[172] Chris Forrester, *Mediation ordered in Intelsat bankruptcy disputes*, ADVANCED TELEVISION (Apr. 23, 2021), https://bit.ly/3v8w0Fx.

While many hope the economics of new NGSO FSS systems will support a sustainable business model, the record to date is not promising.[173] The contrast is stark between the uncertain future of NGSO FSS versus that of terrestrial mobile broadband, which has a strong industry record and well capitalized, operational companies investing tens of billions of dollars every year to serve hundreds of millions of existing, data-hungry American mobile subscribers. Despite the night-and-day difference between terrestrial mobile broadband and NGSO FSS, the Commission need not choose between the two. With a targeted update of the service rules governing the 12 GHz, America can benefit from both.

V. CONCLUSION

The record is clear. The United States needs more mid-band spectrum, and the 12 GHz band is the ideal candidate to satisfy growing consumer demand for mobile broadband. 5G operations can coexist with authorized DBS and NGSO services. Refreshing the 12 GHz band's terrestrial service rules to remove outdated constraints on mobile broadband deployment will unleash 5G in the band most rapidly and in a way that avoids equitable and legal complications.

The Commission has the unique opportunity to reset the service rules and craft a durable set of policies that would ensure all three co-primary services remain viable for years to come. But the Commission must act in the narrow window afforded to it. Abandoning the terrestrial rights in the 12 GHz band to outdated service restrictions would squander valuable spectrum

[173] *See, e.g.*, Chris Daehnick, *Large LEO satellite constellations: Will it be different this time?*, McKinsey (May 4, 2020), https://mck.co/3ys7eSY ("The ambitions for the large LEO concepts may recall the 1990s, when several companies tried to provide global connectivity. Globalstar, Iridium, Odyssey, and Teledesic had impressive plans. In the end, however, all but Iridium scaled back or canceled their intended constellations because of high costs and limited demand. All suffered financial problems.").

resources, stymie innovation and, in the process, miss what economists estimate may be a trillion dollars or more of societal benefit for all Americans.

Respectfully submitted,

<u>/s/ Trey Hanbury</u>

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July 7, 2021

APPENDIX A – REPORT OF ROBERSON AND ASSOCIATES, LLC

Roberson and Associates, LLC
Technology and Management Consultants®

The 12 GHz Band: Analysis of Physical Characteristics and Applicable Technologies

July 7, 2021

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Executive Summary

This technical report examines the suitability of the 12.2-12.7 GHz band (12 GHz band) for 5G services. Our report is intended to assist the Federal Communications Commission in its ongoing rulemaking proceeding considering service rules that would permit two-way mobile operations in the 12 GHz band at higher power levels than are currently authorized.[1]

Based on our review of the technical literature, we find that the 12 GHz band is ideal for 5G deployment. The band combines the propagation characteristics and coverage advantages of lower mid-band[2] spectrum with the high capacity and throughput of the millimeter-wave (mmW) bands. Network architectures, spectrum deployment techniques, and equipment development standards currently used for 5G in other bands can readily extend to the 12 GHz band.

These findings are consistent with the 12 GHz band's location near the lower mid-band frequencies (such as the 3.7 GHz band) and well below the mmW frequencies (such as the 28 GHz band), both of which are the focus of current 5G deployment efforts. Our specific findings are as follows:

- ***The propagation characteristics of the 12 GHz band are highly favorable for 5G and resemble those of the lower mid-band frequencies.*** Lower mid-band spectrum, most notably the 3.70-3.98 GHz band (3.7 GHz band), is regarded as including the prime frequency bands for 5G applications due to its radiofrequency (RF) propagation and path-loss characteristics. In three key aspects of RF propagation—basic free-space path loss, building entry loss (BEL), and environmental effects (*e.g.*, foliage, human body, and atmospheric absorption, as well as scattering)—the 12 GHz band exhibits characteristics significantly closer to the 3.7 GHz band than the mmW bands. As one example, transmissions over the mmW bands exhibit free-space path losses that are 440% to 950% greater than can be expected in the 12 GHz band.

- ***The 12 GHz band promises significant capacity and throughput benefits, similar to those available in the mmW bands, but at lower cost.*** The 500 MHz in the 12 GHz band is significantly greater than the bandwidth available in lower mid-band frequencies. This massive bandwidth allows large channels, supporting higher throughput and more capacity compared to frequencies in the lower mid-band. At the same time, 5G deployments in the 12 GHz band will require only between one-fifth and one-fifteenth the number of base stations that would be required for a similar mmW deployment, significantly reducing costs for 5G network operators. Likewise, semiconductors and other network elements can be produced at lower cost in the 12 GHz band than in mmW frequencies.

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[1] *Expanding Flexible Use of the 12.2-12.7 GHz Band et al.*, Notice of Proposed Rulemaking, 36 FCC Rcd 606 (2021) (*NPRM*).

[2] In this paper, we adopt the following terminology for referring to various spectrum bands: low-band (up to 1 GHz), lower mid-band (1-6 GHz), upper mid-band (6-13 GHz) and high-band (*i.e.*, millimeter wave in the 24-53 GHz range). Specific example frequencies used often in this paper are: 3.7 GHz for lower mid-band, 12 GHz for upper mid-band and 28 GHz for high-band.

- ***The 12 GHz band supports greater aggregate throughput than either the 3.7 GHz or 28 GHz bands.*** When the many technological advantages the 12 GHz band can leverage are combined with its 500 MHz of bandwidth, the band will be able to support higher values of aggregate throughput compared to either the 3.7 GHz or 28 GHz bands. While spectral efficiency ultimately depends on the characteristics of a particular deployment and the channel quality between a base station and end-user device, we estimate that 500 MHz in the 12 GHz band could support aggregate downlink throughput of 20.0 Gbps—a figure markedly higher than either the estimated 15.1 Gbps feasible using the 280 MHz of spectrum in the 3.7 GHz band or the estimated 9.0 Gbps using the 850 MHz of spectrum in the 28 GHz band. The differences in peak spectral efficiency are particularly stark when comparing the 12 GHz and 28 GHz bands. 1 MHz of 12 GHz spectrum can carry 3.76 times as much data as 1 MHz of 28 GHz spectrum (under peak throughput conditions).

- ***Wireless network operators could use the 12 GHz band in multiple ways to add capacity and coverage to their networks.*** Because the 12 GHz band is uniquely positioned between lower mid-band and mmW spectrum, operators may use the 12 GHz band either as a resource to enhance throughput or to achieve more ubiquitous geographic 5G network coverage. For many operators, combining low-band or lower mid-band frequencies with the 12 GHz band is a natural next step in achieving significant increases in both capacity and coverage. A low- or lower mid-band carrier can be used on the uplink to achieve good coverage while the 12 GHz band is used for the downlink to increase capacity. For operators with mmW spectrum, the 12 GHz band can also be used in carrier aggregation mode to extend transmission distances of a mmW deployment. In this scenario, the mmW band can be used for the downlink and the 12 GHz band can be used for the uplink to achieve a larger coverage area for mmW band operations. Finally, the full set of frequencies can be used in a "layer cake" configuration at the base station to optimize both the coverage and the capacity provided by the base station.

- ***Significant technology advances over the past five years have unlocked the potential of 12 GHz and made 12 GHz deployments feasible in terms of cost and performance.*** Innovations in RF technologies and network design techniques have progressed from the laboratory to the field and are now embodied in both 3GPP 5G standards as well as devices and network equipment. These technologies include advanced antenna systems that enable Massive MIMO, beamforming, and adaptive antenna arrays; highly modular antenna structures; and low-cost efficient semiconductor devices supporting frequencies extending into the mmW range. The advanced antenna features, based on use of directional RF radiation patterns, are also conducive to facilitating coexistence with other systems operating in the same band. RF system design techniques and protocol capabilities such as small cells and carrier aggregation are coming into widescale use and can be readily applied to, and deployed, in the 12 GHz band.

- ***Global development of 5G-ready equipment in the 12 GHz band is commercially feasible in compressed timeframes and presents no major technical or cost impediments.*** The same technologies that already support 5G in other mid-band frequencies will readily allow for the production of 12 GHz band-compatible equipment. Leveraging RF design techniques and protocol advances that are now embedded in 5G standards, deployment in the 12 GHz band is likely to track the standards-settings decisions and equipment development milestones of other 5G bands. The 12 GHz band promises reduced design, manufacturing, and testing cost compared to the mmW bands.

In short, we find that the physical characteristics and technological standards governing the 12 GHz band imply enhanced 5G system design, performance, and coexistence that will make 5G deployment in the band cost-effective, achievable at scale, and rapidly realizable for network operators.

1 INTRODUCTION

The FCC has sought comment on the suitability of the 12 GHz band for two-way mobile services.[3] This technical analysis is presented to help inform the FCC in its effort to review and, as appropriate, revise its rules to enable terrestrial 5G services in the 12 GHz band. In particular, information is presented to address the following questions:

- How do the physical characteristics of the 12 GHz band compare to lower mid-band and mmW spectrum, and what are the system design implications of those differences and similarities?
- What current technology capabilities are applicable and relevant to the 12 GHz band, in particular for 5G equipment and network performance and coexistence?
- What are the commercial feasibility and associated time-to-market considerations of deploying 5G in the 12 GHz band?

This report is organized as follows. Section 2 demonstrates that the 12 GHz band has propagation characteristics that are closer to lower mid-band spectrum (such as the 3.7 GHz band) than mmW spectrum in terms of path loss, building entry loss, and other environmental factors that contribute to signal attenuation, while offering the type of capacity and channel bandwidths previously available only in mmW bands.

Section 3 highlights key engineering and network architectural advances in terrestrial 5G technologies since 2016 that make 12 GHz particularly well suited for 5G and greatly increase the feasibility of coexistence between terrestrial and non-terrestrial systems operating in the band.

Section 4 provides a summary comparison of different bands' key performance attributes from the perspective of wireless network operators.

Section 5 explains why, based on the standard lifecycle of global equipment development and standards in use in other frequencies, rapid broadband deployment will be commercially feasible in the 12 GHz band if the FCC authorizes two-way 5G services in the band. The conclusions of our analysis are presented in Section 6.

2 PROPAGATION CHARACTERISTICS OF THE 12 GHZ BAND

Spectrum located between 6 and 24 GHz provides a unique value for 5G by combining the favorable propagation characteristics of lower mid-band spectrum, like the 3.7 GHz band, with

[3] *NPRM* ¶ 21 ("We seek comment on whether adding a mobile allocation to the 12 GHz band to allow flexible, terrestrial use is consistent with this provision. In particular, we seek information on the status of technologies that have been developed or are currently in development that would allow for two-way mobile communications in the 12 GHz band, whether standards have been set related to such technologies, [and] whether there are any international agreements on a band plan or air interface . . . .").

capacity characteristics of the mmW bands. In particular, the 12 GHz band is more similar to lower mid-band spectrum than mmW spectrum in three key aspects: (1) path loss, including antenna characteristics, (2) building entry loss, and (3) losses due to environmental effects (*e.g.*, foliage, human body, atmospheric absorption, and scattering).

The 12 GHz band's similarities to lower mid-band spectrum dramatically enhance the band's utility for mobile broadband networks. In particular, 5G deployments in the mmW bands require 5 to 15 times as many base station sites to provide equivalent coverage as a 12 GHz-based network. The need for fewer sites means that network operators can provide significant additional capacity with a 12 GHz-based deployment at a substantially lower cost than a mmW-based network of base stations.

2.1 *Path Loss in the 12 GHz Band*

The received strength of wireless channel links is most often, if not always, the limiting factor in system performance. Consequently, meticulous wireless engineering efforts is required to design robust wireless networks. For example, in addition to radio signals generally getting weaker over distance, radio transmission can be obstructed by terrain, trees and other foliage, buildings, vehicles, the human body, precipitation, and other natural or man-made objects. These path losses reduce the coverage area and increase the number of base stations and associated backhaul links required to serve subscribers at an acceptable level of performance and consistency. All sources of path loss that cause performance to fall below the design objectives needed for transmission between base stations and end users must be compensated for by some means, such as larger, more complex, and more costly antenna arrays that can provide higher antenna gain.

Network engineers employ propagation models to predict the average received signal level for an assumed separation between the transmitter and receiver. A free-space propagation model, for example, predicts received signal strength when a transmitter and receiver have a clear, unobstructed line-of-sight path between them. Propagation models are used to predict the effect on received signal strength if one or more transmitter parameters, such as carrier frequency or transmitter power, are changed. Higher path loss can result in lower received signal strength and a consequent reduction in performance (either in voice coverage or data rates).

2.1.1 *Free-Space Path Loss*

Spectrum propagation conditions are key determinants in air-interface design and in the type of physical-layer hardware needed for reliable communications.[4] The incremental path losses increase with higher frequency bands due primarily to the effective reduction in antenna size as the frequency increases. Table 1 shows the free space path loss at 3.7 GHz, 12 GHz, 28 GHz, and 39 GHz, illustrating the relationship between path loss and frequency.

[4] Air-interface may be defined as various aspects of the interface between base stations and mobile stations in a cellular system. It typically includes the definitions of logical channels (for traffic and control) and details of the physical channels, such as, the radio frequencies and time slots, multiple access, multiplexing and time slot structures, coding and interleaving, timing and synchronization, modulation, power control, and handover.

Table 1: Additional Free Space Path Loss (in dB) when compared to a carrier at 3.7 GHz

Carrier Frequency	3.7 GHz	12 GHz	28 GHz	39 GHz
Additional path loss (dB)	0	10.2	17.5	20.4
Additional path loss	1x	10.5x	57.2x	111.1x

The additional path loss suffered at different frequencies expressed in decibels may not seem significant, but decibels are a logarithmic unit. The use of a mmW band results in an additional free-space path loss in the 7.3 dB to 10.2 dB range compared to the 12 GHz band—440% to 950% of the loss at 12 GHz. If expressed on a linear scale, a signal received at a certain power level at 3.7 GHz will be reduced by a factor of approximately 10 at 12 GHz, a larger reduction factor of 57 at 28 GHz, and an even larger reduction factor of 111 at 39 GHz. In practice, the larger losses result in reduced coverage area and a corresponding increase in number of base stations and associated backhaul required to serve the subscribers at an acceptable performance level.

2.1.2 *Building Entry Loss (BEL)*

The 12 GHz band's ability to penetrate windows and other normal building materials is similar to lower mid-band spectrum and far superior to mmW bands. As a result, the 12 GHz band's BEL characteristics are correspondingly similar to the lower mid-band spectrum and dissimilar to mmW spectrum bands.

