Mid-band Spectrum Opportunities And Challenges

Balancing Coverage and Capacity for 5G Deployments in the US Market

A Technical Paper prepared for SCTE•ISBE by

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Synopsis

To date the FCC has made ~633MHz of licensed spectrum (below 6GHz) available to mobile network operators, which they have deployed to achieve broadscale coverage. However, to deliver the coverage and capacity required for emerging enhanced mobile broadband (eMBB), augmented reality (AR), virtual reality (VR), fixed wireless access (FWA), vehicle-to-everything (V2X), etc. use cases, much deeper pools of spectrum will be required, with mid-band playing a critical and broad role. Broadband Radio Service / Education Broadband Service (BRS/EBS), Citizens Broadband Radio Service (CBRS), and C-band spectrum bands have the potential to provide over 500MHz of additional capacity, on a much more economically viable deployment footprint than mmWave. This paper will explore the opportunities and challenges mid-band spectrum presents and will share perspective across three categories:

• **Use Case and Competitive Considerations** – the depth of spectrum available in the mid-band increases the economic viability for use cases not traditionally aligned with 3GPP technology, including FWA and video distribution, presenting an opportunity and threat to cable's traditional businesses.

• **Business Model Considerations** – Innovative and flexible models for mid-band spectrum allocation makes operators build their business cases around usage and deployment scenarios, including neutral host and private networks, who bring their own value props. Spectrum acquisition cost is increasing for mid-band spectrum, especially if wide, continuous channels are made available. 5G use cases drive the revenue opportunities and we are just beginning to see the innovation in what can be built on 5G networks.

• Deployment Considerations – While some of the mid-band spectrum (BRS/EBS) can be deployed using a traditional macro approach, greatest performance will be achieved though densification. Line of sight, building penetration, and cell edge performance will drive mid-band site placement considerations.

Introduction:

Mid-band spectrum is lauded as the Goldilocks bands for 5G uses with the just-right combination of coverage and capacity. **This paper will provide an overview of mid-band spectrum in the US, validate the technical claims of mid-band given typical deployments, and explore 5G use cases most aligned with mid-band spectrum with corresponding deployment and business case considerations**. We incorporate our experience with delivering consulting engagements supporting our clients' decision points around mid-band spectrum. We also include our view on how mid-band spectrum can complement 5G deployments in the coming years.

Most 5G deployments will benefit from combining low, mid, and high-band spectrum to leverage the best characteristics of each set of bands. Low band provides ubiquitous coverage and can serve as an anchor band for 5G network cores. Mid-band combines access to wide channels with workable propagation characteristics to deliver gigabit-capable service over cell areas of several square kilometers. High band, or millimeter wave, spectrum uses ultra wide channels to deliver multi gigabit-capable service in hot-spot areas. Mid-band spectrum is capable of providing 5G-capable low latency, gigabit service without the 5-10x cell site densification required for mmWave spectrum. 5G deployments should aim for 100MHz of aggregated spectrum per operator for services. This can come from carrier aggregation of existing smaller bands or aggregating larger channels of mid-band spectrum.

The US is currently limited in its available mid-band spectrum assets and the calls for more mid-band spectrum are growing. On average, US peer wireless markets will have 4x more mid-band spectrum available by the end of 2020 for deployments[1]. There is tremendous political motivation to free up more spectrum for 5G, including mid-band, as the infrastructure and technology improvements are thought to spur innovation. The administration and the FCC want to do what they can to ensure the next generation of apps and start-ups enabled by 5G are done in the US, hence the FCC's 5G FAST plan[2]. The FCC chairman's 5G strategy includes three key components: Pushing more spectrum into the marketplace, updating infrastructure policy; and modernizing outdated regulations. Making additonal mid-band spectrum available falls into the first component of this strategy.

We will focus on the 2.5GHz, 3.5GHz, and 3.7GHz licensed spectrum bands in the US for mobile and fixed wireless uses including commercial considerations for bringing use cases on these bands to the market.

