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5G Mid-Band Spectrum:

The Benefits of Full Power, Wide Channels, and Exclusive Licensing

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Executive Summary

Mid-band spectrum is the key to unlocking the benefits of 5G for American consumers, enterprises, and innovators. This spectrum constitutes a sweet spot, delivering a balance of coverage and deep capacity essential to 5G services. Certain technical aspects of this spectrum are essential for mobile operators to leverage these bands to unleash the full power of 5G and to ensure dependable, high-performance service. These include exclusive licensing, wide spectrum bands of hundreds of megahertz, and full power radio base stations.

These attributes are essential for mid-band spectrum to be deployed on a widespread basis, covering most Americans, with reasonable capital efficiency. As policy makers consider additional mid-bands for 5G and successive generations, it is essential that these key technical attributes, which were used in C-band and 3.45 GHz, are maintained in order for the United States to continue to lead and innovate with 5G.

Mobile data consumption has increased by more than one hundred times since 2010,[1] and the Ericsson Mobility Report predicts that smartphone usage alone will increase to 52 GB/month in 2027 compared to 15 GB in 2021.[2] Technology enhancements, site densification, and new spectrum brought to market have allowed the United States to keep pace with traffic growth up to this point. However, only the delivery of hundreds of megahertz of additional mid-band spectrum with the right technical attributes will provide the capacity necessary to deliver on the 5G promise and to keep pace with the nations that are leading 5G today.

This paper highlights several key 5G use cases: extended reality and the metaverse, industrial IoT, and fixed wireless services, all of which require high performance, low latency, high capacity, and high reliability. In turn, the paper explains in detail how and why exclusively licensed, full power, and wide swaths of spectrum are needed to power robust 5G networks. Finally, the paper notes economic and environmental benefits of such spectrum.

5G Use Cases

Three illustrative use cases demonstrate the benefits of 5G, including its speed and low latency, and how 5G networks need to be able to support hundreds of users in a coverage area with typical speeds of

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[1] "U.S. Wireless Investment Hits Five Year High, CTIA Annual Survey Finds," Jul. 2021. https://www.ctia.org/news/u-s-wireless-investment-hits-five-year-high-ctia-annual-survey-finds.

[2] Ericsson, *Ericsson Mobility Report,* Jun. 2022. https://www.ericsson.com/en/reports-and-papers/mobility-report/reports/june-2022.

hundreds of Mbps. The first use case is extended reality, cloud gaming, and the metaverse; the second use case is fixed wireless access; and the third use case is the industrial internet of things (IoT).

Extended Reality, Cloud Gaming, and the Metaverse

The dominant application consuming mobile data in 4G networks is video. But developers are now turning their attention to new applications, such as extended reality, which includes virtual reality and augmented reality, cloud gaming, and the metaverse.

As Table 1 elaborates, these new applications will consume far more data and require far greater speeds and capacity. A video on a smartphone today consumes 1–3 Mbps, but immersive virtual reality with six degrees of freedom will consume in excess of 200 Mbps,[3] a factor of one hundred times greater. 5G needs wide radio channels to deliver these high throughput rates, along with full power for achieving the high spectral efficiency needed for high aggregate cell capacity supporting multiple simultaneous high-bandwidth users.

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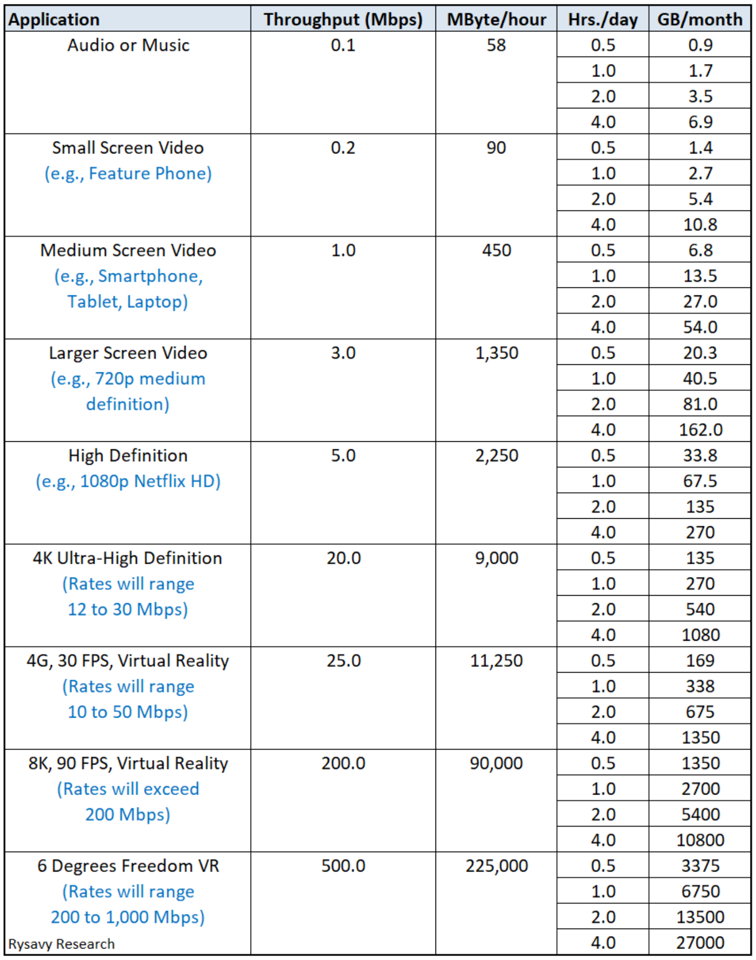
[3] Qualcomm, "VR and AR pushing connectivity limits," Oct. 2018. https://www.qualcomm.com/media/documents/files/vr-and-ar-pushing-connectivity-limits.pdf.