Calculating building entry loss is a complicated function of many factors, including the material properties and geometry of the propagation environment. The ITU has conducted numerous propagation studies at frequencies above 6 GHz, including BEL's effects for the 5, 12, 25.5, and 32 GHz bands[5] for three representative types of buildings used in the United States (see Figure 1).[6]

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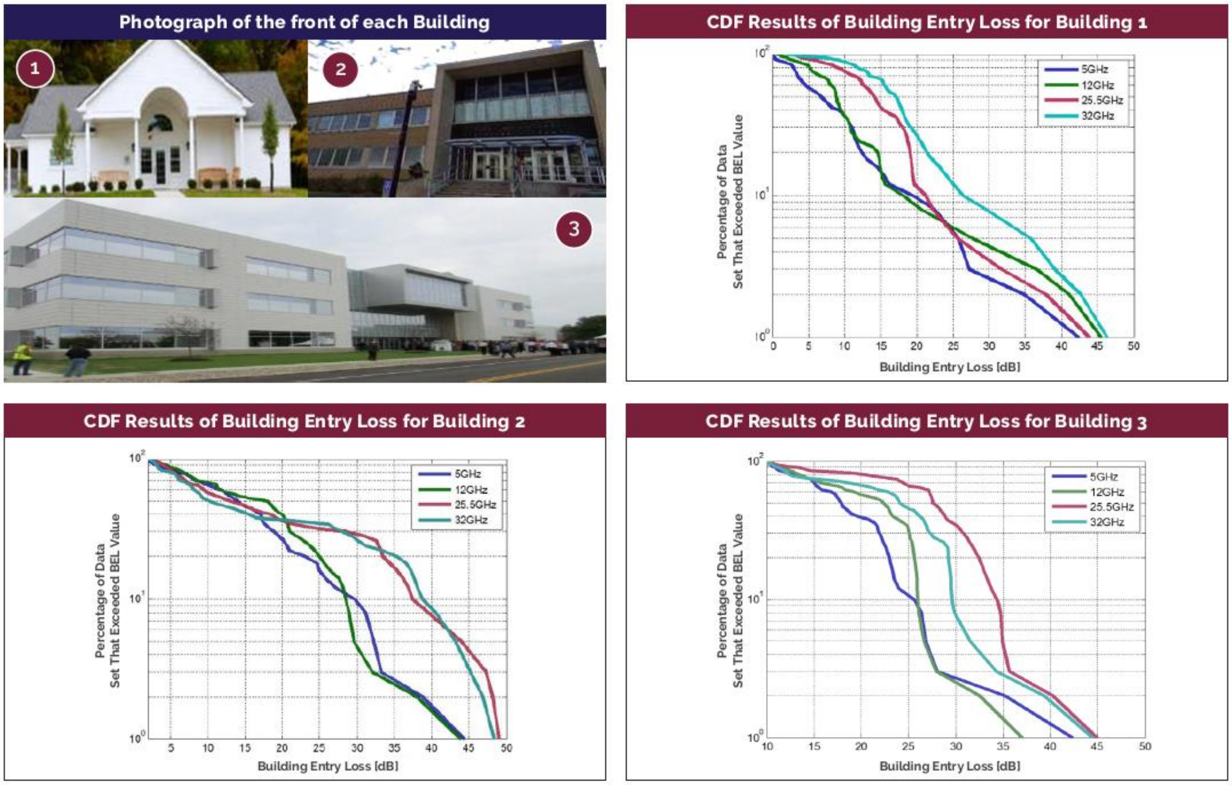
[5] Report ITU-R P.2346-3, *Compilation of measurement data relating to building entry loss*, ITU, at 66, 76-79 (May 2019), https://bit.ly/3uiGuBK (*ITU-R P.2346-3*).

[6] *Id.* at 65 ("The first building that was measured is a recently constructed building similar to a modern US residential building. . . . The second building is an older commercial office building. . . . The third building is a new building that was constructed with a focus on environmental factors, e.g. a lot of recycled/energy efficient material and low E glass windows.").

Figure 1: 5, 12, 25.5, and 32 GHz Cumulative Distribution Function of Building Entry Loss by Building Type[7]



The three graphs in Figure 1 show the Cumulative Distribution Function (CDF) of the BEL in dB for those frequencies. The CDF on the vertical axis for each graph shows the fraction of samples for which a particular BEL exceeded (was worse than) the value on the horizontal axis. For example, the horizontal line above the line marked "10^1" on the y-axis represents the loss that is exceeded 20 percent of the time. For Building 1, the measurements showed that 5 GHz exceeded 12 dB of BEL 20 percent of the time, 12 GHz exceeded 15 dB 20 percent of the time, 25.5 GHz exceeded 19 dB 20 percent of the time, and 32 GHz exceeded 21 dB 20 percent of the time. Said another way, the 5 GHz and 12 GHz signals experienced losses that were *less than* 12 dB and 15 dB, respectively, *80 percent* of the time, while the 25.5 GHz and 32 GHz signals experienced losses that were *less than* 19 dB and 21 dB, respectively, *80 percent* of the time. For Building 2, the 20 percent exceedances for 5, 12, 25.5 and 32 GHz are 23 dB, 25 dB, 33 dB and 35 dB, respectively; and for Building 3 they are 23 dB, 26 dB, 32 dB and 29 dB. Again, the conclusion is that 5 and 12 GHz exhibit similar coverage inside of buildings, while 25.5 GHz and 32 GHz will have much worse in-building coverage.

For Building Type 2 (an older commercial building), 30 dB of loss (a very high value) is exceeded 10% and 4% of the time for 12 GHz and 5 GHz. For the 25.5 and 32 GHz bands, that high loss is

[7] Comments of RS Access, LLC, WT Docket No. 20-443 and GN Docket No. 17-183, at 20 (filed May 7, 2021) (reproducing *ITU-R P.2346-3's* tabulated building loss results for three different buildings types at carrier frequencies 5, 12, 25.5, and 32 GH) (citing *ITU-R P.2346-3* at 66, 78-79) (RS Access Comments).

exceeded at a much higher level—about 30% of the time. The conclusion is that 5 and 12 GHz exhibit similar coverage inside of buildings, while 25.5 GHz and 32 GHz will have much worse in-building coverage.

For Building Type 3 (a newer commercial building), 30 dB of loss is exceeded only about 3% of the time for 5 and 12 GHz, but for 25.5 and 32 GHz, 30 dB loss was exceeded 30% and 8% of the time, respectively—a much higher percentage. The conclusion is that 5 and 12 GHz will have similar coverage inside of buildings[8], while 25.5 and 32 GHz will have much worse in-building coverage.

The tabulated results showed a degree of variability in BEL measurement results as seen in the minimum, maximum and standard deviation values. A comparison based on the mean loss values at different frequencies is a fair indicator of the overall effect on BEL as the carrier frequency is increased from 5 GHz to 32 GHz. Our rationale for comparison based on looking at the mean values is the following:

(1) Measured path loss is dependent on the multipath structure and

(2) The multipath structure is a function of frequency.

Hence, for example, if at a location A there was a constructive interference at frequency f_1, when one measures the path loss at the same location A, but at a different frequency f_2, most likely the interference will not be constructive. In other words, the locations of maxima and minima should change with the frequency and the average value should be a better metric of the BEL that one should expect.

The mean value of BEL at 12 GHz is always less than BEL at either 25.5 GHz or 32 GHz and the difference is in the range 0.5 dB – 7.5 dB across all the three buildings. On computing an estimated BEL value at 28 GHz (based on interpolation between 25.5 and 32 GHz results), it is noted that BEL at 12 GHz is at least approximately 4 dB less than at 28 GHz. A comparison based on maximum losses reported suggests that the loss at 28 GHz is about 15 dB more than the loss at 12 GHz.[9]

In summary, the behavior of 12 GHz closely tracks the lower mid-band 5 GHz penetration characteristics, and the mmW frequencies exhibit significantly worse penetration behavior relative to 5 GHz and 12 GHz. This data also provides strong evidence that the building entry loss characteristics of a carrier at 12 GHz are likely significantly better than a carrier at 28 GHz, and even more superior to a carrier at 37/39 GHz, the mmW frequency bands most often used by U.S. cellular companies.

2.1.3 *Real-World Loss Factors*

In addition to free-space path loss and BEL, there are several real-world propagation conditions that contribute to additional losses. Some of the real-world conditions that impact propagation

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[8] These studies consider signals from a base station located outside a building penetrating the building indoor.

[9] *ITU-R P.2346-3* at 71.

include: variations in terrain, foliage, structures, natural physical objects, rain, fog, and atmospheric oxygen. These additional factors contribute to fading and attenuation losses that are significantly worse at mmW bands (28 GHz and 39 GHz) than at the 12 GHz band.

For mmW bands, the attenuation and blockage characteristics of mmW radio signals are well documented.[10] Some key points noted in prior technical research on mmW transmission include the following:

- mmW emissions may be partially or totally absorbed by a variety of commonly occurring obstacles, including human bodies, foliage, terrain, objects, and atmospheric elements, each of which results in additional losses.

- mmW operations are much more sensitive to blockage by obstacles than lower-frequency operations. Examples of the blockage effects at higher frequencies include the effect of outdoor tinted glass on mmW signals, which exhibits a penetration loss of 40.1 dB at 28 GHz, and three interior walls of an office building that had a penetration loss of 45.1 dB, with a distance of 11.39 m between the transmitter and receiver.

- Any form of rain or even fog can degrade the propagation of mmW signals. This effect is not considered a problem in lower-frequency systems, which have links typically designed with sufficient margin to overcome worst-case rain events.

2.1.3.1 Losses Due to Foliage, the Human Body, and Scattering

The following highlights some of the specific factors that contribute to propagation losses; the precise amount is dependent on the extent to which these factors are present in an environment. The additional loss-inducing factors covered below are due to foliage, human body blockage, and scattering.

2.1.3.1.1 Foliage Losses

The following formula is used to compute foliage loss:[11]

$$\text{Loss (L) in dB} = 0.2*(f^{0.3})*(R^{0.6})$$

where f is the frequency in MHz and R is the foliage depth in meters.

For a depth of R=10 meters (a reasonable size for a large tree), this gives the following losses:

At 3.7 GHz, L = 9.4 dB
At 12 GHz, L = 13.3 dB
At 28 GHz, L = 17.2 dB

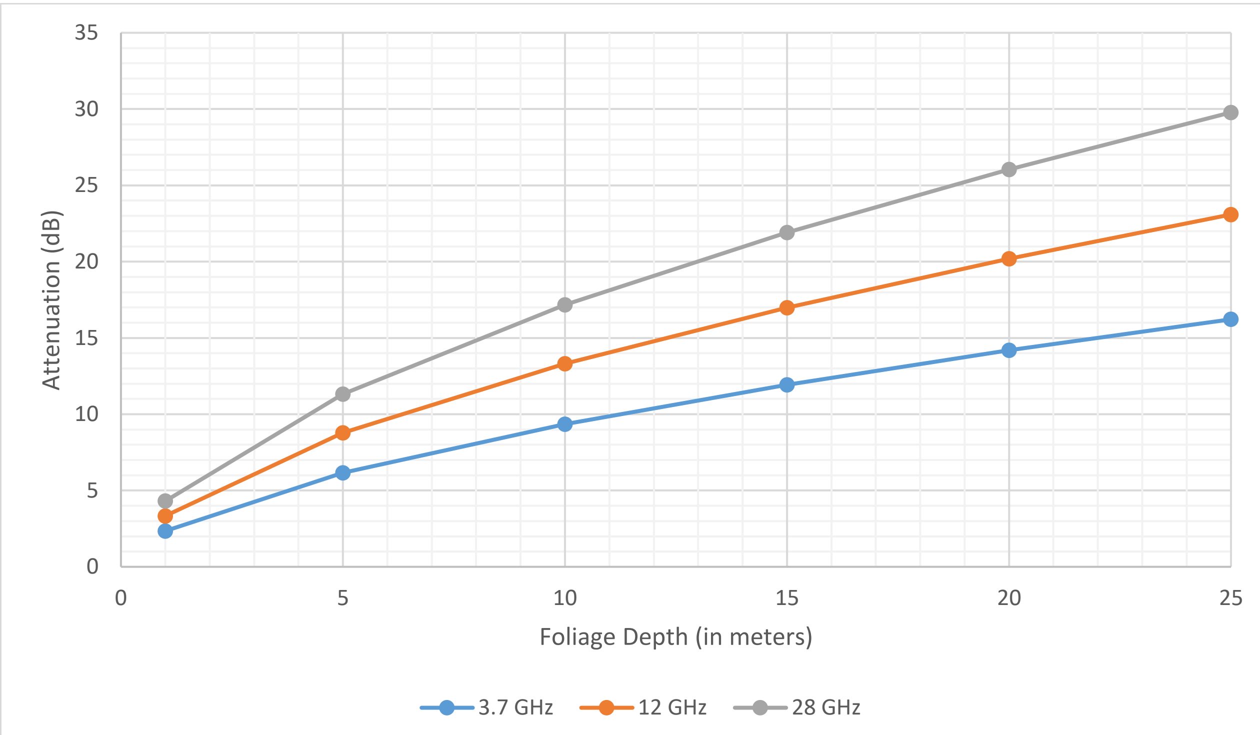
[10] *See, e.g.,* Shu Sun *et al., Propagation Models and Performance Evaluation for 5G Millimeter-Wave Bands*, 67 IEEE Transactions of Vehicular Tech. 9, at 8422-39 (Sept. 2018), https://bit.ly/3qIq9oS.

[11] OET Bulletin Number 70, *Millimeter Wave Propagation: Spectrum Management Implications*, at 14 (July 1997), https://bit.ly/3A7vdrc.

There is approximately a 4 dB difference between 3.7 GHz and 12 GHz and between 12 GHz and 28 GHz. For larger foliage depth (defined as R values in this case), the differences would be even larger (see

Figure 2 below). Thus, in the presence of foliage, the 12 GHz signal suffers a propagation loss that is between the lower mid-band and the 28 GHz band.

Figure 2: Attenuation Due to Foliage



2.1.3.1.2 Human Body Blockage

Another factor that can contribute to signal loss is due to human body blockage.[12] The paper *Modeling Human Blockage at 5G Millimeter-Wave Frequencies* compares human body blockage at 15 GHz and 28 GHz. The paper suggests that a 15 GHz signal experiences about 4-5 dB less loss than a 28 GHz signal.[13] Based on the study results for 15 GHz body blockage, we expect that the human body blockage loss would be even less at 12 GHz and that the gap between 12 GHz and 28 GHz would be even larger. This is further supported by the fact that, according to a report on the dielectric properties of the human body from 10 Hz to 100 GHz,[14] the penetration depth at 12 GHz is consistently greater than the penetration depth at 28 GHz, but varies depending upon the

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[12] Usman Virk & Katsuyuki Haneda, *Modeling Human Blockage at 5G Millimeter-Wave Frequencies*, 68 IEEE Transactions on Antennas and Propagation 3, 2256-66 (2020), https://bit.ly/3w2CtBA.

[13] *Id.* at 2261.

[14] *Dielectric Properties of Body Tissues*, Italian National Research Council, https://bit.ly/2TgoH0H (last visited June 28, 2021); *see also* Camelia Gabriel, *Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies*, U.S. Air Force Report AFOSR-TR-96 (1996), https://bit.ly/3AnNaC9.

material (*e.g.*, blood vs. muscle). Overall, the effect of human body blockage at 12 GHz is significantly smaller than the blockage at 28 GHz.

2.1.3.1.3 Scattering Effects

When a radio wave encounters a surface, some of the wave may reflect back into the environment. The nature of this reflection depends on the roughness of the surface relative to the wavelength of the radio wave (and the incidence angle to which it arrives at the surface). For smooth surfaces, one can view this as resulting in a single reflected wave (referred to as a specular reflection). For rougher surfaces, instead of a single reflected wave, we can view the reflected energy as being scattered in multiple directions. Due to the energy being spread out in multiple directions, this results in each reflection having less energy. The type of reflections that occur will increase a channel's multipath delay profile, which is important for utilizing various MIMO techniques.