[1] https://www.ctia.org/news/mid-band-spectrum-global-update, https://www.ctia.org/news/more-mid-band-spectrum-is-key-to-u-s-5g-leadership

[2] https://www.fcc.gov/5G

1. Defining the Mid-Band Spectrum Frequency Range

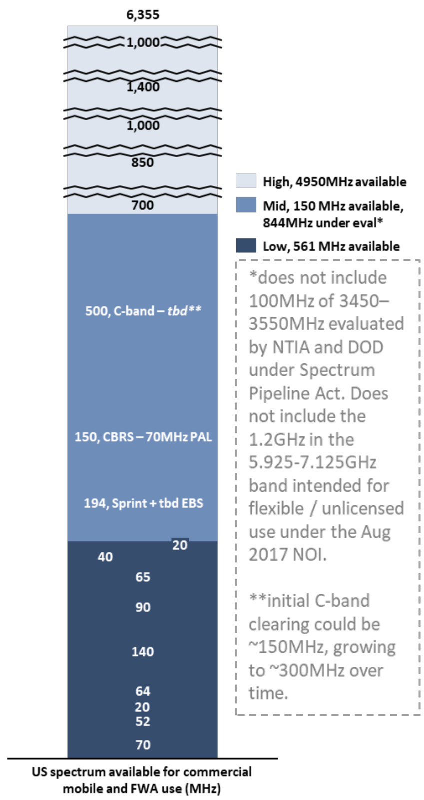


Figure 1. New range of mid-band is 2.5-8GHz

Mid-band spectrum in the US has evolved in its definition. Before millimeter wave (mmWave) spectrum was available for mobile use, the Clearwire 2.5GHz was considered high band spectrum. AWS and PCS were considered high band by some and mid-band by others. Broadcast, SMR, Cellular, and all bands below 1GHz were considered low band spectrum.

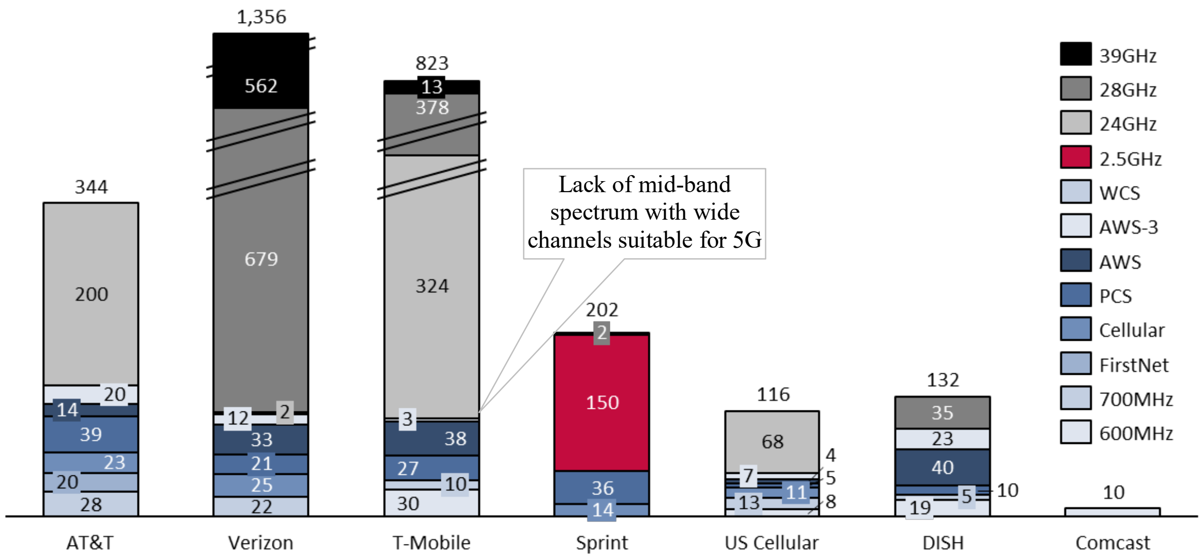
The definitions have shifted with mmWave spectrum now deployed for mobile use. While millimeter wave technically isn't single-digit mm wavelengths until 30GHz, convention has labeled the 24GHz and higher spectrum as mmWave.

Low band spectrum is still 600MHz, 700MHz, and Cellular, but now includes AWS and PCS in the 1700/2100MHz and 1900MHz frequencies, respectively. This grouping is driven by relative characteristics similarities and colocation occurrences, meaning AWS and PCS can work on a 700MHz cell site grid.

Mid-band spectrum can also be grouped by performance characteristic similarities and intended usage. Spectrum from 2.5GHz – 8GHz[3], Figure 1, can be defined as mid-band spectrum in that it provides suitable propagation characteristics with wide channel bandwidths to provide a balance between coverage and capacity. The "sub-6" label has gained in usage and can be consider synonymous with this mid-band label.