Table 1: Throughput Requirements and Data Consumption of Applications



Application	Throughput (Mbps)	MByte/hour	Hrs./day	GB/month
Audio or Music	0.1	58	0.5	0.9
			1.0	1.7
			2.0	3.5
			4.0	6.9
Small Screen Video (e.g., Feature Phone)	0.2	90	0.5	1.4
			1.0	2.7
			2.0	5.4
			4.0	10.8
Medium Screen Video (e.g., Smartphone, Tablet, Laptop)	1.0	450	0.5	6.8
			1.0	13.5
			2.0	27.0
			4.0	54.0
Larger Screen Video (e.g., 720p medium definition)	3.0	1,350	0.5	20.3
			1.0	40.5
			2.0	81.0
			4.0	162.0
High Definition (e.g., 1080p Netflix HD)	5.0	2,250	0.5	33.8
			1.0	67.5
			2.0	135
			4.0	270
4K Ultra-High Definition (Rates will range 12 to 30 Mbps)	20.0	9,000	0.5	135
			1.0	270
			2.0	540
			4.0	1080
4G, 30 FPS, Virtual Reality (Rates will range 10 to 50 Mbps)	25.0	11,250	0.5	169
			1.0	338
			2.0	675
			4.0	1350
8K, 90 FPS, Virtual Reality (Rates will exceed 200 Mbps)	200.0	90,000	0.5	1350
			1.0	2700
			2.0	5400
			4.0	10800
6 Degrees Freedom VR (Rates will range 200 to 1,000 Mbps)	500.0	225,000	0.5	3375
			1.0	6750
			2.0	13500
			4.0	27000

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Fixed Wireless Access

The United States is encouraging the extension of fiber networks, but especially in less dense population areas, a wireless connection is often more practical. Consequently, operators in the United States, and globally, are increasingly using 5G for fixed broadband access. This adds another competitive home broadband option[4] and gives consumers greater broadband choices. Ericsson

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[4] Rysavy Research, *5G Network Planning—Capacity, Performance, Wireline Competitiveness*. https://rysavy.com/broadband-reports/.

forecasts 100 million FWA connections globally by the end of 2022.[5] During Q2, 2022, U.S. cable companies lost 60,000 subscribers whereas wireless operators gained 816,000 subscribers.[6]

FWA, however, must accommodate the much higher data usage of fixed broadband subscribers. Whereas mobile broadband users in North America consumed an average of 15 GBytes per month in 2021,[7] average fixed broadband usage reached 536 GBytes.[8] This level of data consumption demands much greater network capacity.

FWA users also expect consistent service and sufficiently fast download speeds for video and streaming applications. Operators are using a combination of mmWave and mid-band for FWA in the United States, with mid-band the more effective solution in non-urban areas. Exclusive-use spectrum with its predictable qualities is essential for consistent FWA service. Full power operation enables realization of massive Multiple Input Multiple Output (MIMO) capabilities, therefore either extending FWA coverage in rural areas or increasing FWA capacity in denser population areas. Finally, wide radio channels provide the needed high FWA throughput rates at the lowest possible cost.

Industrial IoT

5G has multiple features to address industrial IoT needs, including support for a high density of devices in the environment, high reliability, low latency, network slicing,[9] precise positioning, edge computing, high security, and high throughput. Many IoT applications will require high bandwidth. Consider, for example, ultra-high-definition cameras monitoring manufacturing processes, or deployed on mobile robots, coupled with AI to analyze the video streams. For IoT, exclusive-use, licensed spectrum is necessary for consistent and reliable connections. Simultaneously, power boosts capacity to the

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[5] Ericsson, Ericsson Mobility Report, Jun. 2022. https://www.ericsson.com/en/reports-and-papers/mobility-report/reports/june-2022.

[6] Next/TV, "Cable Finally Loses Broadband Market Share in Q2 with First Negative Growth Quarter Ever," Aug. 2022. https://www.nexttv.com/news/cable-finally-loses-broadband-marketshare-in-q2-with-first-negative-growth-quarter-ever.

[7] Ibid.

[8] Light Reading, "Average data consumption eclipses half a terabyte per month – OpenVault," Mar. 2022. https://www.lightreading.com/cable-tech/average-data-consumption-eclipses-half-terabyte-per-month---openvault/d/d-id/775689.

[9] With network slicing, users will benefit from the network being configured to precisely address different use cases, such as AR/VR. For further details, see 5G Americas, "Commercializing 5G Network Slicing," Jul. 2022. https://www.5gamericas.org/commercializing-5g-network-slicing/.

needed levels for multiple simultaneous high-bandwidth connections in environments such as factories, and wide radio channels yield the necessary high throughput rates.

In order to provide these key new 5G use cases of extended reality/cloud gaming/metaverse, fixed wireless access, and Industrial IoT, operators first need full power. Second, they need wide swaths of licensed spectrum to provide high-quality, dependable, and low-latency services in a robust and efficient manner. Beyond these examples, many future innovative use cases for 5G will require licensed, exclusive use spectrum. Following sections explore the technical reasons for these spectrum attributes.

United States Mid-Band Spectrum Blocks

The United States has been working hard on delivering mid-band spectrum to fuel the 5G revolution. As of today, the United States is able to deploy 200 MHz of full power licensed spectrum in the 3 GHz band. The 3450–3550 MHz band was auctioned this year, and coordination procedures with federal incumbents will become available in late 2022. In the C-band, only the lowest hundred megahertz is cleared for use in forty-six Partial Economic Areas (PEAs), with the remaining 180 MHz of spectrum becoming available in 2023. While 70 MHz of Citizens Broadband Radio Service (CBRS) licensed Priority Access License (PAL) spectrum is available today, it is shared with federal incumbents and restricted to low-power levels. The United States will eventually reach 450 MHz (counting the 70 MHz of low-power CBRS PAL spectrum) by the end of 2023 when C-band clearing is complete, but this progress lags a number of other nations by several years.[10] U.S. regulators will need to free up hundreds of megahertz of additional mid-band spectrum for the United States to regain a competitive footing on the global stage.

Future spectrum allocations must also consider the spectrum characteristics that have been successful in the past and that will create the greatest future benefit to the economy and society—exclusive access to wide channels at full power with sufficiently large license boundaries to facilitate rapid deployment.

