5G Mid-Band Spectrum Deployment

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Executive Summary

Several 5G networks now operate in the United States using a combination of spectrum bands. Of these bands, mid-band spectrum, encompassing 2.5–6 GHz, provides high throughputs with more than one gigabit per second (Gbps) peak speeds and a practical path to widespread deployment. Within mid-band frequencies in the United States, the FCC has enabled Citizens Broadband Radio Service (CBRS), a lower-powered shared band, and has conducted an auction for C-band as a high-powered, exclusively licensed band. Although a good start, many other countries in competition with the United States, such as Japan, South Korea, and China, are moving faster in making mid-band spectrum available for 5G. Furthermore, dividing crucial mid-band spectrum into two fundamentally different approaches undermines the effectiveness of mid-band spectrum in the United States. With additional mid-band spectrum planned for the near future, understanding the merits of the different spectrum approaches will help determine the best spectrum strategy for the future.

C-band consists of 280 MHz of spectrum from 3.70 to 3.98 GHz[1], which the satellite community has agreed to clear. C-band follows a conventional licensing model, like other successful cellular bands, including 600 MHz, 700 MHz, 850 MHz cellular, 1.7 GHz AWS, and 1.9 GHz PCS. This model is also consistent with the way most other countries are licensing mid-band spectrum for 5G and enables the highest-possible 5G performance in the widest coverage areas to be deployed as quickly as possible, including suburban and rural areas.

The key attributes of the C-band licensing model are high power operation and relatively large license areas, consisting of Partial Economic Areas (PEAs). Consistent with previous licensed spectrum rules, the C-band framework enables 5G to deliver the full benefits of high speeds, high capacity, and contiguous coverage over large geographic areas. Multi-stakeholder technical working groups have developed coordination processes to ensure protection for incumbents, consistent with C-band rules.

CBRS, in contrast to C-band, was designed for spectrum sharing between incumbent federal systems, licensed users, and unlicensed-like users. A Spectrum Access System (SAS) database manages access and receives input about federal operations from a sensor network. CBRS uses power limits 327 times lower than C-band in non-rural areas and 654 times lower in rural areas, resulting in much smaller coverage areas. Licenses are at the county level, much smaller than PEAs. While touted as an innovation band, CBRS is a complicated system to develop, deploy, and operate. Furthermore, auction results for Priority Access Licenses (PALs) in 2020 show that the vast majority of licenses were won by companies already in the wireless or telecom business. These included cable companies, wireless internet service providers (WISPs) and mobile operators, with a minimal number of new entities, such as enterprises and universities.

From a network deployment perspective, the lower CBRS power limits result in five times as many cell sites required for coverage in suburban areas, significantly increasing time to deploy, with dramatically higher infrastructure costs. Rural areas require at least seven times as many cell sites. Suburban and rural areas have lower population densities that already strain broadband business models. Smaller license areas also contribute to higher infrastructure costs due to increased coverage boundaries needing protection.

[1] Per 47 Code of Federal Regulations, § 25.103 – Definitions, "Conventional C-band" consists of 3.7–4.2 GHz, originally used for satellite downlink. The term "C-band" in this paper, as in most of the wireless industry, refers to the subset, 3.70–3.98 GHz, expanded in 2020 for flexible use, including cellular networks.

Not only do cleared C-band characteristics improve network deployment efficiency and effectiveness, but the user experience benefits as well, including more reliable connections and higher average throughputs. For example, carrier aggregation works much more efficiently if the bands being combined have similar coverage characteristics. Thus, any new mid-band spectrum, such as 3.45–3.55 GHz, will function more harmoniously with C-band if it is licensed with C-band qualities rather than CBRS qualities.

Spectrum valuations prove how CBRS deployment complexities undermine the spectrum. When normalized for the amount of spectrum made available, CBRS licensed spectrum is valued at less than one quarter of C-band.

Not only will a C-band type of flexible-use licensing model for new mid-band spectrum allocations accelerate 5G deployment and usage generally, but it will also make 5G much more effective as operators deploy beyond metropolitan areas into suburban and rural areas, helping to bridge the digital divide. Given the huge stakes involved, the United States must pursue the most effective spectrum strategy possible.

Current 5G and Spectrum Situation

2020 was a momentous year for wireless technology in the United States, with widespread deployment of 5G technology and multiple 5G networks in operation. Most of the deployments so far take advantage of low-band spectrum using relatively small swaths of spectrum to enable broad coverage, combined with high-band mmWave spectrum deployed in many cities throughout the country for extremely high-speed services.

Mid-band spectrum is key to the ongoing success of 5G. 5G, with its ability to harness a wide range of spectrum, employs a "layer-cake" three-level spectrum model.[2] While low bands provide coverage and mmWave bands provide high capacity and throughput rates in smaller coverage areas, mid-band frequencies (2.5–6 GHz) offer a compelling blend of performance and coverage. In these frequencies, wide radio channels of 80–100 MHz can enable average throughputs of multiple hundreds of megabits per second (Mbps) and peak speeds exceeding one gigabit per second (Gbps). In addition, the radio waves travel far enough at these low frequencies to permit deployment over large areas. These benefits have made mid-band spectrum the most important band for 5G globally.

In these mid-band frequencies, 70 MHz of priority access licensed spectrum in the CBRS band became available in 2020, with an auction concluded in August. In December, an auction began for C-band spectrum, 3.70–3.98 GHz. Another band, 3.45–3.55 GHz, is currently in the comment stage for an FCC Notice of Proposed Rulemaking[3] with a bipartisan Congressional mandate to auction the band by the end of 2021.

Although these three bands represent an excellent start for the United States, many countries are moving faster in opening mid-band spectrum for 5G. A global spectrum report performed by Analysys Mason concludes that relative to thirteen other markets, the United States is far

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[2] T-Mobile, "Not the Onion: T-Mobile Unveils a Betty Crocker Layer Cake," Oct. 2020. https://www.t-mobile.com/news/network/t-mobile-betty-crocker-5g-layer-cake.

[3] FCC, *Notice of Proposed Rulemaking, Facilitating Shared Use in the 3.1–3.55 GHz Band*, WT Docket No. 19-348, Dec. 16, 2019. https://docs.fcc.gov/public/attachments/FCC-19-130A1.pdf.

behind in making licensed mid-band spectrum available.[4] The report further states that by 2022, the average amount of mid-band spectrum for the five leading nations will grow to more than 660 MHz. No country other than the United States is using a CBRS approach to spectrum coordination and assignment.

Furthermore, the United States has split its mid-band spectrum into two different approaches, undermining the effectiveness of mid-band for 5G. CBRS, one approach, requires spectrum coordination using a Spectrum Access System (SAS), lower power, and smaller license areas. In contrast, C-band, the other approach, follows a traditional cellular licensing model with higher power operation, larger coverage areas, and minimal coordination.