Mid-band spectrum holdings in this defined range in the United States has been limited, Figure 2. Average spectrum holdings for major operators by low, mid, and high band breakout show Sprint's 2.5GHz licenses making up most of the current mid-band holdings. Other countries with a similar wireless market will have on average 4x more mid-band spectrum compared to the US by 2020[4]. Playing catch up requires pushing through more spectrum and for the operators deploying that spectrum to align it with their existing portfolios and corporate strategies. Acquiring more mid-band spectrum will help shape how operators define their strategies in the 5G era.

[3] FCC, inCode, https://www.fcc.gov/document/fcc-opens-inquiry-new-opportunities-mid-band-spectrum-0
[4] FCC 5G FAST plan



Sub-2200 MHz	144	113	108	50	48	97	10
mmWave MHz	200	1243	715	2	68	35	0

Figure 2. Average spectrum holdings for major operators by low, mid, and high band breakout

Source: inCode, FCC

2. Mid-band Spectrum in Focus

The industry has recognized the importance of mid-band spectrum in this defined frequency range as it looks ahead to 5G deployments. The FCC has committed to bringing more mid-band spectrum on line with a combination of auctions and flexible use policy approaches. Industry leaders are calling for more spectrum and to speed up the process. FCC Commissioner Michael O'Rielly blogged "**more attention needs to be paid to the mid-bands**"[5] and USCC's Meyers lobbied, "…as we continue to meet the growing demand for data services and further identify and define potential 5G use cases, **we implore the FCC to bring as much mid-band spectrum to market as possible, as soon as possible** and within a framework that will allow regional and smaller wireless carriers to continue to meaningfully participate in this industry."[6]

We will provide an overview of three licensed mid-band spectrum bands and their deployment considerations to validate their place in a 5G spectrum portfolio.

[5] https://www.fcc.gov/news-events/blog/2017/07/10/mid-band-spectrum-win-making

[6] Kenneth Meyers, President, CEO & Director, USCC, Telephone and Data Systems, Inc., United States Cellular Corporation, Q2 2019 Earnings Call, Aug 02, 2019

2.1. CBRS 3550MHz-3700MHz Overview

Citizens Broadband Radio Service (CBRS) is TDD spectrum in the 3550-3700MHz[7] band that was first reserved for military use but could serve 5G customers under a flexible spectrum sharing plan. There is up to 70 MHz of CBRS to be licensed in each county in the Priority Access License (PAL) auction and an additional 80 MHz of unlicensed or lightly-licensed spectrum available for General Authorized Access (GAA).

The CBRS auction is now expected June 25, 2020 following the posting of the final auction rules in October 2018[8] and pending a vote at the September 26, 2019 FCC meeting. inCode estimates a PAL auction price average across the counties at $0.13/MHz-pop. This value is at a discount to the global mid-band spectrum average of $0.18/MHz-pop due to the restrictions and preemption charactistics on the bands. Frictional costs of adding the Spectrum Access System (SAS) / Environmental Sensing Capability (ESC) costs to the CBRS business case could push the 70MHz of PAL spectrum auction price down to $0.10/MHz-pop. Google has announced its FWA pricing for SAS services at $2.25/HH/month[9]. Connected device and mobility pricing may be different.

CBRS is governed by a flexible-use, three-tiered spectrum authorization framework to accommodate a variety of commercial uses on a shared basis with incumbent federal and non-federal users of the band. The three tiers are: Incumbent access, PAL, and GAA.

Incumbent access users include authorized federal users, grandfathered Fixed Satellite Service earth stations, and, for a limited time, grandfathered wireless broadband licensees in the 3650-3700 MHz portion of the band. These users will be protected from harmful interference from PAL and GAA users through exclusion zones and management SAS and ESC services. These capabilities are a prerequisite for commercial CBRS service. Commercial services on the GAA portion of the band are expected to begin in September 2019[10].

The priority access tier consists of PALs that will be assigned using competitive bidding within the 3550-3650 MHz portion of the band. The auction process has been defined with input from multiple rounds of public comment in the last two years. Each PAL is defined as a 10 year renewable authorization to use a 10MHz channel within a county. Up to seven total PALs may be assigned in any given county with up to four PALs going to any single applicant, or 40MHz of spectrum per county.