The Rayleigh criterion[15] gives a threshold on surface roughness, above which scattering becomes significant. This threshold is inversely proportional to the frequency, and so the threshold at 12 GHz for a given incidence angle will be 2.33 times larger than at 28 GHz. For example, with a 70-degree incidence angle, the coefficient for 12 GHz is 1.5 mm while it is 0.6 mm at 28 GHz. This means that with 12 GHz, there will be more specular reflections (and less scattering losses) than at mmW frequencies.

2.2 *System Design Implications*

Under ideal conditions (*i.e.*, free space path loss), a 12 GHz signal at the same power and equivalent antenna gain[16] could travel more than twice as far as the popular 28 GHz signal. Under such conditions, received power decreases with the square of the distance and decreases with the square of the frequency. This means that the coverage area for 28 GHz is less than 20% of the coverage area for 12 GHz. Table 2 provides estimates on the range (distance from the transmitter) at which the 12 GHz and other band signals have the same received power. The range and relative area covered at 12 GHz is denoted by 100%, and calculations at other frequencies are relative to the range at 12 GHz. Notice that this roughly positions the 12 GHz band midway between the lower mid-band and the mmW bands.

Table 2: Equivalent Power Transmitter Distance (under free space path loss conditions)

Carrier Frequency	600 MHz	3.7 GHz	12 GHz	24 GHz	28 GHz	39 GHz	47 GHz
Relative Range	2000%	324%	100%	50%	43%	30%	25.5%
Relative Area Covered	40000%	1051%	100%	25%	18%	9%	6.5%

[15] Shihao Ju *et al.*, *Scattering Mechanisms and Modeling for Terahertz Wireless Communications,* IEEE Int'l Commc'ns Conf., Shanghai, China (2019), https://bit.ly/3dnLUou.

[16] Note the comparison is based on propagation characteristics at 12 GHz compared with other frequencies ranging from low-band to mmW spectrum and the resulting free space path losses. Other important factors, such as transmit power and effective gain, are assumed to be the same.

Table 2 shows that, at high carrier frequencies, each cell reduces in size. The area covered at various frequencies is expressed relative to the area covered at 12 GHz. Table 2 dramatically displays the extreme coverage difference between the low-band and lower mid-band and the more modest coverage reduction between the lower mid-band and the 12 GHz band. Finally, Table 2 shows the coverage difference between 12 GHz and the mmW bands that on average approximates the difference between the low mid-band and 12 GHz. The implication of Table 2 is that as frequencies increase the number of cell sites (*i.e.*, base stations) required to cover a given area also dramatically increases. In addition to the need for a larger number of base stations, there is also an increased number of links for backhaul connectivity to the core network that increases the total infrastructure cost of the network at high frequencies. It is also worth noting that, while free space path loss can be compensated for by increasing the number of antenna elements, other propagation effects like blockage, building entry loss, and the like will still limit cell sizes to a greater degree at higher frequencies.

3 TECHNOLOGY CAPABILITIES IN THE 12 GHZ BAND

In this section, we highlight key engineering advances in terrestrial 5G technology since 2016 that (i) greatly improve the prospects for standardization, commercialization, and deployment of the 12 GHz band; (ii) increase the likelihood of coexistence between terrestrial and non-terrestrial systems operating in the 12 GHz band; and (iii) illustrate how the 12 GHz band can greatly enhance 5G networks. This section then describes advances in related 5G technologies that have the potential to spur rapid 5G deployment and coexistence in the 12 GHz band, including network architectures and standards, small cells, and wireless backhaul.

3.1 *5G Radio Advances*

Standards-setting bodies have specified minimum technical performance requirements for 5G systems. These requirements include (1) peak data rate of 20 Gbps (downlink) and 10 Gbps (uplink); (2) peak spectral efficiency of 30 bps/Hz (downlink) and 15 bps/Hz (uplink); and (3) average spectral efficiency values as shown in Table 3 below[17]:

Table 3: 5G Requirements for Average Spectral Efficiency[18]

	Downlink (bps/Hz)	Uplink (bps/Hz)
In Home	9	6.75
Dense Urban	7.8	5.4
Rural	3.3	1.6

These 5G requirements are orders of magnitude more demanding than 4G systems' capabilities and generally were not realizable with previous generation antenna technologies.

[17] ITU-R M.2410-0, *Minimum requirements related to technical performance for IMT-2020 radio interface(s)*, ITU at 2-3 (Nov. 2017), https://bit.ly/3hhLPEl (*ITU-R M.2410-0*).

[18] *Id.* at 5.

In 2015, the ITU released a report entitled *Technical Feasibility of IMT in Bands Above 6 GHz*.[19] Among other things, the ITU's report identified a range of technologies that could help spur the deployment of IMT in bands above 6 GHz. As the ITU noted, antenna technology that could help realize the promise of 5G in bands above 6 GHz included directional fixed beam antenna arrays; full adaptive antenna arrays; modular antenna arrays; and multi-antenna transmissions using modular phased antenna structures.[20] Semiconductor technology that could hasten 5G deployment in bands above 6 GHz includes devices that enable low power consumption and high-gain beamforming.[21]

These technologies were nascent in 2015, making the prospects of successfully deploying 5G in the 12 GHz band challenging at the time. Since then, the enabling technologies forecasted in 2015 by the ITU have progressed from the laboratory to the field. Massive MIMO and beamforming technologies are now globally deployed in terrestrial 5G systems. Underlying semiconductor technologies and intelligent antennas, too, allow for low power consumption and high-gain beamforming in deployed systems throughout the world.

The remainder of this subsection describes a non-exhaustive sampling of these technological innovations, their use in the field today, and how they can be readily used to enable 5G in the 12 GHz band.[22]

3.1.1 *Massive MIMO*

Multiple-Input Multiple-Output (MIMO) is a method for multiplying the capacity of a radio link. MIMO technology is standardized for 3G and 4G networks and is in reasonably widespread commercial use. Using multiple transmit and receive antennas, MIMO allows a wireless network operator to leverage multipath propagation to transmit and receive more than one data signal simultaneously over one or multiple channels.

MIMO has many advantages for commercial wireless systems. By using multiple transmit and receive antennas, a wireless operator can transmit and receive the same data signal simultaneously over multiple channels. This technique, known as spatial diversity, improves the reliability of RF communication, increases the likelihood of properly receiving the transmitted signal, and minimizes the need for retransmissions. MIMO also allows for a technique known as spatial multiplexing, which feeds independent data into each antenna, with all antennas transmitting at the same frequency and time. By allowing the transmission of independent streams over multiple channels, spatial multiplexing increases overall data capacity. When multipath components have different angular directions, MIMO also allows for a 5G maximization technique known as beamforming (discussed in greater detail in the next section).

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[19] *See generally ITU-R M.2376-0* at 19-27.

[20] *Id.* at 19-24.

[21] *Id.* at 24-27.

[22] A detailed description of these critical technologies is beyond the scope of this report. There are several excellent textbooks that delve into the details of the 5G New Radio technology capabilities. *See, e.g.*, Erik Dahlman *et al.*, *5G NR: The Next Generation Wireless Access Technology* (2018); Sassan Ahmadi, *5G NR: Architecture, Technology, Implementation, and Operation of 3GPP New Radio Standards* (2019).

MIMO deployments in most low- and mid-band spectrum applications typically use two or four transmit and two receive antennas (or branches) to double the capacity of a single channel under optimal conditions. The more antennas the transmitter or receiver is equipped with, the more signal paths are possible and the better the performance in terms of reliability and data rate. In fact, MIMO that utilizes four base station antennas and four handset receive antennas (4x4 MIMO) have already been deployed in many areas by carriers such as AT&T, T-Mobile and Verizon. Customers with advanced handsets that support 4x4 MIMO can already take advantage of higher reliability and transfer rates.[23] The multi-user variant of MIMO (MU-MIMO) provides the ability to serve multiple users and devices simultaneously within the area of a cell sector while maintaining fast data rates and consistent performance, making it a desirable technology for addressing wireless broadband needs.

Massive MIMO (mMIMO) greatly improves the benefits of traditional MIMO using a number of antennas that is many times the number of users. mMIMO consists of multiple antenna arrays utilizing a large number of antennas (at least 32 transmitting and 32 receiving antennas in existing base station implementations) and spatial diversity to create multiple transmission channels for faster data throughput to individual users. The transmit and receive streams are controlled by advanced algorithms to create much higher network capacity.

mMIMO systems require channel state information (CSI) knowledge to better exploit spatial multiplexing and achieve higher data rates than was achievable with previous technologies. CSI acquisition methods exist for both time-division duplex (TDD) and frequency-division duplex (FDD) systems. In TDD system the channel state information is learned only by the base station by taking advantage of the reciprocity of the communication channel response for both the downlink and uplink. This is advantageous because it reduces the complexity of handset devices. In FDD systems, the channel state information is learned by both the base station and the handset. This approach has the advantage that it is more robust to jamming.[24]

mMIMO has proven challenging to implement in lower-frequency bands (*i.e.*, less than 2.5 GHz), where the optimal antenna length is approximately half a meter or around 20 inches. As a result, low-band implementations are quite expensive in size, shape, weight and therefore cost more to purchase and are more difficult to mount on towers. Moreover, it would not be feasible to install that number of antennas on a handset, given the expense and size. In addition, most low-band spectrum is FDD and therefore does not support mMIMO as efficiently as TDD spectrum, for reasons discussed above. From a regulatory and technical perspective, FDD spectrum is not easily converted to TDD.

By contrast, for mid- and high-band frequencies, a mMIMO antenna can be smaller, fitting in base station and user equipment (UE). Since 2016, 3GPP has standardized 5G systems, and equipment manufacturers have developed and commercialized the use of mMIMO systems.[25] As a result, in

[23] Melanie Smith, *5G FAQ series: What is massive MIMO?*, RootMetrics (Feb. 10, 2020), https://bit.ly/3hEc5ZD.

[24] Ashkan Sheikhi *et al.*, *A Comparison of TDD and FDD Massive MIMO Systems Against Smart Jamming*, IEEE Access, vol. 8 at 72068-77 (2020).

[25] Billy Hogan *et al.*, *How to build high-performing Massive MIMO systems*, Ericsson (Feb. 17, 2021), https://bit.ly/3qvGhKs; Peter von Butovitsch *et al.*, *Advanced antenna systems for 5G networks*, Ericsson,

mid- and higher-band frequencies, such as the 12 GHz band, mMIMO has become a very well understood antenna system structure. Massive MIMO is currently the default technology for lower mid-band TDD spectrum, such as 3.7 GHz. In the last five years, digital signal processing capability has advanced significantly, and, coupled with the availability of fast channel state information and increased prevalence of the TDD mode of operation, mMIMO systems have become a significant commercial reality.

Similar results should be readily available in the 12 GHz band. Equipment manufacturers have successfully demonstrated the practicality of implementing mMIMO in bands above 6 GHz and below mmW frequencies.[26] Engineers have shown that mMIMO dramatically enhances the channel capacity and throughput of the 11 GHz[27] and 15 GHz[28] bands. In light of these studies, mMIMO systems could make 5G deployment particularly suitable in similarly situated upper mid-band frequencies like the 12 GHz band.

Other factors, too, make mMIMO particularly well suited for the 12 GHz band relative to other frequencies. First, the 12 GHz band promises larger channel sizes and more overall bandwidth compared to lower mid-band spectrum. Whereas the 3.7 GHz band has 280 MHz of spectrum, the 12 GHz band will presumably offer 500 MHz of spectrum for 5G. Wider frequency channel bandwidth increases overall capacity, which in turn maximizes the opportunity for multibeam transmissions.[29]

Second, mMIMO is more practical in the 12 GHz band compared to mmW frequencies. mMIMO implementation in the 12 GHz band promises to be far less complex to implement compared higher frequency bands in terms of system design, manufacturing, and testing. As noted above, the size of RF components decreases as the band's frequency increases due to the inversely proportional relationship between frequency and wavelength. This implies that manufacturing tolerances must be stricter at higher frequencies. The power density in the antenna also becomes an increasingly important factor as the density of the antennas in the mMIMO antenna array increases.

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https://bit.ly/3doHLRl (last visited July 6, 2021); Henrik Asplund *et al.*, *Advanced Antenna Systems for 5G Network Deployments: Bridging the Gap Between Theory and Practice* (2020).

[26] *See* Billy Hogan *et al.*, *How to build high-performing Massive MIMO systems*, Ericsson (Feb. 17, 2021), https://bit.ly/3qvGhKs.

[27] Satoshi Suyama *et al.*, *Evaluation of 30 Gbps super high bit rate mobile communications using channel data in 11 GHz band 24x24 MIMO experiment*, 2014 IEEE International Conference on Communications, at 5203-08 (2014), https://bit.ly/364tkh7.

[28] Kiichi Tateishi *et al.*, *Indoor experiment on 5G radio access using beam tracking at 15 GHz band*, 2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications, at 1-6 (2016), https://bit.ly/3dnEeCL.

[29] Claude Shannon derived a capacity formula in 1948 that essentially identified capacity (C) as C = W log2 (1 + SNR), where W is the bandwidth of the channel and SNR is the signal-to-noise ratio. Shannon's formula, sometimes called Shannon's limit, identifies the fundamental tradeoff between transmission rate, bandwidth, and signal-to-noise ratio. Claude Shannon, *A Mathematical Theory of Communication*, Bell Syst. Tech. J. 27 (1948).

Thus, mMIMO components, such as digital audio converters,[30] become more intricate and difficult to manufacture at higher frequencies. Likewise, the cost of the instrumentation to measure the performance of RF devices increases with the frequency. In particular, the cost of most RF instrumentation has a sharp increase above 26.5 GHz. Therefore, the cost of instrumentation favors 12 GHz compared to mmW bands. And while there may be more mmW spectrum available for 5G, propagation limitations require very costly deployment efforts to add new transmitters to offset the significant challenges associated with path losses in most practical environments. For these reasons, mMIMO equipment will be more affordable to produce for the 12 GHz band compared to the 28 GHz band.

3.1.2 *Beamforming*

Beamforming is a signal processing technique that improves signal reception, reduces interference, and allows for greater signal focusing on specific user equipment in high-demand areas. Beamforming is normally provided using active antenna systems (such as the MIMO system described in the previous section). Beamforming requires a large number of antenna elements and therefore is most practical in higher frequencies, including upper mid-band frequencies, where the size of each antenna element is comparatively smaller.

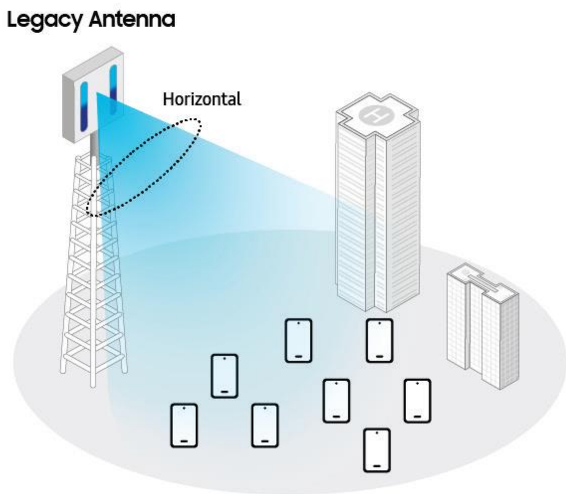
Beamforming can be implemented in multiple ways, such as a pre-defined set of beams in two dimensions, a pre-defined set of beams in three dimensions, or steerable beams. Steerable antenna arrays are used to enable the transmitter to send data to a specific UE, among many devices, by focusing its transmission signal on the location of the specific UE.