Benefits of Exclusively Licensed Spectrum

Operators continue to expand capacity by densifying networks, deploying more efficient technology, and harnessing more spectrum. Between 2016 and 2020, operators increased the number of cell sites by 35%.[11] Meanwhile, 5G with massive MIMO is more than three times as efficient as 4G without massive MIMO. But densification and new technology alone are not sufficient to address the growing demand. As

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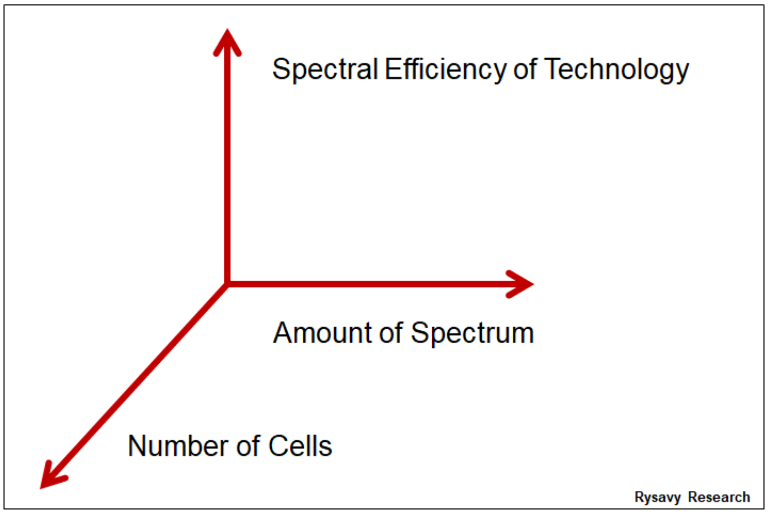
[10] As of June 2022, U.S. operators have access to up to 70 MHz of licensed CBRS spectrum with an authorized power level more than 300 times less than the U.S. C-band. The 100 MHz of C-band spectrum is only available within forty-six PEAs, for a total of 170 MHz. In addition, T-Mobile has about 160 MHz of spectrum at 2.5 GHz.

[11] CTIA, *2021 Annual Survey Highlights*. https://www.ctia.org/news/2021-annual-survey-highlights.

shown in Figure 1, additional spectrum with the appropriate characteristics is an essential third element in building the networks of the future.

Figure 1: Increasing Capacity Needs Efficiency, Densification, and More Spectrum



Only with exclusively licensed spectrum can operators provide a consistent and high quality user experience. As one wireless organization that represents the worldwide mobile communications industry states, “Exclusively licensed spectrum over wide geographic areas is vital to the success of 5G.”[12] Licensed spectrum also produces economic benefits, including licensing revenue for the U.S. government, elevated levels of network investment, and jobs growth. Licensed spectrum is indeed the foundation of the wireless ecosystem. Furthermore, high-performing 5G networks enable other products and services, such as smartphone apps, efficient manufacturing, safer and autonomous vehicles, and smart cities.

Quality of Experience

Consumers—and increasingly enterprise customers leveraging 5G connectivity—expect a consistent experience in terms of reliability, throughput, and ability to accomplish their tasks in a predictable manner. Operators make this possible by operating networks that have ample capacity and signal quality across the coverage area. Table 2 shows the complex set of objectives associated with delivering a high quality of experience and the associated challenges the operator must address. Given these challenges, exclusively licensed spectrum is optimal for operators to provide, and consumers to receive, a consistent high quality of experience. Exclusively licensed spectrum provides a predictable,

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[12] GSMA, *Vision 2030 - Insights for Mid-band Spectrum Needs*, Jul. 2021. https://www.gsma.com/spectrum/wp-content/uploads/2021/04/5G-Spectrum-Positions.pdf.

dependable, and interference-free resource that not only benefits users with a high quality of experience, but also allows operators to scale their networks most quickly.

Table 2: Operator Objectives and Variables Operator Must Manage

Operator Objectives for High Quality of Experience	High average data throughput Low latency Few dropped calls Reliable handoff between cells Support for fixed and mobile users Congestion avoidance Ability to scale capacity to address growing demand Deploying new spectrum quickly
Challenges Operator Must Address to Deliver a High Quality of Experience	Number and location of macro cell sites and small cells Generations of cellular technology supported Varying demand due to moving subscribers Capabilities of subscriber devices, such as frequency bands supported Amount of spectrum deployed, and different bands supported Whether and how to use radio carrier aggregation Interference from co-channel (e.g., shared spectrum scenarios) and adjacent channel users Whether spectrum is licensed, unlicensed, or shared
Key Resource	Exclusively licensed spectrum, which provides a fast-to-deploy, predictable, dependable, and interference-free resource

In contrast, shared spectrum can take multiple forms, including CBRS, other database-approaches, geographic sharing, and temporal-based sharing. These sharing regimes can augment cellular network capacity but may not necessarily be relied upon to address all of the operator objectives. For example, CBRS incumbents may deny use of the spectrum at any time. In contrast to exclusively licensed spectrum, spectrum sharing poses the following issues:

- **Sharing complexity.** Methods, such as sensing or central database control, are needed to implement the sharing approach. In some cases, such as the Environmental Sensing Capability

(ESC) in CBRS, the existence of sensors precludes use of the spectrum in certain geographic areas, reducing the utility and value of the spectrum.[13]

- **Deployment delays.** Developing new, innovative sharing approaches takes considerable research and development. The National Telecommunications and Information Administration (NTIA) estimated a ten-year development time for dynamic spectrum technologies;[14] CBRS took eight years. The complexity of the sharing solution, even once specified, further delays deployment. Simpler coordination approaches, such as geographic sharing, as is being used for the 3.45 GHz band,[15] requires coordination through a portal that will be maintained by the Department of Defense (DOD) and does not require a Spectrum Access System (SAS) or sensor network.[16] This type of approach enables spectrum to be put to use more quickly in commercial networks.
- **Unpredictable resource.** Incumbents may have higher priority and can remove the spectrum resource at any time. If spectrum cannot be relied upon at peak times, then more spectrum must be shared, relative to exclusive use, to provide the same capacity.[17]

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[13] WinnForum, WINFF-20-IN-0065, *CBRS Incumbent Protections and Encumbrances Overview*, Mar. 2020, p. 24: "This protection can impact the availability of spectrum across all PAL channels, and some GAA frequencies, in the area." https://winnf.memberclicks.net/assets/work_products/WINNF-20-IN-0065r1%20CBRS%20Encumbrances%20Overview.pdf.