The GAA tier is licensed to permit open and flexible access to the band for a wide group of potential users including non-tradition operators and enterprises. GAA users are permitted to use any portion of the 3.5 GHz band not assigned to a higher tier user. The GAA users may use unused, previous assigned priority access channels. The SAS and ESC will help manage use across the geographic license area for each PAL The SASs should provide aggregated spectrum usage data to the public upon request.

2.1.1. CBRS Deployment and Business Case Considerations

CBRS PALs have features that make them attractive for predictable business planning. They do have a renewable 10-year term with the ability to partition and disaggregate PALs for more flexible use. The county-level, 10-year term makes CBRS more predictable from a business planning perspective.

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[7] https://www.fcc.gov/wireless/bureau-divisions/mobility-division/35-ghz-band/35-ghz-band-citizens-broadband-radio-service
[8] https://www.fcc.gov/document/fcc-acts-increase-investment-and-deployment-35-ghz-band-0
[9] https://www.google.com/get/spectrumdatabase/sas/
[10] https://www.cbrsalliance.org/news/cbrs-alliance-to-launch-ongo-commercial-services-in-3-5-ghz-cbrs-band/

However, they are still subject to preemption if a higher-tier user needs the spectrum. Mission-critical use cases should be mindful of preemption.

CBRS can be deployed as a rural and suburban FWA broadband solution. A 50Mbps capable FWA service should be possible at inter-site distances (ISD) of 5-7km, Figure 3, based on preliminary data[11]. PALs are appropriate for this type of FWA service to prevent interference and provide reliable service. This level of service is suitable for rural and suburban markets where the subs per sq-km is <5,000. The TDD spectrum can be tuned to favor the downlink (DL) and better match DL/Uplink (UL) usage patterns in a given area. This gives the flexibility to tune the sector for business customers who may have more symmetric DL/UL ratios. Enterprises can also create their own private networks using CBRS spectrum assuming a build on GAA channels or unused PALs.

Figure 3. Illustrative 3.5GHz CBRS deployment in a low to mid-density area to achieve 50Mbps service with 6.5km ISD

Source: Ericsson, inCode

2.2. C-Band 3700-4200MHz Overview

C-band spectrum has traditionally been reserved for satellite downlink and uplink. Earth stations are still in use, but unused spectrum can be put to use with a carefully crafted clearing and migration plan. The C-Band Alliance (CBA), a coalition of incumbent satellite companies which includes Intelsat, SES, Eutelsat, and Telesat, is the organization representing the interests of the incumbents and works closely with the FCC and industry to ensure all interests are represented.

CBA has been in active negotiations regarding how much spectrum could be made available. Up to 500MHz is available, but the CBA is signaling 150-200MHz could be available for auction. CBA proposed a plan in 2019 to migrate satellite customers to a narrow portion of the C-band spectrum to free

[11] Ericsson

up spectrum for a C-band auction. The NPRM for C-Band spectrum may have been approved at the FCC's July 2018 Open Meeting[12] under the intention of a flexible use spectrum policy, but progress has been slow to incumbent pushback and multiple public commentary periods[13].

2.2.1. C-Band Deployment and Business Case Considerations

The main challenge in C-band deployment is coming up with a spectrum clearing plan that works for both the incumbent satellite interests and the wireless industry interests. Spectrum clearing is complicated by needing to fund and launch satellites and potential migrations to fiber transit, in addition to finalizing an incumbent user migration plan.

Spectrum acquisition cost for the C-band spectrum could be 2x the PAL auction clearing price. The spectrum is valuable because of its high channel widths, up to 100MHz. Auction prices for C-band spectrum licenses could be in the $0.25-0.30/MHz-pop range for 100MHz licenses. Larger blocks of spectrum with motivated bidders could drive this up to $0.40/MHz-pop, but will likely remain around $0.25/MHz-pop due to the staged nature of the spectrum clearing and availability.

The C-band 3.7-4.2 GHz spectrum is actually the C-band downlink. There is an associated 5.925-6.425 GHz band known as the C-Band uplink which could also be in play. This 500MHz uplink is within the 1.2GHz wide 5.925-7.125 GHz ("6 GHz") band being considered for unlicensed spectrum use as part of the October 2018 NPRM[14]. Addition of these adjacent bands could make the currently planned C-band spectrum more valuable.