Both approaches have merits, which this paper examines. The question, given needs such as addressing the digital divide and remaining competitive globally, is which approach should receive the greatest emphasis as the United States makes new mid-band spectrum available for wireless services. As described below, a simple, flexible-use licensing model based on full-power operation will lead to deployment of the most capable networks to the greatest number of users.

This paper provides C-band details, CBRS details, deployment considerations, insights from spectrum valuation and auctions, a global comparison, a summary comparison of CBRS versus C-band, and the most effective approach for suburban and rural broadband.

C-Band Details

C-band will provide 280 MHz of crucial mid-band spectrum for 5G services,[5] allowing rapid deployment over large coverage areas. The amount of spectrum is consistent with a Rysavy Research analysis in 2019 that concluded that 5G needs a minimum of 300 MHz to make C-band viable and competitive with the rest of the world.[6] In a recent auction, the FCC set a deadline for clearing the band by December 2025 with the satellite community fulfilling commitments to accelerate clearing the lower 100 MHz for availability by December 2021 and the upper 180 MHz for availability by December 2023.

Like other cellular bands that have been successfully deployed, including 600 MHz, 700 MHz, 850 MHz cellular, 1.7 GHz AWS, and 1.9 GHz PCS, C-band follows a conventional cellular licensing model, consistent with most other countries that have allocated mid-band spectrum for 5G. Channels will be 20 MHz wide, as shown in Figure 1, and operators will be able to operate at the same full-power levels as other cellular bands: 1640 W/MHz in non-rural environments and 3280 W/MHz in rural environments. Licensing areas will be PEAs,[7] much larger than the county areas used in CBRS.

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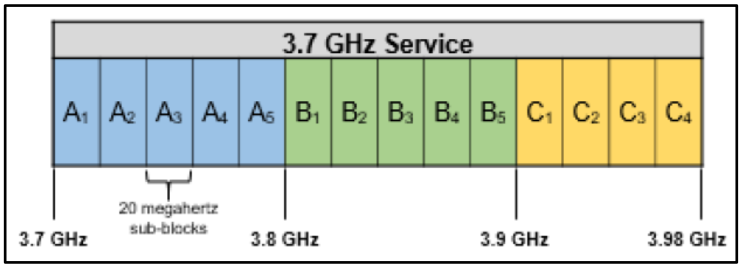
[4] Analysys Mason, *Final Report for CTIA, Mid-Band Spectrum Global Update*, Mar. 2020. https://www.ctia.org/news/report-5g-mid-band-spectrum-global-update.

[5] FCC, Report and Order, *Expanding Flexible Use of the 3.7 to 4.2 GHz Band*, GN Docket No. 18-122, Mar. 3, 2020. https://docs.fcc.gov/public/attachments/FCC-20-22A1.pdf. Note that C-band for 5G excludes Alaska, Hawaii, and the U.S. Territories.

[6] Rysavy Research, "Untangling C-Band for a New Broadband Future," Fierce Wireless, Jan. 2019. https://rysavyresearch.files.wordpress.com/2019/01/2019-01-untangling-c-band-new-broadband-future.pdf.

[7] FCC, "FCC Areas." https://www.fcc.gov/oet/maps/areas.

Figure 1: C-Band Channelization[8]



C-band requires coordination with satellite systems during deployment. A technical working group of the C-band Multi-stakeholder Group developed "Best Practices for Terrestrial-Satellite Coexistence During and After the C-band Transition," a work of thirty-eight companies and organizations, including major fixed-satellite service providers, mobile operators, mobile and satellite equipment manufacturers, trade associations, content providers, and multichannel video program distributors.[9] This effort was conducted consistent with the rules the FCC adopted in the C-band Order. Coordination requirements include licensees incorporating FCC-mandated power flux density (PFD) limits, or equivalent calculated power spectral density thresholds, into network designs to protect incumbent Earth station receivers. Once deployed with adequate protection of incumbents, however, C-band 5G systems do not need to perform any ongoing coordination, as is required with CBRS.

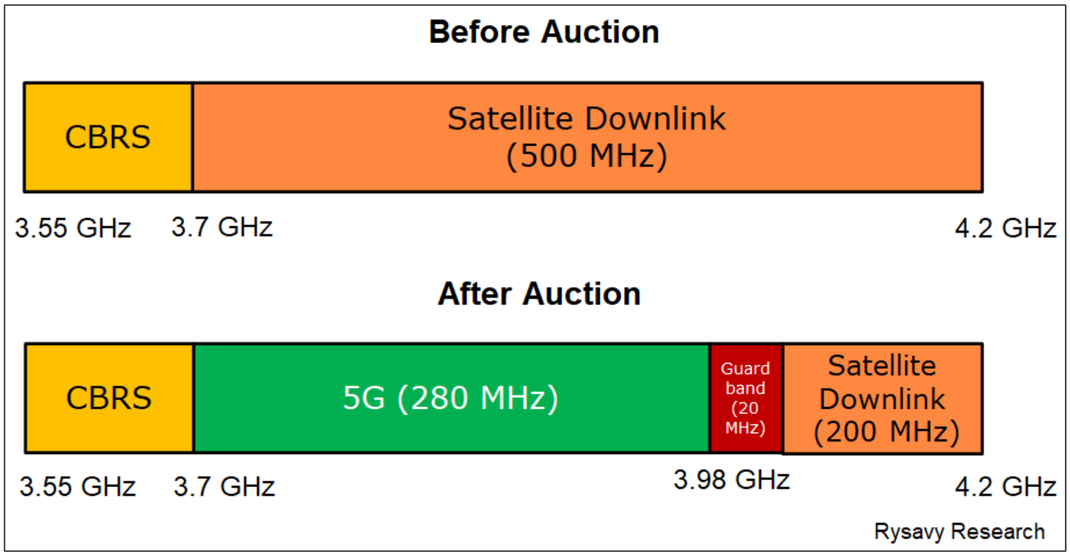
Figure 2 shows how satellite downlink, which operated at 3.7–4.2 GHz before the auction, will move to 4.0–4.2 GHz, freeing up 3.7–3.98 GHz for 5G, with a 20 MHz guard band in 3.98–4.0 GHz.

[8] FCC, Report and Order, *Expanding Flexible Use of the 3.7 to 4.2 GHz Band*, GN Docket No. 18-122, Mar. 3, 2020. https://docs.fcc.gov/public/attachments/FCC-20-22A1.pdf, p. 35.

[9] FCC, "Filing Detail," Nov. 2020. https://www.fcc.gov/ecfs/filing/1113936500088.

Letter to FCC, "Best Practices for Terrestrial-Satellite Coexistence During and After the C-Band Transition," Nov. 2020. https://ecfsapi.fcc.gov/file/1113936500088/C-Band%20TWG-1%20Cover%20Letter%20Final.pdf.