[14] NTIA, *Lessons Learned from the Development and Deployment of 5 GHz Unlicensed National Information Infrastructure (U-NII) Dynamic Frequency Selection (DFS) Devices*, Dec. 2019. https://www.ntia.doc.gov/report/2019/lessons-learned-development-and-deployment-5-ghz-unlicensed-national-information. "Lesson 1: The development time for dynamic spectrum technologies, even when government and industry work closely and cooperatively together on the necessary technical and regulatory framework, can be something on the order of a decade. This is because innovation requires considerable advance work in the absence of existing implementations. The more innovative and technically challenging the new sharing scheme, the longer the advance-work timeline can be expected to be."

[15] This approach in the 3.45 GHz band is sometimes referred to as AMBIT (America's Mid-Band Initiative Team).

[16] FCC and NTIA, *Coordination Procedures in the 3.45–3.55 GHz Band,* Jun. 2021. https://www.fcc.gov/document/joint-public-notice-announcing-345-ghz-coordination-details.

[17] Sharing over larger amounts of spectrum to achieve a reliable level of capacity requires more base station equipment to cover the larger spectrum span, at a higher capital, deployment, and operating cost relative to exclusive licensing. This reduces the value of shared spectrum, while increasing the cost to operators and ultimately to consumers.

- **Unpredictable sharing return on investment (ROI).** An example of the lower quality of shared spectrum is the CBRS General Authorized Access (GAA) spectrum. New GAA users can be added to an area indefinitely. The new GAA stations increase the co-channel interference in the area and reduce the coverage and capacity available to existing sites. Sites that were built to serve a given area may no longer provide the same coverage and capacity as GAA density increases, reducing the ROI of the deployed infrastructure.

Of particular concern with spectrum sharing is that no general-purpose sharing technology exists (nor has any solution been proposed, given the inherent extreme difficulty of sharing among disparate systems), mandating approaches customized for the systems that must interact with each other. For example, CBRS, TV White Spaces, and Wi-Fi Automatic Frequency Coordination (AFC) are all solutions for specific frequency bands. The development process for new spectrum sharing approaches can delay deployments by multiple years.[18]

Economic Benefits

Licensed spectrum has economic benefits that permeate the economy. The C-band auction raised $80.9 billion in auction revenue for 280 MHz of spectrum. In contrast, the market valued 70 MHz of licensed CBRS spectrum at $4.6 billion. On a per MHz basis, this is only one quarter of C-band, demonstrating the much higher value of licensed spectrum using full power. The more recent auction of 3.45–3.55 GHz spectrum raised $21.8 billion, also much higher than CBRS on a per MHz basis. These auction revenues can finance important federal initiatives such as providing funding to modernize DOD equipment as part of relocation efforts, in the process upgrading capabilities while improving the spectral efficiency of federal systems.

By having a dependable spectrum foundation on which to build their networks, U.S. operators are investing $275 billion over seven years in building out 5G, while creating 4.5 million jobs and adding $1.5 trillion to U.S. GDP.[19]

Benefits of Full Power

For cost-effective network coverage over large coverage areas, especially in rural areas, being able to transmit at full power is essential because it reduces the number of required cell sites. To understand the importance of power, one can compare CBRS and its FCC-mandated low-power operation with C-band

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[18] For further discussion, see Rysavy Research, “Spectrum Sharing Insights and Resources.” https://rysavy.com/spectrumsharing/.

[19] CTIA, “The 5G Economy.” https://ctia.org/the-wireless-industry/the-5g-economy#section-4.

Boston Consulting Group, *5G Promises Massive Job and GDP Growth in the US*, Feb. 2021. https://api.ctia.org/wp-content/uploads/2021/01/5G-Promises-Massive-Job-and-GDP-Growth-in-the-US_Feb-2021.pdf.

operating at much higher power. Full power also increases spectral efficiency, directly translating to greater network capacity and ability to support new use cases. This section refers exclusively to the benefits of full power versus other more restrictive power limits and does not suggest any changes should be made to the existing CBRS power limits, given the FCC auctioned the spectrum with those conditions.

CBRS Compared to C-Band

Table 3 compares the non-rural and rural power levels for a 20 MHz channel.

Table 3: Power Limits for CBRS and C-Band

Spectrum Band	Non-Rural FCC EIRP Limit in 20 MHz (dBm)	Rural FCC EIRP Limit in 20 MHz (dBm)
CBRS	50	50
C-Band	75	78

Base stations in C-band can transmit with 25–28 dB more power than the low-power CBRS band, equating to a factor of 327–654 times more power. As a consequence, the coverage area of a CBRS base station is much smaller than that of a full-power cell. To fully overlay a high-power cell's coverage area with CBRS sites, 5–7 times more CBRS cells would be required.[20] Such a huge increase in the number of cell sites would make deployment economically unfeasible in many rural areas.

As an example, an engineering analysis for a suburban area in northern Jackson, Mississippi, shown in Figure 2, reveals that a CBRS deployment would require at least five times as many sites to match the higher-powered C-band coverage. The C-band sites, shown in red, are overlaid on a grid of PCS base stations. The blue circles show the number of CBRS sites that would be required to provide similar coverage, given their much lower power levels.