Beamforming reduces the likelihood of interference that was associated with earlier generation wireless systems. Historically, base stations broadcast the channel resources designated for specific users over the full geographic sector.[31] However, users in the same geographic sector may experience interference. On the other hand, with the introduction of mMIMO-based 5G systems, individualized beams that reduce the interference among different users are now provided. With 2D mMIMO array antennas, it is possible to create multiple beams that are controlled both in azimuth (horizontal plane) and in elevation (vertical plane), as shown in Figure 3.

[30] Digital audio converters are devices that change analog signals into digital formats.

[31] Sector sizes vary depending upon the application.

Figure 3: Base station antennas for legacy (left) and mMIMO systems (right)[32]



mMIMO array antennas have a large number of element antennas (at least 32 transmitting and 32 receiving antennas in existing implementations) arranged in a two-dimensional array so that there are many degrees of freedom that can be exploited by beamforming algorithms to impose constraints on the shape of the resulting beams. In particular, for each of the individual beams shown in Figure 3, two typical constraints are:

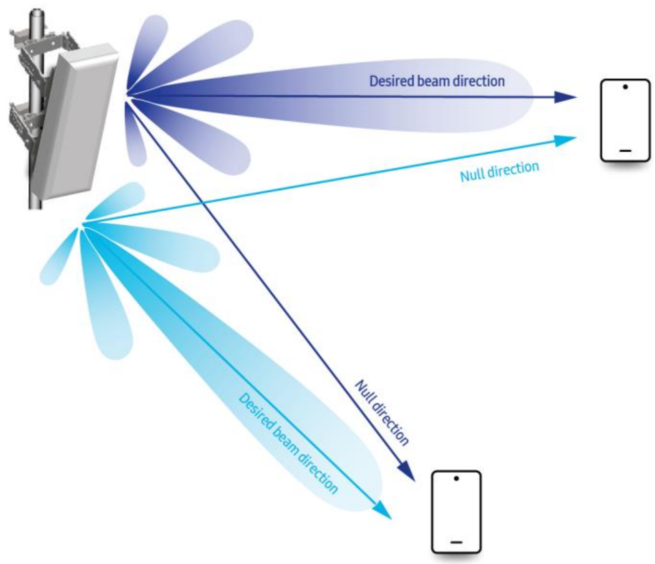
- the directions of maximum radiation that should be aimed towards intended users, which maximizes the strength, quality, and signal to noise ratio of the received signal; and
- the directions of minimum radiation (zeros) that should be aimed towards sources of interference or non-intended users to reduce the interference. This reduces both the overall transmitted power and, importantly, the interference (see Figure 4).

Beamforming algorithms require multipath structure information, which may be obtained through pilot signals and constitutes the channel state information. The practical implementations of these array antennas consist of complex systems composed of three parts: the antennas that radiate energy, the beamforming network that provides the RF signals to each element antenna and the signal processing unit. These systems need to perform many functions, including:

- Estimating the location of users;
- Estimating the locations of sources of interference;
- Creating the signals to control the antenna elements to radiate maxima towards users and zeroes towards non-intended users or sources of interference; and
- Adaptively repeating these operations because users move.

[32] *Massive MIMO for New Radio*, Samsung, at 3 (Dec. 2020), https://bit.ly/3qvnvTD.

Figure 4: Conceptual Representation of Beamforming to Steer Beams Towards Users of Interest and Zeroes Towards Non-intended Users[33]



Nowadays, beamforming is typically performed using digital hardware. However, digital techniques are technologically more challenging at higher frequencies since, among other things, with higher frequencies, the electronics have shorter coherence time period to sample the signal to assess the channel for obtaining real-time channel status information. Therefore, researchers have proposed more complex hybrid methods based on the combination of analog and digital approaches to beamforming for higher frequencies.[34] When the technology implementation challenges are taken into account, the 12 GHz band has the advantage of allowing for the creation of narrower beams compared to the 3.7 GHz band, while still having a reasonable complexity for the beamforming network[35] that is not available at higher mmW frequencies.[36]

As Verizon suggested in the 3.7 GHz proceeding, beamforming techniques such as "beam omission" and "zero-forcing" allow coexistence with satellite earth stations.[37] For the reasons

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[33] *Id.* at 13.

[34] Qi Luo *et al.*, *Low-cost Smart Antennas* (1st ed. 2019).

[35] *3GPP TR 38.820 Technical Report*, 3GPP (June 2020), https://bit.ly/2TdLE4E (3GPP TR 38.820). The report notes that the RF requirements for UE in subrange 1 will be "FR1-like" when subrange 1 goes from 7 GHz to an upper boundary between 10-13 GHz. *Id.* at 58. Section 6.3.1.3 states as follows: "Current RF front-end technology used for > 3.3 GHz TDD bands and Wi-Fi can be extended at least up to 12 GHz. . . . Below 12 GHz it is feasible that a switch supporting branches for FR1 frequencies would support one branch up to 12 GHz." *Id.* at 65. This statement supports the view that 12 GHz performs more like FR1 and digital beamforming applicable to FR1 should apply to 12 GHz band.

[36] The higher frequency of 12 GHz means that the wavelength is shorter than 3.7 GHz and therefore antenna elements are smaller. Due to the smaller size of antenna elements, more 12 GHz elements than 3.7 GHz elements will fit into the same area. With more antenna elements, beamforming supports tighter, more focused beams, and therefore a 12 GHz antenna that is the same size as a 3.7 GHz antenna will support narrower beams.

[37] Letter from Will Johnson, Counsel, Verizon, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 18-122, Attachment at 7-8 (filed Sept. 16, 2019).

explained above, the same techniques suggested by Verizon for the 3.7 GHz band will work equally well or better at 12 GHz. These techniques as presented by Verizon are illustrated below:

Figure 5: Overview of Beam Omission

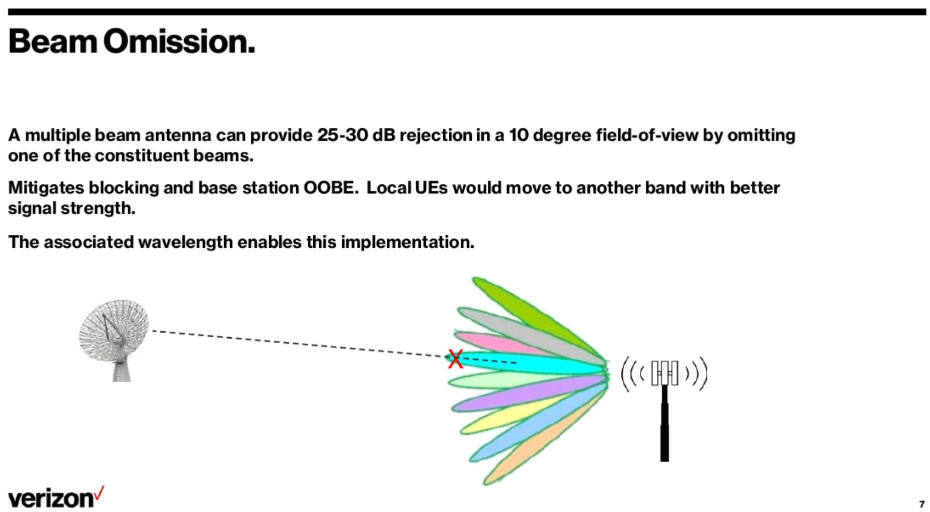
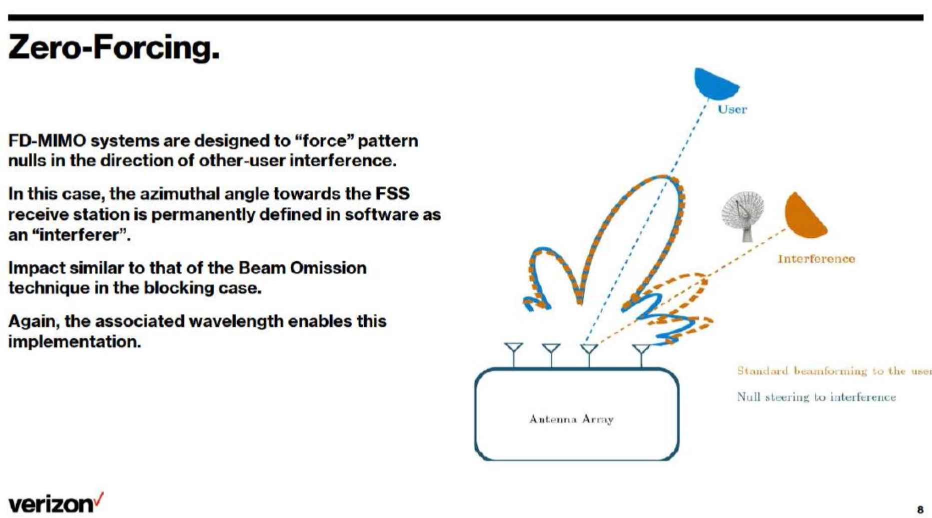


Figure 6: Overview of "Zero-Forcing" in FD-MIMO Systems

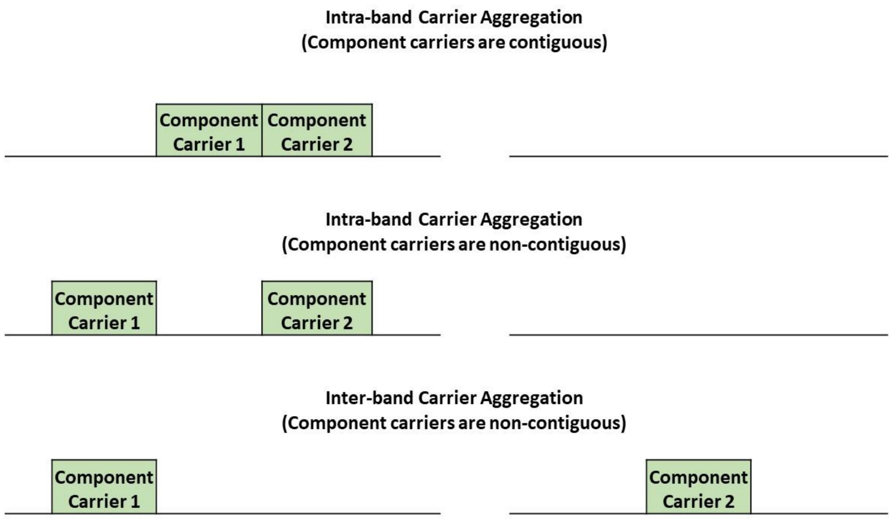


3.1.3 *5G NR Carrier Aggregation*

Carrier aggregation enables the 12 GHz band to complement both the lower mid-band spectrum and mmW bands. Carrier aggregation is a technique that allows a wireless operator to combine channels that have limited bandwidth to increase the network's overall throughput. The ability to aggregate existing low-, mid-, and high-band frequencies with the 12 GHz band in different ways will enable the graceful and cost-effective evolution and migration of an operator's network from 4G to 5G.

Carrier aggregation allows operators to combine their spectrum portfolios across at least three dimensions: (1) within the same band where the channels are contiguous, (2) within the same band where the channels are not contiguous, and (3) across different bands. These implementation options are depicted in Figure 7.

Figure 7: Three Different Models of Carrier Aggregation



Although carrier aggregation was specified for 4G LTE, it promises to prove particularly valuable as operators develop standalone 5G networks that do not rely on legacy 4G architectures.[38] Carrier aggregation also allows an operator to add bandwidth for 5G by combining channels across the various spectrum bands that have been dedicated to 5G. In practice, an operator's ability to harness the benefits of carrier aggregation depends on the spectrum resources available within any given geographic area. In the past year, combining low- and mid-band spectrum bands has become attractive because it extends 5G coverage, boosts network capacity, and increases data speeds.

Carrier aggregation allows operators to achieve the right blend of coverage and capacity by putting particular spectrum bands to the uses for which they are best suited. Through a series of successful interoperability field tests, vendors and carriers have recently demonstrated that carrier aggregation is feasible in 5G use cases. Ericsson, with its ecosystem partners MediaTek, Qualcomm, and network operator customers T-Mobile and Optus,[39] have used carrier aggregation to address the 5G mid-band coverage limitations. Their carrier aggregation solution increases coverage by using

[38] Stefan Rommer *et al.*, *5G Core Networks* (2020).

[39] Ericsson, Press Release, Ericsson spearheads 5G carrier aggregation milestones with key partners (Oct. 15, 2020), https://bit.ly/35UAqoF; Carrier aggregation in 5G, Ericsson, https://bit.ly/3gY8whN (last visited June 28, 2021); MediaTek, Press Release, MediaTek and Ericsson Perform World's First Interoperability Test with Three Combinations of NR FDD/TDD Carrier Aggregation Using Dimensity 1000+ Chipset (Sept. 14, 2020), https://bit.ly/2T71QF6.

lower uplink frequencies to transmit control and data traffic. At the same time, these solutions improve capacity and data throughput by using mid-band frequencies to handle other types of transmissions on the downlink path.

We stress, however, that the commercial benefits of 5G NR Carrier Aggregation greatly depend on the bands available for 5G. Where mid-band spectrum is available, carrier aggregation can improve low-band spectrum utilization,[40] with incremental improvements in capacity (using lower mid-band frequencies on downlink to maximize data rates) without sacrificing range (using lower frequencies on the uplink to conserve power and maintain viable propagation distances). Thus, carrier aggregation is particularly useful for heterogeneous spectrum portfolios. And where new bands can bridge the gap between bands already allocated for 5G, carrier aggregation can prove particularly valuable.

Table 4 illustrates this principle. It shows the different combinations of spectrum bands that may be available to an operator in specific geographic areas. Three spectrum bands are considered: 3.7 GHz, 12 GHz, and 28 GHz. Table 4 shows the value of the addition of 12 GHz in increasing capacity and coverage in areas where an operator may have spectrum in the 3.7 GHz or 28 GHz or both bands.

Table 4: Combination of frequency bands available for 5G inter-band Carrier Aggregation

3.7 GHz	12 GHz	28 GHz	Carrier Aggregation Feasibility	Potential Benefits (capacity and coverage increases)
1 = spectrum available 0 = spectrum not available				
0	1	1	Yes	Yes, use 28 GHz downlink for capacity and 12 GHz uplink for range
1	1	0	Yes	Yes, use 12 GHz downlink for capacity and 3.7 GHz uplink for range
1	1	1	Yes	Yes, use 12 GHz uplink with 28 GHz downlink and 12 GHz downlink with 3.7 GHz uplink, improving the capacity and range of both 3.7 GHz and 28 GHz bands

For many wireless operators, combining low- and lower mid-band frequencies with the 12 GHz band is a natural next step to significantly increase both capacity and coverage than has been possible so far. Operators can rely on low-band and lower mid-band frequencies on the uplink to achieve ubiquitous coverage while using the 12 GHz band to enhance capacity and throughput. As an example, the 12 GHz band can be used with 3.7 GHz band to supercharge downlink capacity with 12 GHz in closer proximity to the base station while preserving/extending the availability of 3.7 GHz band capacity further to the cell edge. Use of 3.7 GHz on the uplink will preserve the full range of 3.7 GHz band spectrum.