Figure 2: C-Band Spectrum Allocation



Because C-band is adjacent to CBRS at 3.7 GHz, full- or partial-time division duplex (TDD) synchronization between systems operating in the respective bands could benefit both systems. Synchronization would reduce the interference effects of a base station in one system from transmitting at the same time as a mobile system in the other system, which could drown out the mobile transmission. In order to address different or evolving use cases, stakeholders will need to balance benefits of improved spectral efficiency and close base station placements with reduced flexibility. Any coordination guidelines, however, should not hamper widespread deployment of C-band.

The combination of high-power limits, large licensing areas, and minimal coordination requirements makes C-band spectrum hugely attractive, as evidenced by auction outcomes discussed further below.

In contrast to C-band, CBRS, as discussed next, presents a different and more complex model for spectrum usage.

CBRS Details

CBRS, operating in 3.55–3.70 GHz, is an ambitious spectrum system designed to accommodate a wide range of users fitting into three categories:

1. **Tier 1.** Incumbent access users, having highest priority, consist of authorized federal users, such as Navy radar, along with fixed-satellite service Earth stations in the 3600-3650 MHz band.[10]

2. **Tier 2.** Priority Access License (PAL) winners, following an auction, received licenses for one or more 10 MHz channels, with a maximum of four channels in a license area. The ten-year renewable licenses are for county-wide areas, much smaller than PEAs.

[10] FCC, "3.5 GHz Band Overview." https://www.fcc.gov/wireless/bureau-divisions/mobility-division/35-ghz-band/35-ghz-band-overview.

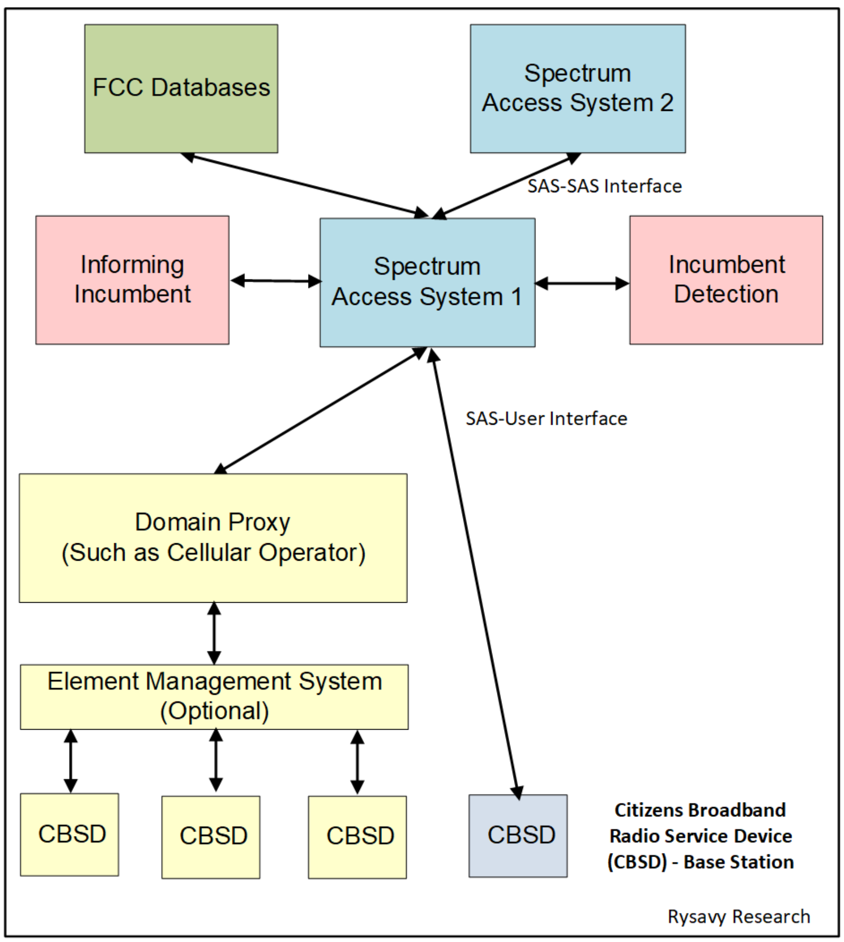
3. **Tier 3.** General Authorized Access (GAA) users do not need licenses but must coordinate with the SAS and must not cause harmful interference with higher-tier users.

CBRS prioritizes users and manages access by using a SAS, (shown in Figure 3), a database operated by certified commercial providers that instructs base stations which channels are available to them.

A network of sensors along coastlines are part of an Environmental Sensing Capability (ESC) that informs the SAS of incumbent usage and removes affected channels from use by PAL and GAA users. In the 3.55–3.70 GHz band, the primary incumbent is Navy radar, so the geographic areas of primary consideration are along both the east and west coast regions, which include major population areas. The interior of the United States is less affected. Use of the ESC concept in other bands would need to consider the operating areas of incumbent systems being considered for protection.

Although other countries have adopted modest spectrum sharing approaches, no other country in the world has attempted a three-tier model like CBRS.

Figure 3: CBRS Architecture



The CBRS band was first identified by NTIA in 2010 for federal/commercial sharing and the FCC's notice of proposed rulemaking for CBRS occurred in 2012. Due to the complex architecture and extensive logistics involved, as well as policymakers' goal of making the band more friendly to commercial entities, the FCC did not conduct its auction for Priority Access Licenses until 2020, eight years later.

The FCC has called CBRS an "innovation band."[11] Certainly, CBRS enables new usage models, such as enterprises deploying private cellular networks, either with a PAL or through the 80 megahertz made available through the GAA approach. Only three enterprises, however, obtained PALs in the 2020 auction. Four universities also won licenses, along with a handful of utilities.[12] WISPs and mobile or cable operators obtained most of the licenses. In other words, companies already in the telecom business dominated the auction, suggesting that these entities valued the PALs more than other potential users.

Although CBRS theoretically achieves its objectives of enabling a broader ecosystem of users, it does so at a cost. Specifically:

- **Complexity.** Systems must coordinate with the SAS. In addition, PALs are 10 MHz channels anywhere in a 100 MHz range (3550–3650 MHz), and channel assignments can change whenever the SAS instructs the base station to turn off, move to another channel, or change power within 300 seconds of detection of a federal incumbent.[13] PAL and GAA users must also protect ESC sensors by reducing or avoiding transmissions within a "whisper zone" around each ESC.

- **Spectrum Management Difficulty.** Because licensed channel assignments can change often, affecting propagation and penetration characteristics, and because incumbents have priority over spectrum resources, operators have greater difficulty managing capacity and the performance for users.

- **Low Power Operation.** CBRS users are restricted to a 5 W/MHz maximum power limit, 327 times lower than C-band and other cellular systems in non-rural areas and 654 times lower in rural areas. The government imposed the power limit to reduce the possibility of interfering with systems in the incumbent tier. Unfortunately, the lower power limits increase infrastructure cost by requiring more cell sites to cover areas, as discussed in the next section.