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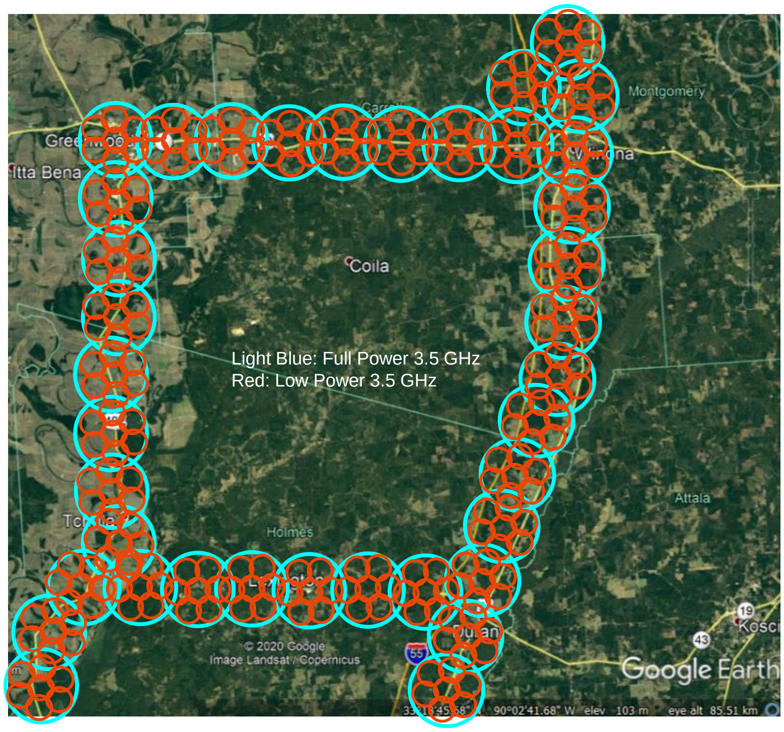
[20] Rysavy Research, *5G Mid-Band Spectrum Deployment*, Feb. 2021. https://rysavyresearch.files.wordpress.com/2021/02/2021-02-5g-mid-band-spectrum-deployment.pdf.

Figure 2: CBRS versus C-Band Site Counts in a Suburban Area

Especially in rural areas, operators are likely to take advantage of full-power operation so they can maximize coverage and provide cost-effective service. Figure 3 illustrates how, in a coverage-limited rural deployment, a theoretical network using CBRS power limits will result in seven times as many cell sites. In suburban and rural areas, an operator is unlikely to find the number of CBRS site locations with electrical power, backhaul, and suitable antenna mounts necessary to provide the density required by the low power base stations. High power cell sites are essential to cover these areas.

Figure 3: CBRS versus C-Band Site Counts in a Rural Area[21]



Enabling Massive MIMO Advantages

Massive MIMO, involving multiple transmit and multiple receive antennas, has been one of the most important innovations for realizing the power of 5G. Massive MIMO can not only increase spectral efficiency by exploiting multiple radio propagation paths in the environment, but can also increase coverage by focusing radio beams into narrower paths. The simultaneous transmissions from multiple antennas, however, results in greater base station power transmission. The maximum coverage and capacity benefits occur only if cell towers can transmit at power levels comparable to conventional cellular bands.[22]

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[21] The rural C-band site coverage assumes eight simultaneous beams to different users, versus a single user for the CBRS site. Thus, the rural analysis shows not only a seven times increase in sites for CBRS, but a huge capacity advantage for C-band. As a benchmark, if the C-band site emphasized coverage over capacity and supported four beams simultaneously instead of eight, then the C-band coverage range would increase, and CBRS would require up to ten times as many sites to fill in the C-band coverage.

[22] A 5G base station achieves much greater capacity and throughput relative to prior generations, reducing the electrical power footprint and thus the carbon emissions of wireless systems. Accenture, *5G Connectivity: A Key*

Without the coverage benefit of massive MIMO, C-band would require far more cell towers than a frequency band like Advanced Wireless Service (AWS) at 1.7 GHz/2.1 GHz. But with the increased coverage from massive MIMO, operators can deploy mid-band 5G using much of their existing macro tower infrastructure. One leading operator, for example, stated that by using 64T64R massive MIMO,[23] it achieves coverage equivalent to the AWS band with non-massive-MIMO technology.[24] This advantage is enabling the operator to quickly rollout C-band nationwide, benefiting millions of subscribers.

In denser deployment areas where coverage is not the primary consideration, full-power massive MIMO increases spectral efficiency. In this mode, the base station communicates with multiple devices simultaneously on the same frequency subchannels using separate radio beams. The multiple beams, however, add up to greater cell power and achieve their greatest efficiency with full-power operation. One reason is that full power improves signal to noise and interference ratios (SINR), enabling higher-order modulation and lower overhead in error correction coding. The resulting threefold or greater improvement in spectral efficiency yields proportionally greater data capacity per cell site, necessary for the types of high-bandwidth applications discussed in the section on 5G use cases above.

5G Benefits of Wider Channels

Wider radio channels provide distinct advantages for 5G. Wide channel sizes can be accomplished via opportunities to acquire multiple blocks of adjacent spectrum—an advantage of sufficient mid-band spectrum being made available. Sufficient spectrum must be brought to the marketplace to enable all wireless operators to achieve 60–100 MHz of mid-band spectrum today, and later, increase to 200–300 MHz per operator in a few years as 5G applications grow. These wider spectrum band needs vary depending on the size of the customer base, usage profiles, and growth rates. With wide radio channels, operators can improve the user experience with high throughputs and high-capacity networks, while enabling bandwidth-intensive applications not possible before.

Enabling Technology to meet America's Climate Change Goals, January 26, 2022, at 16: "5G can reduce carbon emissions through a more efficient use of energy per bit of data transmitted." https://api.ctia.org/wp-content/uploads/2022/01/5G-Connectivity-A-Key-Enabling-Technology-to-meet-Americas-Climate-Change-Goals-2022-01-25.pdf.

[23] 64T64R means 64 transmit radios and 64 receive radios at the base station.

[24] Fierce Wireless, "Verizon ramps C-band speeds with Massive MIMO," Mar. 2022. https://www.fiercewireless.com/5g/verizon-ramps-c-band-speeds-massive-mimo.

5G Wide Channel Capability

5G standards define the use of wide radio channels. Whereas 4G LTE is limited to a maximum radio channel size of 20 MHz, 5G standards specify use of radio channels up to 100 MHz in frequency bands below 7 GHz and up to 400 MHz in mmWave radio channels at 24 GHz and higher.[25] Beyond these wide channels, 5G can aggregate radio channels for a total bandwidth of 800 MHz. Just as the Wi-Fi industry considered wide channels[26] essential in the creation of the 6 GHz unlicensed band, so too does 5G depend on wide channels for the full realization of its capabilities. 5G vendors have corroborated the need for wide radio channels, such as 100 MHz, in mid-band frequencies.[27]

With a 100 MHz radio channel, an operator can deliver peak throughput rates of 1 Gbps and average throughput rates of 100s of Mbps. Organizations globally agree with the need for wide channels. The European CEPT[28] Electronic Communications Committee states, "Large bandwidths of 80–100 MHz contiguous spectrum are considered by industry as important to deliver high throughput 5G services in the 3400–3800 MHz frequency band."[29] Looking into the future, an international wireless organization states that for 5G success, operators should have access to multiple contiguous 100 MHz channels in the 2025–2030 timeframe.[30]

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[25] 3GPP Technical Specification 38.104, *NR; Base Station (BS) radio transmission and reception*. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3202.