Aggregating the 12 GHz band with mmW spectrum, meanwhile, can enhance coverage and capacity in the opposite direction. Operations can use the mmW band on the downlink for greater

[40] T-Mobile, Press Release, T-Mobile, Ericsson, LG & MediaTek Achieve a World's First with LG VELVET 5G, Combining Sub-6 GHz 5G with Carrier Aggregation (Oct. 6, 2020), https://t-mo.co/3w2z31M.

throughput while using the 12 GHz band, with its superior propagation characteristics, on the uplink to achieve greater coverage and in-building penetration.

3.2 *5G Network Architecture and Standards*

To support the growing number of mobile broadband subscribers and their bandwidth-intensive applications, wireless operators increasingly rely on advances in network architectures to handle traffic in high-density areas and to maintain adequate quality of service at the macro-cell edges. As this subsection discusses, the 12 GHz band allows operators to maximize these architectural innovations—such as small cells and wireless backhaul, among other things—that promise to be core elements of 5G network development.

3.2.1 *Deployment Models*

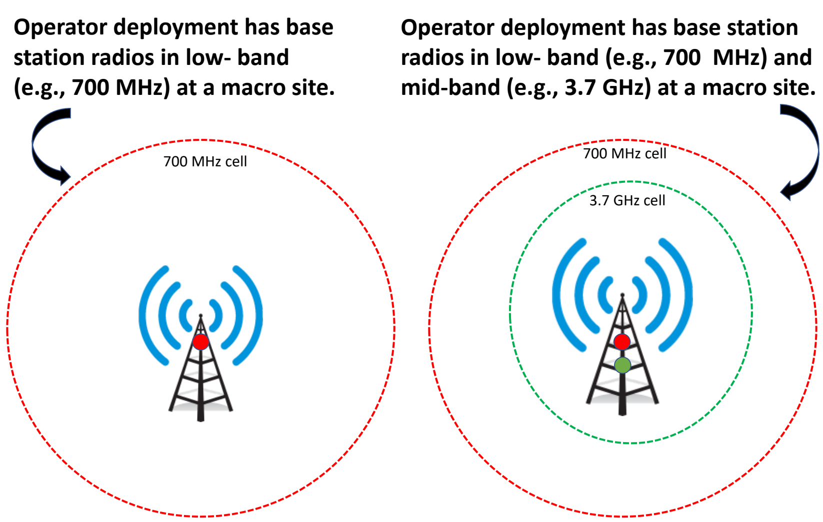
For wireless carriers, the prospective addition of the 12 GHz band offers greater flexibility to grow their network. The preferred mode of deploying 5G base stations in the 12 GHz band will be influenced by the network operator and whether it is an incumbent or a greenfield operator.

3.2.1.1 Macro-cells

An incumbent operator is already established as a cellular carrier and offering service using a combination of one or more spectrum bands that it possesses in a given area. An incumbent network operator could be using a combination of one or more low-band and mid-band frequencies to serve its customers with macro-cells.

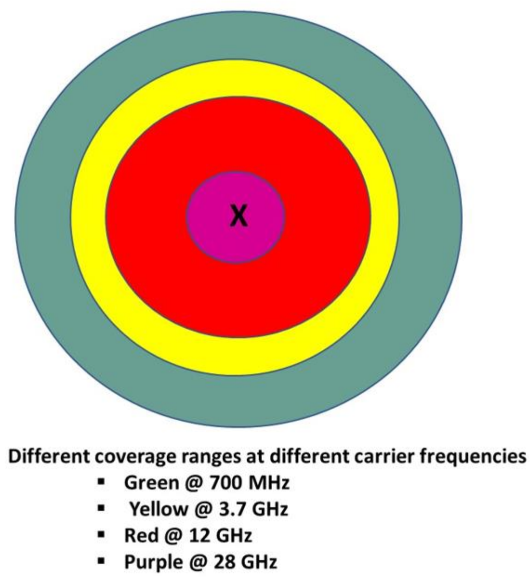
Each additional base station radio provides additional capacity to serve mobile users that are capable of receiving at the different frequencies used by the base stations. An operator that has spectrum in the 700 MHz band, for example, can deploy lower mid-band 3.7 GHz spectrum using the same macro-cell sites, as shown in Figure 8 below. The 12 GHz band can play a similar role in adding capacity to existing low- and lower mid-band deployments.

Figure 8: Example of Incumbent Operator Cell Site Deployments



Indeed, an operator that uses multiple frequency bands at a macro-cell site can serve its users (with a multi-mode device capable of operating in the multiple bands) using a frequency band that is optimal for the user based on its needs, location relative to the base station and congestion status of the cell site. This can help ensure user performance requirements are satisfied while the operator can optimize both the coverage and capacity of its radio and network resources. Figure 9 presents a sample multi-band deployment strategy.

Figure 9: Example of an Operator adding 12 GHz band to an Existing Macro-cell[41]



At some point in the evolution of an operator's network, it may become impossible to simply increase capacity at a cell site by adding additional radios at different frequency bands on the cell tower. Possible reasons could be due to weight, size, power and/or other technical or business constraints. In this situation, the incumbent operator may consider selective addition of small cells at 12 GHz or any band in the operator's possession. This configuration is similar to that described in the next section of the report focusing on greenfield operators.

3.2.1.2 Small-cells

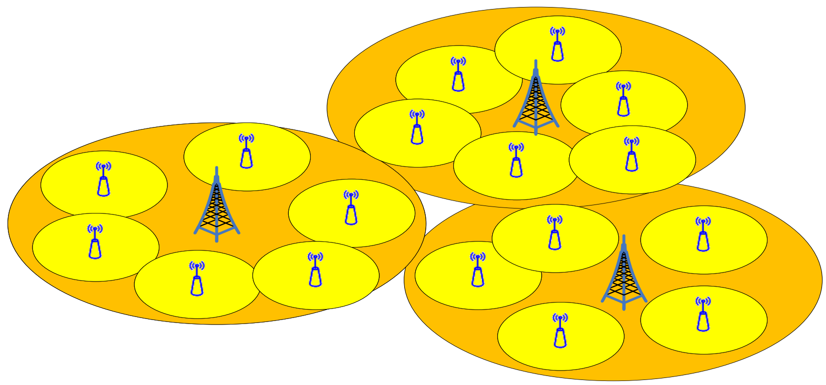
Once a macro-cell network is in place including the optimal set of low, mid- and high-band spectrum to provide the best coverage possible, there may still be "holes" in the coverage map where the signal strength is limited or, more likely, where the macro-cells are unable to meet the localized capacity demand. In such a case, Small Cells can be deployed to meet customer demand. Given its unique capacity and coverage characteristics, the 12 GHz band may offer an ideal spectral choice for meeting this small-cell capacity need.

Figure 10 shows how the light-yellow small cells may be used in a heterogeneous overlay manner to supplement the dark-yellow macro-cell network of 12 GHz sites. As noted, these small cells

[41] Figure 9 is not scaled based on the propagation characteristics of the 700 MHz, 3.7 GHz, 12 GHz, or 28 GHz bands.

can be used to boost capacity where needed and/or to improve coverage to areas where the macro-cell has trouble reaching.

Figure 10: A Heterogeneous Overlay Network Architecture of Macro- and Small-Cell Base Stations[42]



3.2.2 *Wireless Backhaul*

Backhaul connectivity is critical for 5G networks and especially important for heterogeneous networks with numerous small cells. In a best-case deployment scenario, backhaul should provide very high throughput (multiple Gbps) and low latency over a dedicated point-to-point link using optical fiber. Microwave backhaul and xDSL are less ideal alternatives currently used to satisfy throughput and latency expectations. The backhaul alternatives present different tradeoffs in availability, robustness, installation, and operating costs.

Recent 5G NR specifications allow operators to use the same band to connect wireless backhaul base stations to the core network while simultaneously serving mobile broadband subscribers. This feature, known as Integrated Access and Backhaul (IAB)[43] and featured in 3GPP Release 16 of 5G NR, enables rapid and cost-effective mmW deployments through backhauling in the same spectrum. IAB leads to greater performance, more efficient use of spectrum resources, and lower equipment costs. It also reduces the need for fiber backhaul at a particular node. IAB technology is not limited to any specific 5G NR band and can be extended readily to other frequency bands, such as the 12 GHz band. Given the significant amount of bandwidth available at 12 GHz, operators could assign a small portion of the band for wireless backhaul while using the remainder for commercial access.

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[42] *ITU-R M.2376-0* at 29.

[43] *Innovations in 5G Backhaul Technologies: IAB, HFC & Fiber*, 5G Americas (June 2020), https://bit.ly/2T83fey; Henrik Ronkainen *et al.*, *Integrated access and backhaul: A New Type of Wireless Backhaul in 5G*, Ericsson Technology Review (June 23, 2020), https://bit.ly/3w6lLBg; Matthew Baker & Miikka Poikselkä, *5G Releases 16 and 17 in 3GPP*, Nokia (2020), https://bit.ly/3dp78CK; Amitabha Ghosh & Mark Cudak, *Integrated access and backhaul: Why it is essential for mmW deployments*, Nokia (Nov. 13, 2020), https://nokia.ly/3jlm8Fj; Integrated access and backhaul radio transmission and reception, 3GPP, TS 38.174, https://bit.ly/3hbTW56 (last visited July 6, 2021).

4 Throughput Characteristics of the 12 GHz Band

Throughput, or capacity, is a key attribute in evaluating spectrum for 5G services. Indeed, supporting high throughput is key to meeting the performance requirements for 5G.[44] In this section, we characterize the throughput that can be obtained using 500 MHz of bandwidth at 12 GHz. Since there have been no trials testing 5G technology at 12 GHz, we utilize available information at the neighboring 5G bands of 3.7 GHz and 28 GHz to estimate the throughput at 12 GHz and compare it to that obtained in these other bands. We consider both the peak aggregate downlink throughput and the peak per-user downlink throughput that can be obtained. The aggregate downlink throughput measures how many bits per second a single base station can send to multiple users within a cell, while the per-user throughput looks at the throughput that can be delivered to a single user.[45]

The results of our analysis show that:

- The peak aggregate downlink throughput realizable at 12 GHz should be superior to both the 3.7 GHz and 28 GHz bands when practical spectral efficiency values at the different frequencies are taken into account.

- The peak per-user downlink throughput realizable at 12 GHz should be comparable to that at 3.7 GHz and 28 GHz and could exceed these if one can aggregate larger bands of spectrum to serve a single user.

The 12 GHz band allows operators to more flexibly and cost-effectively deploy and adapt their mobile networks while achieving increases in both range and capacity. The 12 GHz band also enhances the value of low-band and lower mid-band spectrum because of the opportunity to aggregate bandwidth to achieve additional capacity. 12 GHz enhances the value (or utility) of mmW spectrum band by providing the opportunity to aggregate and extend its range.

4.1 *Aggregate downlink throughput*

We summarize the key attributes that contribute to our analysis of the aggregate downlink throughput in Table 5.

[44] *See generally ITU-R M.2410-0*.

[45] We discuss downlink throughput here. Similar trends would be observed for uplink throughput (*i.e.*, the throughput from end users sending to a single base-station).

Table 5: Key Attributes of the 3.7 GHz, 12 GHz, and 28 GHz Bands for Aggregate Downlink Throughput

Band (GHz)	Additional Free Space Path Loss over 3.7 GHz (dB)	Additional Loss due to Blockage over 3.7 GHz (dB)	Band-width (MHz)	Array Gain Over 3.7 GHz (dB)	SU-MIMO Layers	MU-MIMO Layers	Peak Spectral Efficiency (bps/Hz)	Estimated Peak Throughput (Gbps)
3.7	0	0	280	0	4	16	77.1	15.1
12	10.2	4	500	10.2	4	16	57.1	20.0
28	17.6	8	850	17.6	2	4	15.2	9.0

The aggregate downlink throughput can be viewed as the product of the following three factors:[46]

*Throughput (bps) =TDD fraction * Bandwidth (Hz) * Spectral Efficiency (bps/Hz)*

We discuss each of these three factors next.

4.1.1 *TDD Fraction*

Most spectrum for 5G is deployed using TDD, meaning that the same spectrum band is used at different times for both uplink and downlink communication. 5G supports a flexible frame structure in which the fraction of time devoted to uplink and downlink transmissions can vary depending on how an operator configures these parameters. The TDD fraction in the equation above accounts for the fraction of time that the system is configured for downlink transmissions. Common reported values for the TDD fraction are between 70% and 80%. In our subsequent analysis we assume that the TDD fraction is 70%.

[46] A more detailed model could include additional factors such as the fraction of data needed for control overhead. We ignore these here as they would be the same across different spectrum bands for 5G.

4.1.2 *Bandwidth*

For a given band of spectrum we consider the entire available bandwidth for that band when characterizing the aggregate downlink throughput. Note that depending on device capabilities it may not be possible for one user to utilize the entire band, but different portions of the band could be allocated to different users. As shown in Table 5, we consider 280 MHz of spectrum at 3.7 GHz, 500 MHz of spectrum at 12 GHz and 850 MHz of spectrum at 28 GHz. By moving to higher carrier frequencies, larger amounts of bandwidths are available. If all other parameters were fixed, this would result in a throughput gain of 79% for 12 GHz compared to 3.7 GHz and a throughput gain of over 200% for 28 GHz compared to 3.7 GHz. However, as we will discuss next, the gain from larger bandwidths at 28 GHz is offset by a decrease in spectral efficiency in practical mmW systems.

4.1.3 *Spectral Efficiency*

Spectral efficiency measures how many bits per second can be sent per unit of bandwidth (*i.e.*, it has units of bits per second per Hz (bps/Hz)). A more spectrally efficient technology can therefore "pack more throughput" into a given amount of spectrum.

For 4G and 5G bands, spectral efficiency is calculated based on the following:

*Spectral Efficiency (bps/Hz) = Number of MIMO layers * Effective "MCS" rate (bps/Hz)*

"Number of MIMO layers" reflects the number of multiple-input multiple-output (MIMO) streams that can be sent.[47] The modulation and coding scheme (MCS) affects how much data can be sent per stream. Each of these factors may degrade as the frequency increases.

Being able to send multiple MIMO layers depends on the availability of hybrid or digital beamforming solutions, which is more challenging at high carrier frequencies (systems using analog beamforming can only send one layer). The number of layers that can be sent to a given user in mmW bands can also be limited due to propagation characteristics that make mmW channels "sparser" compared to mid-band channels.[48] Evidence of these trends can be seen in current products—for example, Qualcomm's Snapdragon X65 5G chip for end-user devices supports 4x4 MIMO for lower mid-band, but only 2x2 MIMO for mmW, meaning that at 3.7 GHz, four MIMO layers can be obtained, while at most two can be obtained at 28 GHz.[49]

We believe that 12 GHz can support similar MIMO configurations as those supported in lower mid-band frequencies and would exhibit a similar advantage over 28 GHz. In addition to

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[47] MIMO systems combine antenna arrays, wave propagation, and signal processing to improve the performance of communication systems in terms of signal quality increase, interference reduction and improved spectral efficiency. *See* Section 3.1.1.