- **Small License Areas.** Although considered beneficial for some entities, such as smaller WISPs and cable companies, the smaller license areas increase deployment cost for ubiquitous coverage 5G networks, as discussed in the next section.

- **Frequency Coordination Challenges.** The SAS attempts to assign channels to licensees fairly by assigning contiguous channels when possible and assigning the same channels across license boundaries. However, if the number of channels an operator owns varies by license area, these two conditions cannot always be satisfied, creating protection requirements in the middle of a city that reduce the spectrum's utility.

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[11] FCC, "Innovation in the 3.5 GHz Band: Creating a New Citizens Broadband Radio Service," Mar. 2015. https://www.fcc.gov/news-events/blog/2015/03/27/innovation-35-ghz-band-creating-new-citizens-broadband-radio-service.

[12] iGR, "Some of the more interesting bidders in the CBRS PAL Auction," Sep. 2020. https://igr-inc.com/media-center/opinion-articles/articles/20200908_interesting_bidders_CBRS_PAL.asp.

[13] FCC rules 96.15 (a) (4).

Furthermore, the ESC has proven challenging, and various entities[14] are now proposing an alternate approach, called the Incumbent-Informing Capability (IIC). Recently, one of the SAS providers, which has been a strong proponent for spectrum sharing in CBRS, has suggested moving away from the ESC model to the IIC model. One of the key reasons cited is that the ESC model blocks large areas from network deployment due to "whisper zones" that must be maintained around each sensor in the ESC.[15] The need for a new framework, fundamentally different from the initial one, completely untested, and as yet undeveloped, highlights the predictable challenges of spectrum-sharing approaches.[16]

Although CBRS supports new use cases, such as private networks and industrial IoT, the focus of this paper is on how CBRS types of rules, including low power and small license areas, impact spectrum deployment for 5G networks intended to cover extended geographic areas, particularly with future spectrum bands, such as 3.45–3.55 GHz.

Deployment Considerations

Different constraints on spectrum have significant consequences on deployment, for instance, affecting the number of sites needed to cover an area and the resulting costs. 4G and 5G networks also do not use spectrum in isolation, but often combine bands using a powerful technology called carrier aggregation, a technology that can be undermined by mismatched spectrum, as explained in this section.

Three important aspects of spectrum rules that impact deployment are power limits, licensing areas, and coordination requirements.

The impact of power limits depends on the type of coverage. In denser population areas, such as cities, networks are usually capacity limited, meaning capacity considerations determine the coverage area of a cell site and hence the total number of sites. Consequently, an operator has to deploy cell sites with smaller coverage areas than the maximum possible based on just signal propagation. Nevertheless, even in capacity-limited deployments, higher-power base stations can improve both in-building coverage and user throughputs. For example, in a case where two base stations are serving a similarly sized urban area but one is permitted to transmit with 9 dB more power, the higher-power base station can support multiple users simultaneously at the same data rate as one user served by the lower-power base station.[17] Urban areas benefit considerably from higher base station power levels.

In less dense areas such as suburban and rural locations, a 5G cell site at its maximum size should have sufficient capacity to address the data consumption of active subscribers. In this

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[14] For example, CommScope, *Comments in in the matter of Facilitating Shared Use in the 3100-3550 MHz Band*, Nov. 2020. https://ecfsapi.fcc.gov/file/11200789219315/CommScope%2019-348%20Comments.pdf.

[15] Google, Ex Parte, "In the Matter of Facilitating Shared Use in the 3100-3550 MHz Band (WT Docket No. 19-348); 3.5 GHz SAS and ESC Applications (GN Docket No. 15-319)," Dec. 17, 2020. https://ecfsapi.fcc.gov/file/1218754825672/2020-12-17%20Google%20Ex%20Parte%20(19-348)%20--%20FINAL.pdf

[16] For example, see Rysavy Research, "Scary Experimentation at 3.5 GHz," Jun. 2016. https://rysavyresearch.files.wordpress.com/2017/08/2016-06-scary-experimentation-3-5-ghz.pdf.

[17] Massive MIMO enables multiple beams that can simultaneously serve separate users, increasing user performance and network efficiency.

coverage-limited deployment case, larger cells translate to more rapid deployment timeframes and lower infrastructure costs because the operator does not have to install as many sites.

Lower population densities are inherently challenging for wireless business models because of the small number of subscribers in any area. A profitable network must support enough subscribers to offset the equipment capital cost and the significant per-site operating costs. Thus, site density can make a huge difference between a profitable and unprofitable deployment business case.

Per FCC technical rules, the base station power level for CBRS is considerably lower than that for C-band. Table 1 compares the non-rural and rural power levels for a 20 MHz channel.

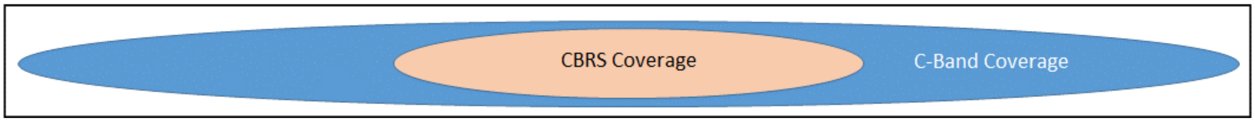
Table 1: Power Limits for CBRS and C-Band

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 CBRS, equating to a factor of 327–654 times more power. This drives a significant difference in the number of cell sites needed to cover a given area.

As a consequence, the coverage area of a CBRS base station is significantly smaller than that of comparable full-power cells. As shown in Figure 4, the lower power limits significantly reduce the coverage footprint of a CBRS cell relative to a full-power cell, resulting in many more cell sites, and therefore markedly slower and more expensive deployments.

Figure 4: Coverage Differences due to CBRS Power Levels



To fully overlay a high-power cell's coverage area with CBRS sites, 5–7 times more CBRS cells would be required.[18] As an example, an engineering analysis for a suburban area in northern Jackson, Mississippi, reveals that a CBRS deployment would require many more sites to match the higher-powered C-band coverage. Figure 5 illustrates how a network using CBRS power limits, in such a coverage-limited suburban deployment, would result in five times as many cell sites.

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[18] Coverage analysis courtesy CTIA. Assumes hexagonal cells, massive MIMO with 256 antenna elements, and eight spatial streams. Analysis also assumes carrier aggregation with uplink supported on a lower band, such as 600–850 MHz (using frequency division duplex). Forward link path loss analysis shows a suburban high-power cell site having a radius of 1.24 km, a rural high-power cell site having a radius of 3.44 km and a CBRS rural cell site having a radius of 1.28 km. While current mid-band deployments are leveraging 8x8 antenna arrays with 64 elements, future 3 GHz deployments are expected to evolve to 16x16 arrays or larger.