[26] IEEE 802.11be (Wi-Fi 7) will support channels up to 320 MHz. See Wi-Fi Alliance, *Wi-Fi 6E and 6 GHz Update*, Mar. 2021. https://www.wi-fi.org/download.php?file=/sites/default/files/private/202103_Wi-Fi_6E_and_6_GHz_Update.pdf.

[27] Ericsson, *Comments, In the Matter of Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*, GN Docket No. 18-122. https://www.fcc.gov/ecfs/file/download/Ericsson%20Comments%20to%203.7%20to%204.2%20NPRM%20(102918)%20(final).pdf?folder=1029090668540.

Nokia, *Comments, In the Matter of Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*, GN Docket No. 18-122. https://www.fcc.gov/ecfs/file/download/DOC-58edf196f7800000-A.pdf.

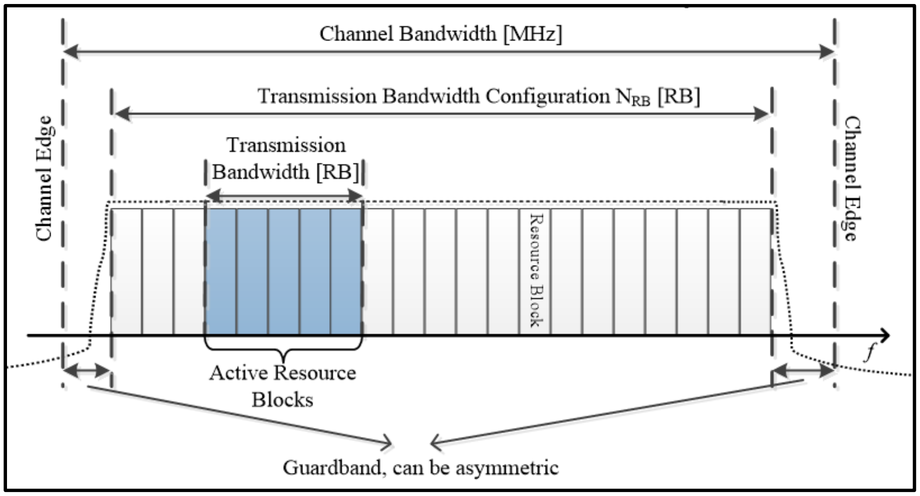
[28] European Conference of Postal and Telecommunications Administrations. https://www.cept.org/.

[29] CEPT Electronic Communications Committee, *ECC Report 287, Guidance on defragmentation of the frequency band 3400-3800 MHz*, Oct. 2018. https://docdb.cept.org/download/1363. Page 36.

[30] GSMA, *Estimating the mid-band spectrum needs in the 2025-2030 time frame*, Jul. 2021. https://www.gsma.com/spectrum/wp-content/uploads/2021/07/5G-mid-band-spectrum-needs-vision-2030.pdf.

Given a certain amount of overhead in using any radio channel, including guard bands as shown in Figure 4, the wider the radio channel, the smaller the percentage of radio resource that the overhead consumes. Thus, wider channels are spectrally more efficient.

Figure 4: Transmission Bandwidth and Guard Bands[31]



Due to the guard band overhead, Table 4 shows how a 5G 100 MHz radio channel uses 98.3% of the radio resource whereas a 20 MHz radio uses only 91.8%.[32]

Table 4: Radio Resource Utilization as Function of Channel Bandwidth

Channel Bandwidth	Transmission Bandwidth	Efficiency
100 MHz	98.28 MHz	98.3%
80 MHz	78.12 MHz	97.7%
60 MHz	58.32 MHz	97.2%
50 MHz	47.88 MHz	95.8%
40 MHz	38.16 MHz	95.4%
20 MHz	18.36 MHz	91.8%

The same increased utilization of the radio resource is true in 4G LTE, in which a 20 MHz radio channel is more efficient than lower bandwidths.

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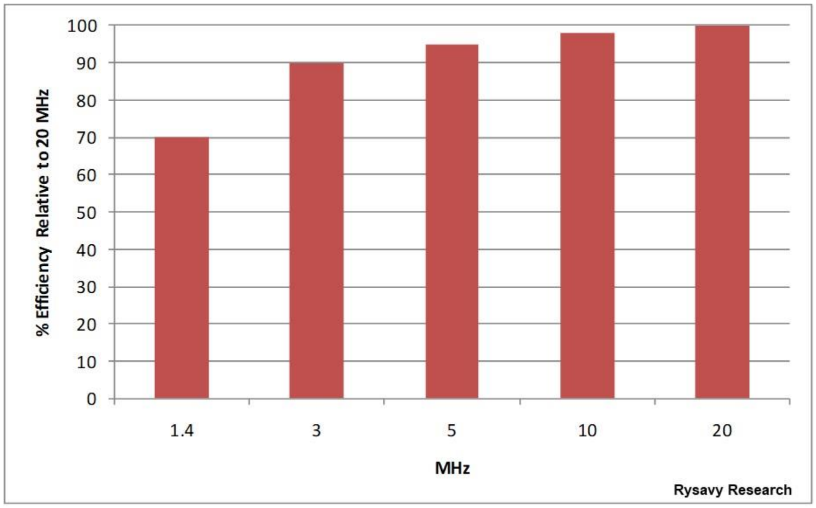
[31] 3GPP Technical Specification 38.104, *NR; Base Station (BS) radio transmission and reception*. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3202.

[32] CEPT Electronic Communications Committee, *ECC Report 287, Guidance on defragmentation of the frequency band 3400-3800 MHz*, Oct. 2018. https://docdb.cept.org/download/1363.