[48] Shu Sun *et al.*, *Mimo for millimeter-wave wireless communications: beamforming, spatial multiplexing, or both?*, 52 IEEE Comms. Magazine 12, at 110-21 (Dec. 2014), https://bit.ly/3x2RpkB.

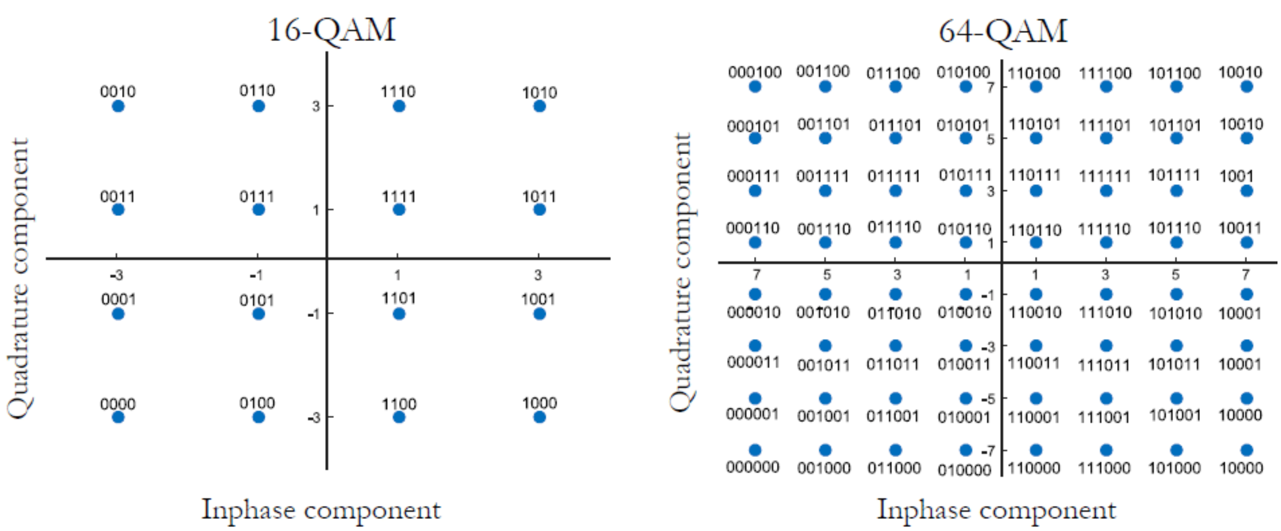
[49] Qualcomm, Qualcomm® Snapdragon™ X65 5G Modem-RF System, https://bit.ly/3h7yC0L (last visited June 26, 2021). Note that here at FR2, 2x2 MIMO refers to the number of MIMO layers that the chip can deliver, not the number of antenna elements which due to hybrid beamforming may be much larger.

providing multiple MIMO layers to a given device, as discussed in Section 4.1, MU-MIMO can increase spectral efficiency by enabling MIMO layers to be sent to multiple devices simultaneously. In mid-band spectrum, manufacturers have reportedly demonstrated 16 layer MU-MIMO deployments sending two streams to eight devices.[50] MU-MIMO at mmW is also being pursued, but propagation limitations are more challenging and require hybrid or digital beamforming. As a result, the number of layers supported in mmW products is lower than those for mid-band spectrum.[51] The only reported demos of MU-MIMO at mmW frequencies that we are aware of have been done within labs, such as a Samsung demo that reported using mmW MU-MIMO to transmit to two devices.[52] Because beamforming is more challenging at higher frequency bands, the spectral efficiency of the 3.7 GHz band is roughly eight times that of the 28 GHz band assuming the same MCS rate.

The second factor that influences spectral efficiency is the effective MCS rate. 5G NR supports Quadrature Phase Shift Keying (QPSK) and 16-, 64-, and 256-bit quadrature amplitude modulation (QAM). These can transmit 2, 4, 6, and 8 bits per symbol, respectively.

Figure 11 shows that, as the number of symbols increases, so too does the precision needed to convey data accurately.

Figure 11: Signal Space Constellations for 16-QAM and 64-QAM



The modulation rate a given link can use depends on the channel quality. Received signal-to-noise ratio (SNR), or the ratio of the received signal power to the noise power, can dramatically affect a

[50] Bevin Fletcher, *T-Mobile pulls more out of 2.5 GHz in MU-MIMO 5G demo with Ericsson*, FIERCE WIRELESS (Sept. 10, 2020), https://bit.ly/3hcowM8; Bevin Fletcher, *Ericsson hits 5.4 Gbps throughput in MU-MIMO C-band test*, FIERCE WIRELESS (Sept. 11, 2020), https://bit.ly/3hcU6t7.

[51] For example, the Samsung's Compact Macro mmW unit supports 4 MIMO layers. Compact Macro (Access Unit), Samsung, https://bit.ly/2UaXa13 (last visited June 28, 2021).

[52] Samsung, Press Release, Samsung Demonstrates the Full Potential of 5G mmW with Speeds of 8.5Gbps Across Multiple Devices (Apr. 14, 2020), https://bit.ly/3qz0RJZ.

channel's quality.[53] In other words, lower SNR values require a lower MCS rate for reliable communication. Section 2.1 details how propagation characteristics of the 12 GHz and other bands affect the quality of communications transmissions. For example, assuming the same antenna configurations, the larger free-space path loss at higher frequencies shown in Table 5 leads to lower received SNR in 12 GHz compared to 3.7 GHz and a much lower value at 28 GHz. At high SNR values, the theoretically optimum rate versus SNR (in dB) can be approximated by the following equation[54]:

$$\textit{Effective MCS rate/layer} \approx 0.33 \times SNR_{dB}$$

Compared to 3.7 GHz, this calculation translates into a loss of 3.8 bps/Hz and 5.8 bps/Hz for 12 GHz and 28 GHz, respectively, using the free space and blockage loss values in Table 5. These losses can be compensated for, in part, by larger antenna arrays, which are physically more feasible at higher frequencies. Indeed, if we assume that the number of elements in the array scales with frequency while keeping the area fixed, then the resulting array gain will compensate for the free-space path loss.[55] This array gain will not compensate for some of the other propagation impairments discussed, such as blockage due to foliage or human bodies. These limitations are accounted for in the third column of Table 5.

Hardware impairments can also reduce MCS rates—a more significant concern at higher frequencies. For example, phase noise[56] increases by at least 6 dB with every frequency doubling.[57] Hence, the phase noise at 12 GHz would be more than 6 dB lower than that at 28 GHz. In orthogonal frequency-division multiplexing systems like those supporting 5G NR, phase noise can create two issues: common phase errors within each carrier and inter-carrier interference.[58] These issues, in turn, can limit the use of higher-order modulation schemes, resulting in a lower effective MCS rate. Given that phase noise is lower at 12 GHz compared to 28 GHz, this favors higher-order modulation schemes at 12 GHz.

Other hardware impairments such as power amplifier non-linearities and "I/Q imbalances" also become more challenging at higher frequencies and may limit the use of higher-order modulation

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[53] Code rate is a measure of the redundancy added to ensure reliable communication. A low coding rate corresponds to increased redundancy and is used under poor link condition and/or to achieve ultra-high reliability.

[54] This is a high SNR approximation to the Shannon formula, C = 12log(1+P/N), which gives the theoretical limit on the MCS rate that can be reliably obtained as a function of the SNR.

[55] *See supra* Table 5. In practice, the number of antenna elements used for mmW antennas is typically larger than the number used at lower frequencies for this reason. However, the antenna area of mmW antennas is also typically smaller than those used at lower frequencies so that the resulting antenna may not fully compensate for the increased path loss as we have assumed here.

[56] *What is Phase Noise?*, everythingRF (Aug. 13, 2019), https://bit.ly/3w3ezWv ("Phase noise is defined as the noise arising from the rapid, short term, random phase fluctuations that occur in a signal. These random fluctuations are caused by time domain instabilities called as phase jitter.").

[57] Stefan Andersson *et al.*, *Design Considerations for 5G mm-Wave Receivers*, Ericsson, at 6 (June 6, 2017), https://bit.ly/2St15ph.

[58] 5G includes different techniques to mitigate these impacts such as using larger sub-carrier spacing to reduce inter-carrier interference and adding phase-tracking reference signals to reduce the common phase errors. Such techniques create transmission overhead and thus impact the overall rate.

for mmW bands compared to the 12 GHz band.[59] Current products' specifications support this conclusion. For example, Samsung's 5G Exynos Modem 5123 only supports 64 QAM in mmW but 256 QAM in lower mid-band.[60] This corresponds to a difference in the maximum effective MCS rate by a factor of 1.33 between 3.7 GHz and 28 GHz when using these products. Each of these factors that limit the MCS rate at 28 GHz is less challenging to overcome at 12 GHz, suggesting that the supported MCS rates at 12 GHz may be more similar to those at 3.7 GHz. A 3GPP study on the 7-24 GHz frequency range suggests that device requirements at the lower end of this range would be more "FR1-like."[61]

In summary, while moving to higher frequencies increases the amount of bandwidth that can be allocated to a user, the spectral efficiency will decrease given current technology limitations. The realized spectral efficiency will depend on the deployment and the channel quality between a base station and end-user device. Existing measured data on peak spectral efficiency in the 3.7 GHz and 28 GHz spectrum bands substantiates this:

- Ericsson reported hitting a peak rate of 5.4 Gbps using 100 MHz of 3.7 GHz band spectrum, with 16 layer MU-MIMO and 8 devices.[62] The TDD-fraction for this trial was not reported and so we assume 70%. This gives a peak spectral efficiency of 77.1 bps/Hz, and a per-device spectral efficiency of 9.6 bps/Hz.
- Qualcomm and Ericsson reported a single user throughput of 2.5 Gbps using 160 MHz of TDD spectrum in a 70% downlink configuration with 4x4 MIMO.[63] This gives a peak spectral efficiency of 22.3 bps/Hz.
- Samsung reported obtaining 8.5 Gbps across 2 devices using mmW MU-MIMO and 800 MHz of spectrum. Again, the TDD fraction was not reported and so we assume it to be 70%, giving a spectral efficiency of 15.2 bps/Hz and a per-device spectral of 7.6 bps/Hz.[64]
- Verizon reported a peak rate of 5.06 Gbps to a single device using 800 MHz of spectrum at 28 GHz. Again, the TDD fraction was not reported and so we assume it to be 70%, giving a peak spectral efficiency of 9.0 bps/Hz.[65]

Table 6 summarizes the peak spectral efficiencies we have estimated from these reported trials data for both 3.7 GHz and 28 GHz. We use the reported values with MU-MIMO to calculate the aggregate peak downlink throughput for these bands as given in Table 5.

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[59] Ming Xiao *et al.*, *Millimeter Wave Communications for Future Mobile Networks*, 35 IEEE J. on Selected Areas in Comms. 9, at 1909-35 (Sept. 2017), https://bit.ly/2TK8QHY.

[60] Samsung, *Modem: Exynos Modem 5123*, https://bit.ly/3hcvhgI (last visited June 26, 2021).

[61] 3GPP TR 38.820.

[62] *See supra* note 50.

[63] Bevin Fletcher, *Qualcomm, Ericsson near peak in 5G standalone carrier aggregation test at 2.5 GHz*, FIERCE WIRELESS (Aug. 24, 2020 6:43 PM), https://bit.ly/3joHSjy.

[64] *See supra* note 52.

[65] Verizon, Press Release, Verizon, Ericsson and Qualcomm first in the world to achieve 5G peak speed of 5.06 Gbps (Oct. 20, 2020), https://vz.to/3y3cXNX.

Table 6: Summary of Reported Peak Spectral Efficiencies

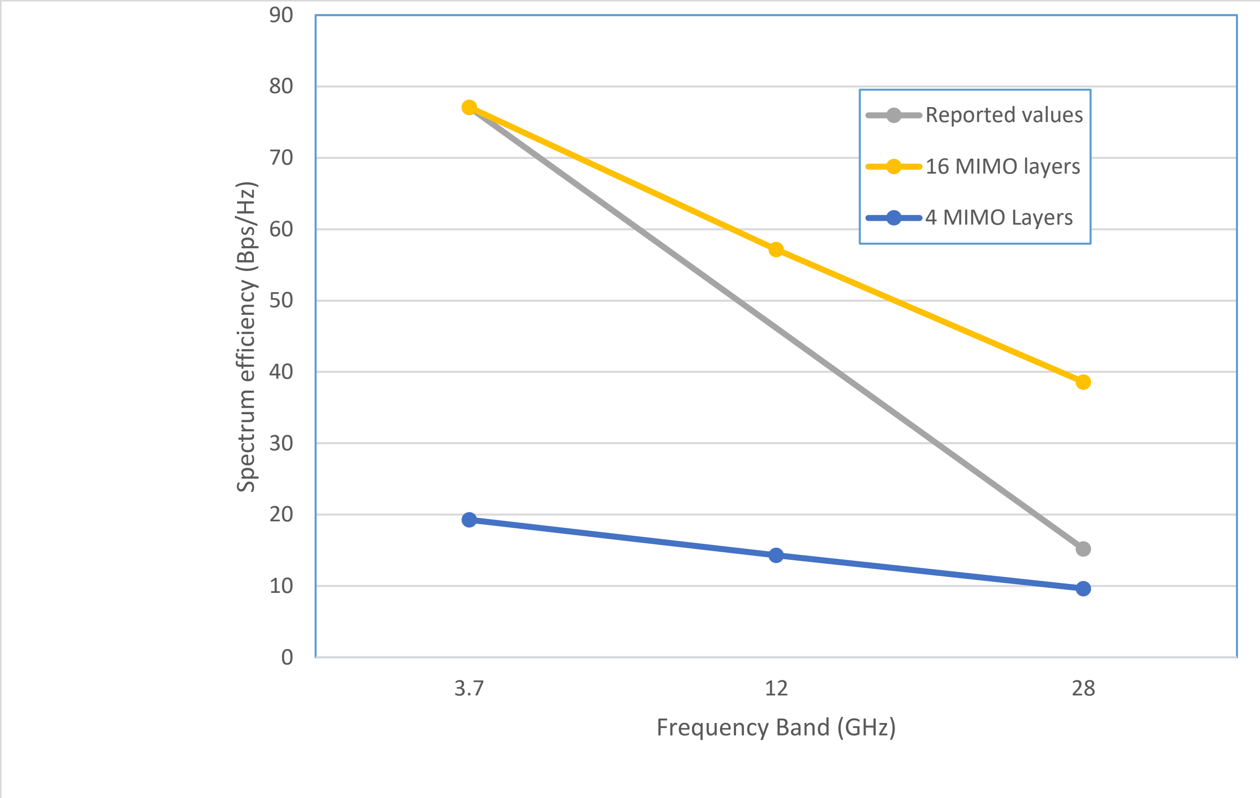
Band	MU-MIMO	Peak Spectral Efficiency
FR1	Y	77.1 bps/Hz
FR1	N	22.3 bps/Hz
FR2	Y	15.2 bps/Hz
FR2	N	9.0 bps/Hz

We estimate the spectral efficiency for 12 GHz as follows. Starting with the reported spectral efficiency at 3.7 GHz, we determine the corresponding SNR by using the Shannon capacity formula, which gives the achievable data rate for a given SNR value. We then adjust the SNR value by accounting for the propagation losses and antenna gains at 3.7 GHz given in Table 5 and use this new SNR to determine a new feasible data rate. As we have noted for 12 GHz, we assume the same MIMO configuration as at 3.7 GHz when doing this calculation. This gives a spectral efficiency of 57.1 bps/Hz as reported in Table 5.