Figure 5: CBRS versus C-Band Site Counts in a Suburban Area

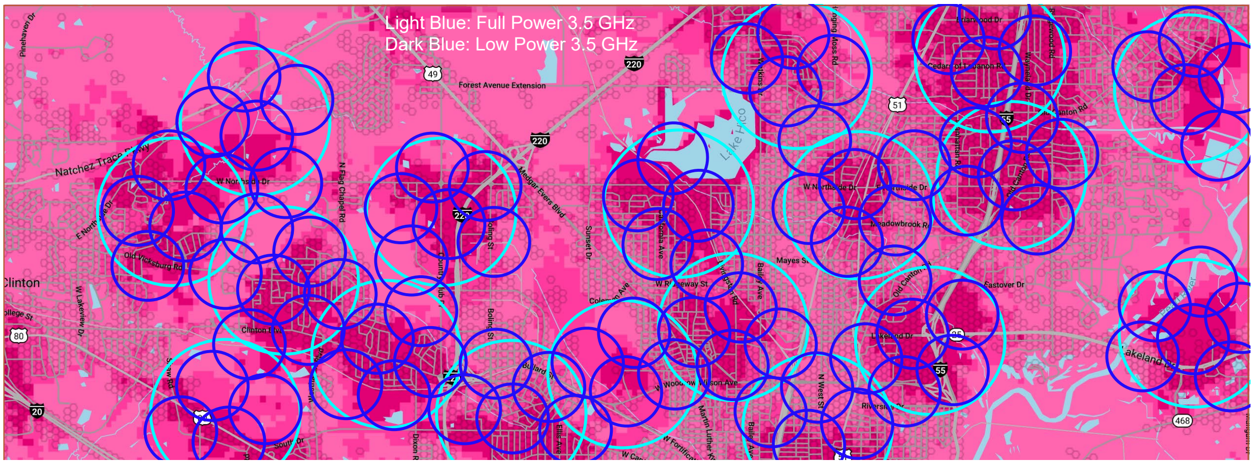
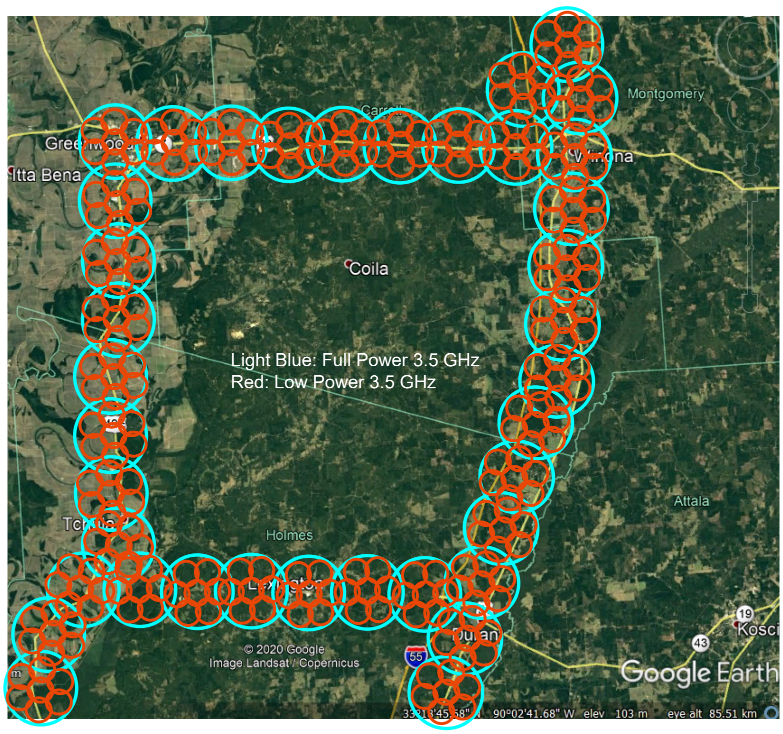


Figure 6 illustrates how a theoretical network using CBRS power limits, in a coverage-limited rural deployment, results in seven times as many cell sites.

Figure 6: CBRS versus C-Band Site Counts in a Rural Area



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 significant 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.

These CBRS power limits, whether using CBRS itself or applied to new bands, would significantly delay 5G deployment to suburban and rural areas, given the time required to acquire, build, and deploy new towers to support the new low-power sites. Specifically, these delays are likely to take two years or longer,[19] depending on the local jurisdictions; in fact, such a large increase in towers in suburban and rural areas might not even be feasible. Zoning restrictions limit where new towers may be sited, and many locations have no source of power or backhaul.

In addition to these significant time delays, cell site costs would be prohibitive in many cases. Obtaining physical access, building towers, providing power, obtaining backhaul, and covering operational and maintenance costs of all these sites vastly increases deployment costs. These costs are especially significant because the radio-access portion of a network constitutes some 80% of the total infrastructure costs.[20]

Furthermore, most 5G networks will employ massive multiple-input multiple-output (MIMO) antennas, with which the base stations can focus radio waves into narrow, concentrated beams, which increases range. With massive MIMO, the coverage area of a cell at 3.5 GHz can match the coverage area of a non-massive MIMO cell operating at lower bands.[21]

With massive MIMO, mid-band 5G base stations will use an adaptive antenna array to form highly directional beams toward mobile devices. Spectrum bands, including the C-band, can use this highly directional antenna array to deliver stronger Effective Isotropic Radiated Power (EIRP). For example, an antenna array of sixteen-by-sixteen elements achieves a beamforming antenna gain of 31.2 dBi for a single beam. 5G base stations can readily achieve a conducted power of 25 dBm per element, producing a total EIRP of 80 dBm. If multiple beams are directed to different users, then the power per beam would be lower, but the overall higher EIRP greatly increases the coverage and capacity of the base station. Full-power spectrum bands can use this power to achieve excellent coverage and broadband data rates over a large geographic area, reaching the high EIRP permitted by the FCC technical rules of 1640 watts per MHz in non-rural areas and 3280 watts per MHz in rural areas.

A base station artificially constrained to lower power, such as with CBRS or with new bands restricted to CBRS power limits, is inherently limited in both coverage and capacity. Thus, base station transmit power is essential to achieving a higher coverage range, penetrating deeply within buildings, and providing a higher signal-to-noise ratio (SNR) that enables higher-order modulation and lower coding overhead to deliver the best possible broadband speeds.

Proponents of smaller license areas claim that the small license provides opportunities for local entities to acquire and use spectrum where they wish. This flexibility, however, comes with a hidden cost. When different entities own a given license in neighboring areas, then both entities must adhere to the boundary protection criteria, which restrict base station deployment flexibility and power levels near the boundary. The restrictions impact the ability of either entity to fully serve customers in this no-man's land around the boundary. This

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[19] Cell Tower Info.com, "Cell Tower Zoning and Permitting." https://www.celltowerinfo.com/cell-tower-zoning/

[20] Heavy Reading, "RAN Sharing: Cutting the Cost of Mobile Broadband." http://www.heavyreading.com/mobile-networks/details.asp?sku_id=1669&skuitem_itemid=1021.