Figure 5: LTE Efficiency Relative to 20 MHz Bandwidth[33]



The inherent high efficiency of wider channels combined with avoiding the overhead of carrier aggregation (discussed below) decreases the cost per bit. One analysis shows that the cost per MHz of 100 MHz can be 70% lower than with a 20 MHz wide channel.[34] Consumers and enterprises both benefit from the resulting more affordable broadband services.

Carrier Aggregation

Carrier aggregation (CA) combines multiple radio channels to deliver higher bandwidth to users. Not only does CA increase throughput rates, but it can also increase coverage. For example, by combining mid-band with a low band for control signals and uplink data, one vendor calculates that inter-band carrier aggregation in 5G can improve population coverage by 50% compared to using only the mid-band frequency.[35]

CA is thus a valuable tool for operators with multiple spectrum bands. CA, however, is not a good substitute for wider radio channels in the same band. A single 100 MHz radio channel, in mid-band

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[33] Rysavy Research, *Global 5G: Rise of a Transformational Technology*, Sep. 2020. https://rysavyresearch.files.wordpress.com/2020/09/2020-09-global-5g-rise-of-a-transformational-technology.pdf.

[34] GSMA, *Estimating the mid-band spectrum needs in the 2025-2030 time frame*, Jul. 2021. https://www.gsma.com/spectrum/wp-content/uploads/2021/07/5G-mid-band-spectrum-needs-vision-2030.pdf.

[35] Ericsson, "What, Why and How: The Power of 5G Carrier Aggregation," Jun. 2021. https://www.ericsson.com/en/blog/2021/6/what-why-how-5g-carrier-aggregation.

for instance, is more efficient than the aggregation of two 50 MHz radio channels, as shown above in Table 4. Similarly, aggregating five 20 MHz radio channels is not as efficient as two 50 MHz channels.

Additional disadvantages of intra-band carrier aggregation include: [36]

- Intra-band carrier aggregation requires highly linear power amplifiers along with high-isolation switches, further adding to expense relative to a single wider channel.
- Base station and device equipment manufacturers must perform complex test and measurement procedures to verify correct operation.

Environmental Benefits

Larger amounts of spectrum being able to operate at full power results in greener 5G networks. In addition, 5G-enabled use cases will substantially lower carbon emissions.

Benefits of Sufficient Spectrum and Full Power

The analysis above shows that being able to operate at full power reduces the number of necessary cell sites by almost an order of magnitude. In addition, without adequate spectrum, operators have no choice but to increase capacity by densifying their networks. In both situations, the larger number of sites has a negative environmental impact by consuming more energy. Mobile network energy consumption can be 1.8 to 2.9 times higher without sufficient spectrum.[37]

Benefits of 5G-Enabled Use Cases

An Accenture report projects that 5G-enabled use cases will lower U.S. carbon emissions by up to 20% by 2025, abating 331 million metric tons of carbon dioxide by then, equivalent to removing 26% of all passenger vehicles from the road for a year. [38] 5G innovation across transportation, manufacturing, energy, agriculture, and other sectors will transform American life and reduce emissions. For example, by 2025, 5G-enabled manufacturing use cases will be able to reduce carbon emissions by 67.4 million

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[36] RF Wireless World, "Advantages of Carrier Aggregation | Disadvantages of Carrier Aggregation." https://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-LTE-Carrier-Aggregation.html. Viewed May 5, 2022.

[37] GSMA, *Vision 2030 - Insights for Mid-band Spectrum Needs*, Jul. 2021. https://www.gsma.com/spectrum/wp-content/uploads/2021/07/5G-mid-band-spectrum-needs-vision-2030.pdf.

[38] Accenture, "5G-Enabled Technologies Could Solve for One-Fifth of U.S. Climate Change Target by 2025, New Study Finds," Jan. 2022. https://newsroom.accenture.com/news/5g-enabled-technologies-could-solve-for-one-fifth-of-us-climate-change-target-by-2025-new-study-finds.htm.

metric tons.[39] Manufacturing use cases include 5G-enabled factories that monitor production processes in real time and use predictive maintenance tools, increasing efficiency and productivity.

The transportation sector is the largest emitter of greenhouse gases, accounting for 27% of total emissions in 2020, according to the EPA.[40] 5G is helping evolve the transportation sector to be more sustainable and safe, which helps consumers and companies alike save on gas costs. By 2025, use cases in this sector will help reduce emissions by the amount removed from 106 million acres of U.S. forests each year.[41] Logistics companies are "platooning" trucks together, so they function as a single unit, which has safety and efficiency benefits. 5G-powered drone delivery and other last-mile logistics options can also minimize the number of trucks needed. And for consumers, 5G-enabled connected vehicles can lower costs at the gas pump thanks to real-time data that communicates information about the car's environment and by enabling driverless transportation.

The agriculture industry will see the benefits of precision agricultural tools enabled by 5G, which will save water resources, limit fertilizer applications, and save farmers time and energy going to and from the fields. More productive and healthy crops will also result.

In the energy sector, 5G-powered sensors can be used to better predict and manage energy supply and demand. Use cases like these exist across multiple industries and will help U.S. companies and sectors become more efficient and sustainable.

Lower 3 GHz Case Study

Government and industry are jointly analyzing mid-band 3.1–3.45 GHz, currently used by DOD, for additional 5G use.

The Third Generation Partnership Project (3GPP) has defined specific 5G bands to facilitate global harmonization and to ensure support from both infrastructure and device vendors. Specifically, band

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[39] *Ibid.*

[40] EPA, "Sources of Greenhouse Gas Emissions," https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions. Viewed Sep. 5, 2022.

[41] CTIA on Twitter, https://twitter.com/CTIA/status/1511040946074537992.

n77 is 3.3–4.2 GHz.[42] Multiple countries around the world, as detailed in Appendix A, have licensed bands in the 3.3–3.45 GHz range for exclusive-use, high power, 5G networks.