Figure 12 illustrates this approximation. In this figure, the middle grey line corresponds to a linear interpolation of the reported spectral efficiency values with MU-MIMO for 3.7 GHz and 28 GHz in Table 6. The top yellow line represents the calculated spectral efficiencies at 12 GHz and 28 GHz, using the process described above and assuming that in each case one can use 16 MIMO layers as in the reported 3.7 GHz data. This will likely be the case for 12 GHz but is not the case for commercial deployments at 28 GHz. The lower blue line shows the spectral efficiency obtained using only four MIMO layers, which is more representative of commercial 28 GHz products. This is given by simply dividing the spectral efficiency values in the yellow curve by 4. Note that at 28 GHz, the grey line is above the blue by about 5 bps/Hz. This can be explained by the fact that the reported value we are using at 28 GHz is from a lab test, which likely did not suffer from any propagation losses due to blockage as factored into our model. The reported 28 GHz spectral efficiency without using MU-MIMO is 8.4 bps/Hz, which is much closer to the blue line at 28 GHz.

Note also that if the estimated peak spectral efficiency for 12 GHz in Table 5 were to be reduced by 50%, then 12 GHz would still yield a larger total peak throughput than 28 GHz. While this number would need to be verified through testing, it gives an indication of the potential comparative peak aggregated downlink throughput that might be achievable with the 500 MHz of spectrum in the 12 GHz band.

Figure 12: Estimated Aggregated Downlink Spectral Efficiencies



4.2 *Per-User Peak Throughput*

We also used the preceding procedure to characterize per-user throughput in these different spectrum bands. For per-user throughput, the bandwidth term corresponds to the bandwidth assigned to an individual user. At 28 MHz, bandwidths as large as 400 MHz per carrier are allowed in 5G deployments, while the maximum bandwidth per carrier at 3.7 GHz is 100 MHz. These can be increased through carrier aggregation and, in practice, current products allow for aggregating a total of between 200 and 300 MHz in FR1 and between 800 MHz and 1 GHz in FR2.[66] For 12 GHz, if we follow the FR1 requirements/implementations, this would allow for between 200 and 300 MHz of aggregated spectrum. However, given the amount of spectrum available at 12 GHz, larger amounts of spectrum might be aggregated, resulting in up to 500 MHz of aggregated spectrum. Given this is Table 7, we show an estimated per-user throughput for 12 GHz assuming both 200 MHz of aggregated spectrum and 500 MHz of aggregated spectrum.

[66] For example, the Qualcomm X65 modem supports up to 300 MHz in FR1 and 1 GHz in FR2, while the MediaTek M80 chip supports 200 MHz in FR1 and 800 MHz in FR2. *See* Qualcomm® Snapdragon™ X65 5G Modem-RF System, Qualcomm, https://bit.ly/3h7yC0L (last visited July 6, 2021); 5G Modems, MediaTek, https://bit.ly/3Awsfg9 (last visited July 6, 2021).

We use the single user spectral efficiencies from Table 6, for 3.7 GHz and 28 GHz and estimate the 12 GHz spectral efficiency in the same way as above. As in the reported trials we assume four MIMO layers for a single user at 3.7 GHz and 12 GHz, while only two MIMO layers at 28 GHz. We do not consider MU-MIMO here since we are only considering one user.

Table 7 suggests that 200 MHz of 12 GHz spectrum offers per-user throughput of 2.4 Gbps which is somewhat lower than that obtained using the same amount of spectrum at 3.7 GHz but significantly higher than 200 MHz of 28 GHz spectrum. However, if 500 MHz of spectrum could be aggregated at 12 GHz for a single user, the per-user throughput would increase to 6 Gbps which is larger than that obtained using either 200 MHz of 3.7 GHz or 800 MHz of 28 GHz spectrum.

Table 7: Per-User Throughput in Different Bands, Assuming Maximum Carrier Aggregation

Band (GHz)	Aggregated Bandwidth (MHz)	SU-MIMO Layers	Spectral Efficiency (bps/Hz)	Per-User Peak Throughput (Gbps)
3.7	200	4	22.3	3.1
12	200	4	17.2	2.4
28	200	2	9.0	1.5
12	500	4	17.2	6.0
28	800	2	9.0	5.0

5 Commercial Feasibility of 12 GHz Deployment

This section explains why broadband deployment will be commercially feasible in the 12 GHz band in a rapid timeframe if the FCC authorizes two-way 5G services in the band. Based on our technical experience and expertise, we believe commercial ecosystems are well suited to deploy 5G-compatible equipment and satisfy a growing need for mid-band spectrum. Component systems have already integrated services for frequencies above and below 12 GHz, and the band presents no unique challenges compared to other bands in which the FCC has authorized 5G services. Overall, new consumer and network devices can be 12 GHz compatible one to two years after band adoption.

5.1 *Deployment Timelines*

Allocation of the 12 GHz band for two-way mobile services is a prerequisite to the commercial development of compatible equipment, which will then be a function of the innovation environment and basic economics of mobile telecommunications.

3GPP Technical Standard Development—The Commission's adoption of a report and order allocating the 12 GHz band for two-way mobile services will jump-start the 3GPP standards development process. Commission action would give the regulatory certainty that commercial providers require to invest the time and resources into multi-stakeholder collaboration, 3GPP study items, and working groups through ex-post product implementations.[67] Moreover, 3GPP members cannot articulate technical specifications without band specifics. For example, chipset providers must be aware of band details (*e.g.*, sub-band spacing and guard band presence, emission limits in adjacent bands, and sub-band sizes) to develop transceiver hardware and software. Only then can technical standards development process proceed. The 12 GHz band serves as a unique point of consensus for major vendors and operators.[68] As a result, the standards lifecycle can accelerate. Providers can articulate technical specifications and develop sample hardware in 9 – 18 months.

IMT Adoption—The ITU relies on standards-setting bodies, such as 3GPP, to develop technical specifications the ITU can adopt for globally compatible operating and equipment standards.[69] The ITU's transposition of technical specifications into an International Mobile Telecommunications (IMT) operating standard indicates global validation and allows digital ecosystems to proceed.[70] For IMT-2020, the ITU-R has adopted 3GPP Releases 15 and 16 for 5G radio access technology.[71] The ITU's coordination with 3GPP may continue for the 12 GHz band, and a subsequent release may be adopted by the ITU for 5G service.

Commercial Product Deployment—Development of components for 12 GHz operation will begin once the Commission adopts a report and order. ITU-R designation ensures worldwide compatibility for commercial component and chipset providers to support 12 GHz capability. Design and integration into end products, such as user equipment and base stations, will then be expedited. As with recent implementations of other new bands, RF front-end equipment (*e.g.*, power amplifier, low noise amplifier, filter) should be able to be 12 GHz capable within 6 months after authorization. 12 GHz antennas will be designed during handset development and should not limit product schedules.

5.2 *Commercial Support in Other Bands*

Commercial providers can succeed in 12 GHz because there is a business case for implementation unencumbered by constraints. Multiple manufacturers mass-produce commercial components that support operations below and above the 12 GHz band.[72] In short order, they can do the same for 12 GHz-compatible components.

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[67] *About 3GPP Home*, 3GPP, https://bit.ly/2Sw2knF (last visited June 26, 2021); *see also Understanding 3GPP*, QUALCOMM ONQ BLOG (Aug. 2, 2017), https://bit.ly/3jiFx9Z (describing 3GPP procedures for standard development).

[68] *See* Mark Racek, *Why the U.S. Needs Mid-Band Spectrum to Win at 5G*, ERICSSON (Jul. 31, 2020), https://bit.ly/3A2U13L; *see also 5G Can Help the United States Recover, But Needs Mid-Band Spectrum*, 5G AMERICAS, https://bit.ly/3xVTgaF (last visited June 24, 2021).

[69] *See, e.g.*, *3GPP Meets IMT-2020*, 3GPP (Nov. 28, 2020), https://bit.ly/2U7quWd.

[70] *FAQ on International Mobile Telecommunications (IMT)*, INTERNATIONAL TELECOMMUNICATIONS UNION (May 1, 2021), https://bit.ly/3zZM0wq.

[71] *See* Yigang Cai, *5G Specifications (3GPP), 5G Radio Standard (IMT 2020) and Standard Essential Patents*, IEEE COMSOC BLOG (Jul. 10, 2020), https://bit.ly/3x1vSIP; *see also* ITU, Press Release, ITU Completes Evaluation for Global Affirmation of IMT-2020 Technologies (Nov. 26, 2020), https://bit.ly/3hcCYn1.

[72] *See, e.g.*, *Future of 5G: Building a unified, more capable 5G air interface for the next decade and beyond*, Qualcomm (Feb. 2020), https://bit.ly/3hlb5e4.

Industry Demand—Mid-band spectrum is crucial for realizing 5G's potential. The 12 GHz band will be critical to accomplishing this goal. Mid-band spectrum provides optimal coverage and capacity benefits to satisfy a rapidly growing consumer demand for mobile traffic. The 12 GHz band provides the largest swath of contiguous spectrum to do so.[73]

Commercial Feasibility for Components—Vendors can adapt existing technologies to incorporate the 12 GHz band without requiring new materials, processes, or tools. Components capable of 12 GHz operation will use the technologies and materials supporting existing mobile services in mid-band spectrum. Consequently, the underlying technologies to support 12 GHz components already exist in mass-production and can transition to support operations in the band with minimal cost implications. Examples include:

- User RF Front End Components (*e.g.*, low noise amplifiers, power amplifiers, synthesizers, and filters) are already operational for cellular service in mid- and high-band spectrum. Vendors can incorporate the 12 GHz band using these materials.
- Handset antennas have custom form factors and will need to be designed for 12 GHz. Individual antenna design is not a constraint, however. User equipment already includes multiple antennas to support signaling in over 60 radio frequency spectrum bands.[74] Adding the 12 GHz band is no different than prior band additions.
- Base stations, like user equipment, already support operation above and below 12 GHz. Through existing technologies and materials, base stations will integrate RF front end, transceiver, and antenna components to service 12 GHz.

Because the 12 GHz band is upper mid-band spectrum, the costs for 12 GHz enabled components will likely share in the cost structures of currently deployed mid-band service components, as also noted in the 3GPP technical report 38.820.[75] Unlike mmW equipment, components for 12 GHz operation will not require exotic semiconductor materials, sophisticated waveguide components, or cost-prohibitive development and testing equipment. As a result, widescale use of 12 GHz systems will not be cost prohibitive. If commercial vendors can produce mmW components with limited constraints, they can do the same for 12 GHz.[76]

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[73] *See* RS Access Comments, Appendix B.

[74] *See* iPhone 12 and iPhone 12 mini, Apple, https://apple.co/3xPa8A2 (last visited July 6, 2021).

[75] 3GPP TR 38.820. The report notes that the RF requirements for UE in subrange 1 will be "FR1-like" when subrange 1 goes from 7 GHz to an upper boundary between 10-13 GHz. This supports the view that 12 GHz is more like FR1 than FR2. *Id.* at 58. The report includes a ray tracing simulation for an outdoor deployment at 15 GHz with MIMO and notes that "there is a large potential for utilizing spatial multiplexing diversity gain in the UE to increase cell coverage." *Id.* at 64. Section 6.3.1.3 notes that "[c]urrent RF front-end technology used for > 3.3 GHz TDD bands and Wi-Fi can be extended at least up to 12 GHz." *Id.* at 65. The same section also notes that "[b]elow 12 GHz it is feasible that a switch supporting branches for FR1 frequencies would support one branch up to 12 GHz." *Id.* The report later notes that "LC filters using printed elements in a module or a passive substrate should also be feasible up to 12 GHz but would require special attention of the ground design. High Q filtering is limited but diplexing and harmonic rejection function should be feasible." *Id.* at 67.

[76] *See* N. Ingraham, *The Pixel 5 is More Expensive in the US Than it Needs to be*, ENGADGET (Oct. 1, 2020), https://engt.co/35W7gp2.

12 GHz Does Not Present Unique Challenges—The 12 GHz band does not present unique challenges relative to already deployed bands for 5G service. The 12 GHz band does not include Federal incumbents that the Commission must move or accommodate. The 12 GHz band can be harmonized for global use given its near-global mobile service allocation.[77] Co-frequency sharing with incumbents in the 12 GHz band is logistically feasible given band characteristics and the limited number of licensees, based on other analysis submitted in this proceeding.[78] Furthermore, utilizing the 12 GHz band is technically feasible. The 12 GHz band is bounded in complexity by deployed services at lower mid-band and mmW spectrum bands. Propagation characteristics at the 12 GHz band outperform already deployed mmW bands at 24, 28, and 39 GHz. Coverage areas and signal ranges for 12 GHz service closely align with the 3.7 GHz band and can be serviced through large and small-cell deployments.[79]

5.3 *Viability of 12 GHz Equipment Development*

The ecosystem for 5G equipment and devices is established and robust. Commercial providers can realize solutions relevant to 12 GHz operation with minimal complication.

State of Commercial Affairs—Major vendors and operators have recently announced technology enhancements that maximize service capabilities and improve user experiences. These announcements indicate a mature 5G technology ecosystem and wide-scale commercial availability. Common features include:

- New antenna designs and beam management technologies (*e.g.*, beam switching, recovery, and refinement) increase signal coverage and channel capacity.[80]

- Consolidation of critical circuitry and improvement in antenna components enable fully integrated antenna arrays with 100+ transceiver and antenna elements.[81]

- mMIMO technology yields service gains by spatially multiplexing several data streams through multiple transmit and receive antennas.[82] As a result, the signal capacity of a channel is enhanced.[83]

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[77] Comments of Dish Network Corporation, WT Docket No. 20-433 and GN Docket No. 17-183, at 14 (filed May 7, 2021).

[78] *See* RS Access Comments, Appendix A.

[79] *See generally* Mohammed Mohiuddin, *C-Band: A Stepping Stone that Makes 5G Persuasive*, SAMSUNG, https://bit.ly/35WhCp2 (last visited July 6, 2021); *see also generally* Ari Kynaslahti, *What to Know About Spectrum, and How the U.S. C-Band Auctions Impact 5G*, RCR WIRELESS (Apr. 12, 2021), https://bit.ly/3gWsSrK.

[80] *See* Samsung, Press Release, Samsung Introduces Complete C-Band Network Solutions Portfolio (Apr. 19, 2021), https://bit.ly/3vZTaOb.

[81] *See* Monica Alleven, *Ericsson launches 3 new radios for mid-band 5G*, FIERCE WIRELESS (Feb. 22, 2021 12:43 P.M.), https://bit.ly/3jPcPOo; *see also* Chris Pearson, *5G Radios are Packed with Advanced Antenna Technology*, 5G AMERICAS (Aug. 2019), https://bit.ly/2UCE6sx.