[21] Rewheel-Tutela, "Site density is key to LTE network performance – and critical for 5G," Feb. 2019. https://www.tutela.com/hubfs/Assets/Rewheel_Tutela_LTE_5G_performance_drivers_Europe_17022019_FINAL.pdf.

hidden cost is most obvious when boundaries occur in a city. For instance, New York City is divided into several counties, but falls within a single PEA. A licensee with a channel in one county but not the neighboring county must protect the neighboring operations and restrict the coverage footprint, creating discontinuities within the city and reducing the efficient use of spectrum. In contrast, when the city falls within a single license, as with the PEA, then the licensee is able to effectively serve customers throughout the city.

Although more difficult to quantify with respect to costs, the dynamic coordination requirements for CBRS interfacing to a SAS also increase deployment costs. The operator must connect its network to the SAS, confirm correct operation, manage this connection on an ongoing basis, and pay the third-party SAS provider.[22]

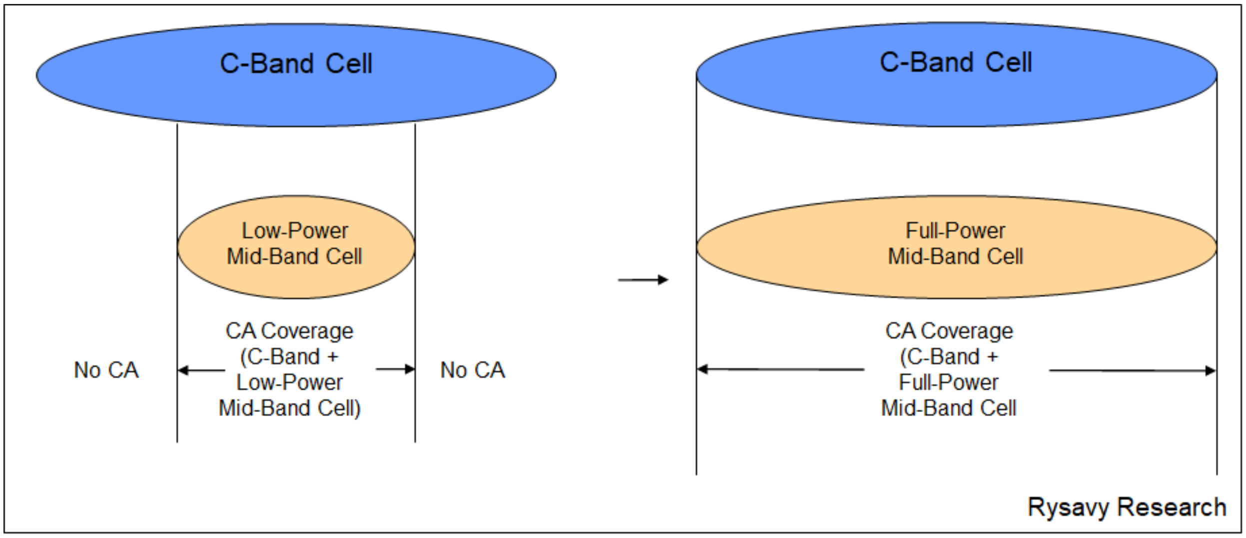
As already mentioned, 5G networks often use multiple radio bands simultaneously. Carrier aggregation technology combines multiple radio channels to create a virtual "super channel." A frequently stated goal of 5G for mid-band is to deploy 80–100 MHz channels,[23] much more easily realized if C-band can be combined with another mid-band frequency. If an operator were to combine C-band with radio channels in another mid-band frequency, 3.45–3.55 GHz for example, the user experience will be superior if both channels are operating at the same higher-power level. Even though carrier aggregation between two bands with different power levels is technically possible, as shown in Figure 7, it results in the aggregated channels only being available in a subset of the C-band cell coverage area. In contrast, aggregating frequencies at the same power level will provide the carrier-aggregation benefit across the entire coverage area.

Mid-band channels with similar characteristics have the further benefit of more effectively managing traffic loads across the bands, more consistent user throughputs, fewer handovers, and fewer dropped connections.

[22] For example, see Light Reading, "Google Puts a Price on CBRS SAS: $2.25/Month Per Home," Mar. 2019. https://www.lightreading.com/mobile/5g/google-puts-a-price-on-cbrs-sas-$225-month-per-home/d/d-id/750288.

[23] For example, see GSMA, *5G Spectrum, GSMA Public Policy Position*, Mar. 2020. https://www.gsma.com/spectrum/wp-content/uploads/2020/03/5G-Spectrum-Positions.pdf.

Figure 7: Carrier Aggregation in Mid-Band Frequencies



Similar power levels also enable operators to deploy both bands in the same physical grid, resulting in simpler and more cost-effective deployments. The alternative of using lower-power sites means additional sites are needed to match C-band coverage, as well as additional transport connectivity between C-band sites and the lower-power sites to implement inter-site carrier aggregation.

Fixed-wireless access deployments will also benefit from higher power levels. WISPs, utility companies, and cellular operators depend on directional antennas to increase range, enabling longer propagation distances than in deployments based on continuous coverage. With higher-power operation, still using directional antennas, WISPs, utility companies, and cellular operators could further extend the range of their systems, making wireless technology even more practical for rural broadband. A utility company that provides wireless services recently argued for higher power levels, which would enable licensees to provide greater coverage with fewer sites, enabling flexibility in network planning and deployment, while reducing deployment costs.[24] A further advantage is the improved signal quality accompanying higher power levels, which increases throughputs and capacity.

Additionally, higher-power mid-band operation in rural scenarios will make it possible to provide practical ubiquitous coverage for fixed and mobile operation.

[24] Comments of Southern Linc, "In the Matter of Facilitating Shared Use in the 3100-3550 MHz Band, WT Docket No. 19-348," Dec. 7, 2020. https://ecfsapi.fcc.gov/file/12082437622306/Southern%20Linc%20Reply%20Comments%20on%203450-3550%20MHz%20FNPRM%20(WT%2019-348).pdf

Insights from Spectrum Valuation and Auctions

Spectrum valuations provide insight into how rules impact the usefulness of spectrum. CBRS resulted in $4.6 billion of auction revenue for 70 MHz of PALS. Scaled to 280 MHz, this valuation equates to $18.4 billion.

In contrast, the C-band auction reached $80.9 billion. C-band brought in roughly eighteen times more gross proceeds for only four times the amount of spectrum as CBRS, before clearing costs and acceleration payments. This indicates that the market considers C-band spectrum and its associated spectrum rules at least four times as valuable as CBRS spectrum with its rules.