A logical approach would be for the United States to make at least 200 MHz, including 150 MHz with the 3.3–3.45 GHz portion, which has a global allocation, available for exclusive-use licenses. Incumbent military systems that need to operate in 3 GHz could tune or relocate below 3.3 GHz and coordinate or share 50 MHz of spectrum with commercial networks. However, given the lengthy time periods to develop sharing approaches, freeing up 200 MHz would make critical new mid-band spectrum available in the needed timeframe and would be consistent with the Spectrum Innovation Act of 2021.[43] In addition, consumers would benefit from global economies of scale that produce lower-cost service and lower-cost devices.

Conclusion

The wireless industry has repeatedly demonstrated that it can efficiently and effectively use wireless spectrum for the benefit of consumers, enterprises, government, and the economy. A consistent high quality of experience, including high throughputs, high capacity, high reliability, and low congestion, requires careful management of multiple factors, including device capabilities, infrastructure, wireless technology used, and spectrum resources. Only exclusive-use licensed spectrum, with its dependable, predictable, and interference-free characteristics, can provide the desired high quality of service. Countries with which the United States competes have come to the same conclusion and continue to base their spectrum allocations on this approach.

In addition, given the high bandwidth requirements of emerging applications, whether extended reality or fixed wireless access, and given the need to support these applications over wide coverage areas, the allocated spectrum must consist of wide radio channels being able to propagate at high power.

Mid-band spectrum remains the most important band for realizing the full capabilities of 5G. Future allocations in mid-band should follow the spectrum approach that has been so successful in other mid-band frequencies, such as C-band and 3.45 GHz blocks. This approach has been the most efficient and effective by leveraging full power capabilities to maximize coverage with reasonable capital expenditures. Today, the United States lags a number of countries in delivering licensed, exclusive use mid-band spectrum for 5G. The United States has kept pace with traffic growth by using new generations of technology, densifying networks, and deploying new spectrum. But the country needs hundreds of

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[42] 3GPP Technical Specification 38.101, *NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone*. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3283.

[43] U.S. Congress, *H.R.5378 - Spectrum Innovation Act of 2021*. https://www.congress.gov/bill/117th-congress/house-bill/5378?s=1&r=6.

megahertz of additional, exclusive use mid-band spectrum at high power to remain competitive globally and to deliver on the 5G promise.

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About Rysavy Research

Rysavy Research LLC is a consulting firm that has specialized in computer networking, wireless technology, and mobile computing since 1993. Projects include spectrum and capacity analysis, reports on the evolution of wireless technology, network security assessment, strategic consultations, system design, articles and reports, courses and webcasts, network performance measurements, and working as a testifying expert in patent-litigation. Peter Rysavy has written more than 190 articles and reports. Clients include more than one hundred organizations.

From 2000 to 2016, Peter Rysavy was the executive director of the Wireless Technology Association, an industry organization that evaluated wireless technologies, investigated mobile communications architectures, and promoted wireless-data interoperability.

Peter Rysavy graduated with BSEE and MSEE degrees from Stanford University in 1979. More information is available at https://www.rysavy.com.

Appendix A: Global Mid-Band Spectrum Bands

Country	Spectrum Band(s)	Authorized Power
Andorra	3400-3600 MHz	(To be confirmed) TBC
Australia	3400-3700 MHz	TRP 48 dBm/5 MHz
Austria	3410-3800 MHz	No power limit
Bahrain	3600-3850 MHz	TBC
Bangladesh	3500-3560 MHz	TBC
Bulgaria	3500-3800 MHz	No power limit
Chile	3300-3400 MHz 3600-3650 MHz	TBC
China	3400-3600 MHz 4800-5000 MHz	TBC
Croatia	3400-3800 MHz	No power limit
Cyprus	3400-3800 MHz	No power limit
Czech Republic	3400-3800 MHz	TRP 47 dBm/5 MHz
Denmark	3410-3800 MHz	TRP 47 dBm/5 MHz
Finland	3410-3800 MHz	TRP 47 dBm/5 MHz
France	3400-3800 MHz	No power limit
Germany	3400-3700 MHz *3700-3800 MHz*	No power limit *Local licensing*
Greece	3400-3670 MHz 3700-3770 MHz	No power limit
Hong Kong	3400-3600 MHz	TBC
Hungary	3490-3800 MHz	No power limit
Iceland	3500-3800 MHz	No power limit
Ireland	3410-3435 MHz 3475-3800 MHz	TRP 47 dBm/5 MHz
Israel	3500-3800 MHz	TBC
Italy	3400-3800 MHz	No power limit

Country	Spectrum Band(s)	Authorized Power
Japan	3400-4100 MHz 4500-4600 MHz	EIRP 60.8 dBm/MHz per 3 sectors
Kuwait	3400-3800 MHz	TBC
Latvia	3400-3450 MHz 3550-3600 MHz 3650-3700 MHz	TBC
Luxembourg	3420-3750 MHz	No power limit
Malaysia	3400-3600 MHz	TBC
Malta	3500-3800 MHz	No power limit
Mauritius	3400-3600 MHz	TBC
New Zealand	3410-3750 MHz	No power limit
Norway	3400-3800 MHz	TBC
Oman	3400-3700 MHz	TBC
Peru	3450-3475 MHz 3550-3575 MHz	TBC
Philippines	C-Band	TBC
Portugal	3400-3800 MHz	TBC
Qatar	3500-3800 MHz	No power limit
Romania	3600-3800 MHz	No power limit
San Marino	C-Band	TBC
Saudi Arabia	3400-3800 MHz	TBC
Singapore	3400-3600 MHz	TBC
Slovakia	3400-3800 MHz	No power limit
Slovenia	3420-3800 MHz	No power limit
South Africa	50 MHz in band	TBC
South Korea	3400-3700 MHz	TBC
Spain	3420-3800 MHz	No power limit
Sri Lanka	C-Band	TBC
Sweden	3400-3720 MHz	TRP 47 dBm/5 MHz
Switzerland	3500-3800 MHz	TBC

Country	Spectrum Band(s)	Authorized Power
Taiwan	3340-3610 MHz	TBC
United Arab Emirates	3300-3800 MHz	No power limit
United Kingdom	3400-3800 MHz	58 dBm/MHz
United States	3700-3800 MHz	62 dBm/MHz
Uzbekistan	C-Band	TBC