[82] *See* David Tse & Pramod Viswanath, *Fundamentals of Wireless Communication* (2005); *see also Massive MIMO for New Radio*, SAMSUNG (Dec. 2020), https://bit.ly/3y3gQ5H.

Service deployments are already realizing these features through commercial product rollouts supported by hardware and software component providers. Table 8 shows one example of commercially available base station configurations:[84]

Table 8: Typical Commercial TDD mMIMO Base Station Antenna Configurations[85]

TxRx	Antenna elements (row x column x polarization)	Maximum number of layers (Lm)
64T64R	128 (8x8x2) 192 (12x8x2)	16
32T32R	64 (8x4x2)	8
16T16R	32 (4x4x2) 96 (12x4x2)	8

Extending Commercialization to 12 GHz— Similar to the state of affairs in mmW bands, providers can develop a hardware and software ecosystem for global deployment at 12 GHz. Additionally, 12 GHz operations can be easily integrated with present configurations to enhance service deployments. Based on the maturity status of 5G industry and developments in global deployments, 12 GHz service could be integrated in 5G equipment in 12 – 24 months.

6 Conclusion

The 12 GHz band is an ideal complement to existing spectrum allocations for 5G deployment. The band combines much of the propagation characteristics and coverage advantages of lower mid-band spectrum with the high capacity and throughput of the millimeter-wave (mmW) bands. Network architectures, spectrum deployment techniques, and equipment development standards currently used for 5G in other bands can readily extend to the 12 GHz band. These findings are consistent with the 12 GHz band's location near the lower mid-band frequencies (such as the 3.7 GHz band) and well below the mmW frequencies (such as the 28 and 39 GHz bands), both of which are the focus of current 5G deployment efforts.

Recent technology advances embodied in standards will take advantage of the 12 GHz band's physical characteristics, are commercially available, and can readily be applied to 5G devices and networks. Wireless operators have the tools to deploy 12 GHz technology cost-effectively in their networks to increase 5G capacity. As one example, mMIMO and beamforming antenna systems have been embodied in 5G standards during the last five years and equipment is commercially available for these technologies. Likewise, recently developed technology for low-cost

[83] *See* Billy Hogan, *et al.*, *How to Build High-Performing Massive MIMO Systems*, ERICSSON (Feb. 17, 2021), https://bit.ly/3qvPDWp; *see also* Bevin Fletcher, *Samsung Touts 30% Boost for Massive MIMO with Beamforming Accuracy*, FIERCE WIRELESS (Feb. 24, 2021 9:32 A.M.), https://bit.ly/3y2GcAm; *see also* Linda Hardesty, *Nokia's CEO Says Massive MIMO Radio Coming Soon*, FIERCE WIRELESS (Apr. 29, 2021 4:51 P.M.), https://bit.ly/2UasMny.

[84] *See Advanced Antenna Systems for 5G*, 5G AMERICAS (Aug. 2019), https://bit.ly/3qtstA4 (surveying advanced antenna designs for 5G systems).

[85] *See id.* at 29.

semiconductor devices at mmW frequencies (28 and 39 GHz) suggest that even lower cost versions can be applied to 12 GHz, enabling low-cost RF components for 5G 12 GHz systems. And 5G standards-based carrier aggregation techniques are now mainstream, allowing operators to readily apply them to combinations of lower mid-band with 12 GHz for capacity improvements or mmW spectrum with 12 GHz to extend coverage.

In short, we find that the physical characteristics of 12 GHz spectrum coupled with the technologies that are now available for 12 GHz implementations imply the ability to produce high-performance 5G system designs in a manner that is cost effective, achievable at scale, and rapidly realizable for network operators.

APPENDIX A: COMPANY AND AUTHOR PROFILES

Roberson and Associates, LLC, is a technology and management consulting company serving government, commercial, and academic customers and provides specialized engineering focused services in the areas of radio frequency (RF) spectrum management, RF measurement and analysis, strategy development, and technology management.

Nat Natarajan, PhD, Principal Engineer III, Principal Author

Dr. Natarajan joined Roberson and Associates in 2014 after over three decades of industry experience in wireless communication and networking systems. In his current position, he has been engaged in serving customers with innovative and efficient spectrum sharing strategies that serve business as well as public interests.

Previously, Dr. Natarajan worked as a Mobility Network Consulting engineer and architect at Cisco Systems, and his work included commercial customer deployment of Universal Mobile Telecommunications System (UMTS) Femto and Macro Long Term Evolution (LTE) systems. Prior to Cisco, Dr. Natarajan joined Motorola and was a Fellow of the Technical Staff. He developed the adaptive routing algorithms for Iridium, a Low Earth Orbit (LEO) satellite communication system. He subsequently pioneered and advocated All-IP Packet switching for mobile wireless networks and led the early customer demonstrations of 4G systems, including VoIP, SIP, Mobile IP, and seamless inter-technology handoffs, such as Wi-Fi and Cellular RAN through a sequence of customer trials. He led early research, standardization, and pre-commercial implementations of 802.16e/ Worldwide Interoperability for Microwave Technology (WiMAX), as well as LTE, Frequency Division Duplex (FDD), and Time Division Duplex (TDD). Prior to Motorola, Dr. Natarajan was a Research Staff Member at IBM Thomas J. Watson Research Center in Yorktown Heights, NY. He began his wireless career at IBM with fundamental contributions to Wireless Local Area Network (WLAN) architecture concepts and specifications of the baseline 802.11 standard that have been acknowledged by the Institute of Electrical and Electronics Engineers (IEEE).

Dr. Natarajan is an accomplished master network innovator. Through much of his career, he has served as a trusted advisory consultant to a variety of customers across the globe. He has 35+ refereed technical publications, three Cisco Achievement Awards, Motorola Science Advisory Board Associate recognition, Global Standards Awards for Outstanding Performance, and 5 IBM Achievement Plateau awards. Dr. Natarajan has 38 issued U.S. patents, including several implemented in commercial wireless systems.

Dr. Natarajan earned his Bachelor of Technology from Indian Institute of Technology (Chennai), Master of Engineering with Distinction from Indian Institute of Science (Bangalore), and Ph.D. from Ohio State University, Columbus, OH. He is an IEEE Senior Member and a member of its communication society.

Bill Alberth, VP, Mobile Technologies

Mr. Alberth joined Roberson and Associates in 2013. With more than 170 patents issued or pending, he is a leading innovator in the wireless communications field and is presently consulting to several startups and established corporations on topics of technology, wireless technology, and intellectual property. Mr. Alberth is passionate about developing and commercializing new technology, and his patent portfolio covers mobile communications across hardware, software, network, end-to-end services, and various aspects of wireless technologies.

Mr. Alberth created and led a team responsible for a majority of the intellectual property filed by Motorola Mobility, which included use and construction of a watch phone device. He was the Top Inventor at Motorola Mobility. As Mobile Devices Chief Technology Officer, Mr. Alberth was responsible for developing differentiating technologies. He was a Dan Noble Fellow and a Member of Motorola's Science Advisory Board where he led the technical ladder and served on Motorola's Patent Committee. He regularly consults on technology licensing, technology investment, and acquisitions and also served as an expert legal witness. He is a regular consultant to carriers on wireless connectivity and emerging technologies and has presented to the Federal Communications Commission on spectrum and other topics.

Prior to his current assignment, Mr. Alberth was responsible for leading new product development and introduced various analog and digital mobile communication products. He has over 30 years' experience in digital communications, radio frequency systems engineering, digital signal processing, new technology introductions, and has product development experience in Long-Term Evolution (LTE), Code Division Multiplex Access (CDMA), Universal Mobile Telecommunications System (UMTS), Third Generation (3G), Personal Digital Cellular (PDC), and analog technologies.

Mr. Alberth graduated with a Bachelor of Science in Electrical Engineering from the University of Illinois in Urbana-Champaign and a Master of Science in Electrical Engineering from Illinois Institute of Technology. He is an advisor to Northwestern University's Electrical and Computer Engineering Department.

Randy Berry, PhD, Principal Engineer III

Dr. Berry joined Roberson and Associates in 2018. Dr. Berry is also the Lorraine Morton Professor in the Department of Electrical Engineering and Computer Science at Northwestern University, which he joined in 2000. His research interests include topics in wireless communications, spectrum sharing, and network economics. He has published numerous papers in these areas.

Dr. Berry is the recipient of a 2003 CAREER award from the National Science Foundation. He was appointed an IEEE Communications Society Distinguished Lecturer for 2013-14. He has served as an Editor for the IEEE Transactions on Wireless Communications from 2006 to 2009, and an Associate Editor for the IEEE Transactions on Information Theory from 2009 to 2011, in the area of communication networks. He has also been a guest editor for the IEEE Journal on Selected Topics in Signal Processing special issue on “Dynamic Spectrum Access” and the IEEE Transactions on Information Theory special issue on “Relaying and Cooperation.” He has served on the program and organizing committees of numerous conferences including serving as the Co-Chair of the 2012 IEEE Communication Theory Workshop and a technical Co-Chair of 2010 IEEE ICC Wireless Networking Symposium. He was elevated to IEEE Fellow in the class of 2014 for contributions to resource allocation and interference management in wireless networks.

Dr. Berry received his Master of Science and Ph.D. degrees in Electrical Engineering and Computer Science from the Massachusetts Institute of Technology in 1996 and 2000, respectively, where he was part of the Laboratory for Information and Decision Systems. His undergraduate education was at the University of Missouri-Rolla, where he received his Bachelor of Science degree in Electrical Engineering in 1993. In 1998 he was on the technical staff at MIT Lincoln Laboratory in the Advanced Networks Group.

Danilo Erricolo, PhD, Principal Engineer III

Dr. Erricolo joined Roberson and Associates in 2018. He is also a Professor in the Department of Electrical and Computer Engineering, an adjunct Professor of Bioengineering, and the Director of the Andrew Electromagnetics Laboratory at the University of Illinois at Chicago.

His research focuses on electromagnetics applied to solve problems including modeling electromagnetic wave propagation for wireless communications and radar systems; antenna design and related RF front-end, in particular for full-duplex communication systems; detection of underground tunnels; and reducing temperature raise in ultra high field Magnetic Resonance Imaging.

Dr. Erricolo is a University of Illinois Scholar, a Fellow of IEEE and currently the Editor-in-Chief of the IEEE Transactions on Antennas and Propagation. He has authored or coauthored more than 290 publications in refereed journals and international conferences. He was the Guest Editor of the Special Issues on RF Effects on Digital Systems of the Electromagnetics Journal (2006), and the Lead Guest Editor of the Special Issue on Propagation Models and Inversion Approaches for Subsurface and Through Wall Imaging of the International Journal of Antennas and Propagation (2012).

He was the General Chairman of the 2012 IEEE International Symposium on Antennas and Propagation and USNC-URSI National Radio Science Meeting, held in Chicago, IL, USA in July 2012. He was Chair of the Chicago Joint Chapter of the IEEE Antennas and Propagation Society (AP-S) and Microwave Theory and Techniques Society (2011-2016); an Elected Member of the Administrative Committee of the IEEE AP-S (2012–2014); and Chair of the Distinguished Lecturer Program of the IEEE AP-S (2015–2016).

Dr. Erricolo was elected a Full Member of Commissions B, C, and E of the U.S. National Committee (USNC) of the International Union of Radio Science (URSI), a committee of the U.S. National Academies. He was Chair (2009–2011), Vice Chair (2006–2008) and Secretary (2004–2005) of USNC-URSI Commission E on Electromagnetic Environment and Interference; Chair of the USNC-URSI Ernest K. Smith Student Paper Competition (2009-2014); Vice-Chair of the Local Organizing Committee of the XXIX URSI General Assembly, held in Chicago, IL, USA in August 2008; and Member at Large of USNC-URSI (2012–2017).

He has served on more than 40 conference technical program committees, chaired over 60 conference sessions, and organized more than 20 special sessions at international scientific conferences.

He received the Laurea degree of Doctor (summa cum laude) in electronics engineering from the Politecnico di Milano, Milan, Italy, in 1993 and the Ph.D. degree in electrical engineering and computer science from the University of Illinois at Chicago, Chicago, Illinois, USA, in 1998.

Kenneth Zdunek, PhD, Senior Vice President and Chief Technology Officer

Dr. Zdunek joined Roberson and Associates in 2009 and is Vice President and the Chief Technology Officer. He has over 40 years of experience in wireless communications, cellular, and public safety systems. Concurrently, he is a Research Professor in Electrical Engineering at Illinois Institute of Technology in Chicago, Illinois, where he participates in research in the area of dynamic spectrum access and efficient spectrum utilization. He has taught a graduate course in wireless communication system design. He is a Fellow of the Institute of Electronics and Electrical Engineers (IEEE) and recognized for his leadership in integrating voice and data in wireless networks.

Recent contributions at Roberson and Associates include analyses and leadership of analyses of the impact of unlicensed and licensed communications networks on satellite and terrestrial networks, authorship of analyses submitted to the FCC and ITU-R in support of client initiatives, and client support at FCC and ITU-R meetings,

Prior to joining Roberson and Associates, Dr. Zdunek was Vice President of Networks Research at Motorola and was awarded Motorola's Patent of the Year in 2002 for a voice-data integration approach licensed and extensively used in cellular communications. He holds 18 other patents, including a patent on drone detection and patents used in public safety trunked systems and cellular and trunked systems roaming. He directed the invention and validation of Nextel's Integrated Digital Enhanced Network (iDEN^{R}) voice-data air interface and IP-based roaming approach and was the principal architect of Motorola's SmartNet^{R} public safety trunking protocol suite.

Dr. Zdunek was awarded a Bachelor of Science in Electrical Engineering degree and a Master of Science in Electrical Engineering degree from Northwestern University, and a Ph.D. in Electrical Engineering from Illinois Institute of Technology. He is past president and serves on the board of directors of the Chicago Public Schools Student Science Fair, Inc.

Dennis Roberson, President and CEO

Mr. Roberson is the Founder, President, Chief Executive Officer, and Member of Roberson and Associates, LLC and has over 40 years of industry experience. In parallel with this role, he serves as a Research Professor in Computer Science at Illinois Institute of Technology where he has been an active researcher in the wireless networking arena, a co-founder of IIT's Wireless Network and Communications Research Center (WiNCom), and a co-founder of the Intellectual Property Management and Markets Program. His wireless research has focused on dynamic spectrum access networks, spectrum measurement systems and spectrum management, and wireless interference and its mitigation, all of which are important to the Roberson and Associates mission.

Previously, he served as Vice Provost for Research at Illinois Institute of Technology. Prior to IIT, Mr. Roberson was Executive Vice President and Chief Technology Officer at Motorola. He had an extensive corporate career, which included major business and technology responsibilities at IBM, Digital Equipment Corporation (DEC, now part of HPE), AT&T, and NCR. He has several issued and pending patents. He has been involved with a wide variety of technology, cultural, educational, and youth organizations, including service as Chair of the Federal Communications Commission Technical Advisory Council, and membership on the Commerce Spectrum Management Advisory Committee. Mr. Roberson serves on the governing and/or advisory boards of several exciting technology-based companies. He is a frequent speaker at universities, companies, technical workshops, and conferences around the globe.

Mr. Roberson has Bachelor of Science degrees in Electrical Engineering and in Physics from Washington State University and a Master of Science in Electrical Engineering from Stanford University.