The difference in value is certainly not due to the frequencies involved–they are effectively the same–but rather to the factors discussed above: coordination requirements, lower power operation, more difficult spectrum planning, and smaller license areas.

Global Comparison

As mentioned above, many other countries are making mid-band spectrum available for 5G faster than the United States, including China, Japan, and South Korea. Nearly all countries are globally harmonizing their use of mid-band spectrum to international standards, such as using 3GPP designated n77 (3300–4200 MHz) and n78 (3300–3800 MHz) bands. By harmonizing with these standards, which are consistent with the C-band spectrum approach rather than CBRS, the United States will benefit from global economies of scale for infrastructure and subscriber equipment.

Beyond harmonization considerations, leadership in 5G deployment is crucial because not only does the wireless industry benefit, but the 5G services make economies more efficient and competitive. In addition, synergistic technologies such as AI, edge computing, and autonomous cars all will thrive on a robust 5G platform.

Table 2 lists all the countries that have committed to 5G within the 3.3–3.8 GHz tuning range. None of them are imposing a spectrum approach such as CBRS.

As the United States considers how to allocate mid-band spectrum beyond C-band and CBRS, it should understand the repercussions of a more complex spectrum management policy. Specifically, if the strategic national goal is for the highest-possible performing 5G networks over the broadest coverage areas, then a CBRS approach to spectrum will place the United States at a global competitive disadvantage, including against countries such as China.

Table 2: International Lower 3 GHz Mid-Band Spectrum Plans[25]

Country	3.3 – 3.8 GHz Range	Comments
United States	Planned	70 MHz auction in 2020 3.7-3.98 GHz auction in 2020
Argentina	Considering	
Australia	Assigned	
Austria	Assigned	
Bahrain	Assigned	
Belgium	Planned	
Brazil	Planned	Considering additional
Cambodia	Planned	
Canada	Planned	
Chile	Considering	Some planned
China	Assigned	
Costa Rica	Considering	
Ecuador	Planned	
Egypt	Planned	
Finland	Assigned	
France	Assigned	
Germany	Assigned	
Greece	Planned	
Hong Kong	Assigned	
India	Planned	
Ireland	Assigned	
Israel	Assigned	
Italy	Assigned	
Japan	Assigned	
Mexico	Assigned	
Netherlands	Planned	
Norway	Planned	
Peru	Planned	
Philippines	Assigned	
Poland	Planned	
Portugal	Planned	
Qatar	Considering	
Romania	Planned	
Saudi Arabia	Assigned	
Singapore	Planned	
South Korea	Assigned	
Spain	Assigned	
Sweden	Planned	
Switzerland	Assigned	
Taiwan	Assigned	
United Kingdom	Assigned	Planning additional
	Legend	
	Assigned or Planned	
	Considering	

[25] GSA, *3300-4200 MHz: A Key Frequency Band for 5G. How Administrations Can Exploit Its Potential*, 2020. https://gsacom.com/paper/3300-4200-mhz-a-key-frequency-band-for-5g/

Summary of CBRS vs. C-Band Approaches

The following table, based on the preceding discussion, summarizes the relative strengths of CBRS and C-band approaches for wide-area networks.

	CBRS	**C-Band**
Maximum Power Level	5 W/MHz	1640 W/MHz non-rural and 3280 W/MHz rural
Coverage	Small coverage areas for each cell site	5–7 times greater coverage area for each cell site than CBRS
Infrastructure Cost	High for larger coverage areas	For larger coverage areas, significantly lower than CBRS due to much smaller number of sites
License Areas	County level, 3,233 total[26]	Partial Economic Areas (PEAs), 406 total[27]
Licensees	Small to large entities for GAA, medium to larger entities for PALs	Larger entities
Coordination	Complex: Spectrum Access System and Environmental Sensing Capability operating on an ongoing basis	Minimal and only during initial deployment to protect fixed earth satellite stations
Spectrum Planning	Difficult due to varying spectrum assignments and possibility of incumbent use	Predictable and stable
Global Alignment	Poor, no other country is pursuing a CBRS architecture	Good, consistent with rest of the world
Spectrum Value	High	Very high. More than four times higher than CBRS
Ability to Address Rural Broadband	Good, but often requires external, directional antennas to fixed locations	Excellent, supporting mobile broadband over a larger coverage area

[26] FCC, "Auction 105: 3.5 GHz Band." https://www.fcc.gov/auction/105/factsheet.

[27] FCC, "Auction 107: 3.7 GHz Service." https://www.fcc.gov/auction/107/factsheet

Best Spectrum Strategy for Suburban and Rural Broadband

The analysis in the preceding sections can be applied to determine the best spectrum strategy to address the digital divide, including delivering suburban and rural broadband solutions. The FCC states that 97% of Americans can access broadband service in urban areas, but only 65% in rural areas.[28] Expansion of 5G with low-band coverage to more than 200 million people in 2020 by three national providers was a positive step towards expanding 5G. However, more work is needed to further expand coverage and to help bridge the digital divide.

Although rural broadband today misses many potential subscribers, the situation would be worse without today's existing mobile cellular networks. Cellular operators, including AT&T, U.S. Cellular, and Verizon, have also deployed fixed internet services based on LTE. T-Mobile, as part of Sprint merger conditions, has committed to delivering 5G download speeds of at least 50 Mbps to 90% of the rural population within six years.[29]

For suburban and rural areas, a C-band type of spectrum policy is preferable to CBRS for the following reasons:

1. **Faster to deploy and lower cost.** Fewer cell sites, better propagation characteristics, less fiber backhaul, larger license areas, lower and faster siting processes, and simpler coordination requirements translate to viable business models, motivating operators to deploy networks in underserved areas and leading to more Americans connected for the same amount of investment.

2. **Better performance.** More effective carrier aggregation resulting from consistent operating characteristics across bands will deliver higher average throughputs across coverage areas.

3. **Ubiquitous coverage.** Whereas smaller WISPs are more likely to provide point-to-point fixed wireless access, larger operators will emphasize continuous coverage over large areas.

Figure demonstrates the benefits of mobile coverage in a rural environment. For example, a large farm operation employing agricultural automation will benefit from ubiquitous coverage across the entire area of operations versus just having connectivity at specific buildings.

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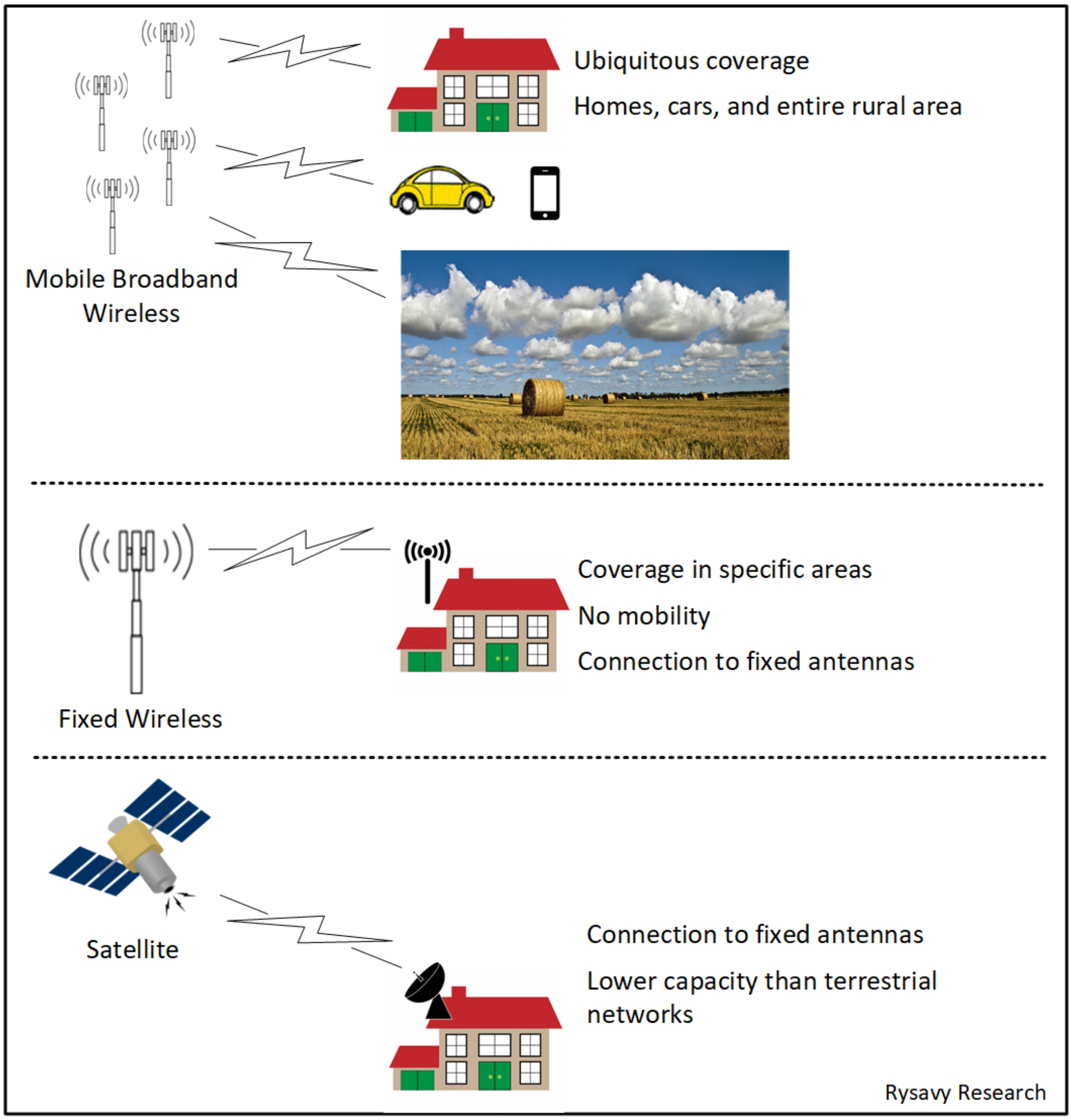
[28] FCC, "Bridging The Digital Divide For All Americans." https://www.fcc.gov/about-fcc/fcc-initiatives/bridging-digital-divide-all-americans.

[29] FCC, *Notice of Proposed Rulemaking and Order*, GN Docket No. 20-32, Apr. 2020. https://docs.fcc.gov/public/attachments/DOC-363491A1.pdf.

Figure 8: Rural Coverage



Other broadband solutions will also play a role in rural environments, including satellite systems and High Altitude Platform Services (HAPS), but as analyzed by Rysavy Research, these will play a limited role and will not have the capacity to address the most common use cases demanded in these environments.[30]

Not only will a C-band type of spectrum policy in new mid-band spectrum, such as in 3.45–3.55 GHz, benefit rural broadband, but it aligns more closely to what the rest of the world is planning with mid-band spectrum and allows the United States to maintain global leadership.

[30] Rysavy Research, "Latest Tech Aims to Solve the Riddle of Rural Broadband," Aug. 2020. https://rysavyresearch.files.wordpress.com/2020/09/2020-08-latest-tech-for-rural-broadband.pdf.

Conclusion

The United States finds itself at a spectrum crossroads. The FCC has aggressively licensed mmWave frequencies, which allow 5G to reach unprecedented data speeds and capacity, but which only propagate over small coverage areas. Meanwhile, 5G in low bands enables broad coverage but with only modest speed improvements. In contrast, mid-band frequencies, which offer the best combination of capacity and coverage, are the most effective means for achieving high performance over large coverage areas.

Countries around the world are racing to make 5G available to consumers and enterprises. Winning the global 5G race will not only benefit the wireless industry, but also will give other industries a competitive advantage, while helping advance related technologies such as self-driving vehicles and artificial intelligence.

Unfortunately, as other countries allocate large amounts of mid-band spectrum for 5G using a simple licensing model, the United States has undermined its mid-band spectrum position first by licensing less spectrum so far than other countries, and second by fracturing its spectrum policy into two different approaches. C-band follows a traditional approach, but CBRS uses a spectrum sharing approach that, in combination with small license areas and low power limits, makes CBRS-based networks expensive to deploy over large areas.

In considering rules for future mid-band spectrum, such as 3.1–3.55 GHz, the United States should consider a strategy that not only makes the United States competitive globally, but also helps address the digital divide, enhancing broadband in suburban and rural areas. In both cases, a simple, flexible-use licensing model based on full-power operation will result in operators deploying the most capable networks to the greatest number of users.

Abbreviations and Acronyms

The following abbreviations are used in this paper. Abbreviations are defined on first use.

CBRS – Citizens Broadband Radio Service

EIRP – Effective Isotropic Radiated Power

ESC – Environmental Sensing Capability

GAA – General Authorized Access

Gbps – Billion bits per second

HAPS – High Altitude Platform Services

IIC – Incumbent-Informing Capability

Mbps – Million bits per second

MIMO – Multiple Input Multiple Output

PAL – Priority Access License

PEA – Partial Economic Area

PFD – Power Flux Density

SAS – Spectrum Access System

SNR – Signal to Noise Ratio

TDD – Time Division Duplex

WISP – Wireless Internet Service Provider

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 has written more than 190 articles and reports.

Clients include more than 100 organizations.

From 2000 to 2016, Peter 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 graduated with BSEE and MSEE degrees from Stanford University in 1979. More information is available at https://www.rysavy.com.