The cell site grid would be on par with the CBRS grid, but still denser than the 2.5GHz grid. Likely deployment approach would be to collocate C-band radios on existing macro or small cell towers and densify as needed based on pop density and cell edge performance specs. C-band would still be a lower deployment cost than mmWave and could still provide 500-1000Mbps service. C-band FWA service would benefit from outdoor mounted antennas for customer premise equipment (CPE). The band will like perform similar to CBRS, though the allowed power has not been set yet, and going from outdoor to indoor antennas could drop the DL line rate from 500 Mbps to 100 Mbps with the additional path loss.

2.3. BRS/EBS 2496-2690 MHz Overview

The 2.5GHz Broadband Radio Service / Education Broadband Service (BRS/EBS) spectrum is the single largest band of contiguous spectrum (194MHz) below 3GHz. This band was historically reserved for educational TV and Tribal Nations, but much of the spectrum has gone unused for more than twenty years, particularly in rural areas. Educational institutions largely use the internet for their broadcast needs. Sprint is the largest BRS/EBS spectrum lessee in the United States, holding nearly 80% of license leases. Sprint is the largest holder of license leases in the BRS band.

The 2.5 GHz band, which extends from 2496-2690 MHz, is comprised of 20 channels allocated for EBS, 13 channels allocated for commercial BRS, and associated guard band channels[15]. EBS licensees operate in 114MHz of the 2.5GHz band; the remaining 80MHz is assigned to the BRS, totaling 194MHz.

Currently, there are 1,300 EBS licensees holding 2,193 licenses. Many of these licensees don't use their spectrum, but the rules allow them to lease out their excess capacity to non-educational entities to use for

[12] https://www.fcc.gov/news-events/events/2018/07/july-2018-open-commission-meeting
[13] https://ecfsapi.fcc.gov/file/0719066596388/DA-19-678A1.pdf
[14] https://transition.fcc.gov/oet/ea/presentations/files/oct18/3.1-Rulemakings-JSP.PDF
[15] https://docs.fcc.gov/public/attachments/DOC-358065A1.pdf

non-educational purposes, e.g. Sprint. Sprint uses over 1000 BRS licenses and leases approximately 1500 of the 2,193 EBS licenses, or 68% of all EBS licenses at 2.5 GHz to service as the workhorse spectrum of its tri-band 3G/4G LTE network using 800 MHz, 1.9 GHz, and 2.5 GHz. These leases are authorized to have terms of up to 30 years and can contain rights of first refusal or purchase options helping Sprint's position when negotiating on distribution terms for the remaining leases and overlays.

2.3.1. BRS/EBS Deployment and Business Case Considerations

The 2.5GHz band can currently support significant capacity and throughput where deployed, including two- channel and three-channel carrier aggregation (CA), 2CA and 3CA, for up to 40MHz and 60MHz of spectrum, respectively. These CA profiles can provide 200-500Mbps of DL capacity on Sprint's existing site grid size.

Sprint is pushing to adopt counties, or Basic Trading Areas (BTA), and Partial Economic Areas (PEA), as the appropriate geographic service area unit for new overlay licenses. Almost all of the EBS license areas today are misshapen and irregularly configured which makes it difficult for deployment planning. This will benefit any of the new licensees or lessees as the network grid planning will be more predictable. The site deployment cost will be comparable to today's macro site colocation costs.

Spectrum acquisition costs for 2.5GHz have risen in the past 2 years as it became apparent that 5G deployments were in need of more mid-band spectrum. Sprint's 2.5GHz holdings were valued at $0.27/MHz-pop in 2016. Auction prices for the remaining licenses from the total 194MHz of BRS/EBS spectrum could be similar to Sprint's current 2.5GHz holdings valuation at $0.50/MHz-pop[16] if valued today. Future auctions for the remaining licenses could see a migration to a band plan with two sizes of licenses: a 100MHz block and a 16.5MHz block. This is still tbd, but makes the auction more valuable given the high channel widths that could become available in the mid-band.

3. Mid-band Use Case and Competitive Considerations

5G use cases have a chicken-and-the-egg dilemma. Will the use cases wait for the technology in its final form or will the technology continue to be designed to fit the envisioned use cases? We have an idea of what use cases could take off, but we are probably wrong. With 4G and LTE no one anticipated the age of apps that was created when the industry transitioned from 3G voice to 4G data. The iPhone release in 2007 ushered in the age of apps by rewarding innovation with capable mobile infrastructure. The 5G era will foster innovation, but the mash up of creativity will be driven by the capabilities of this new network, Figure 4. ITU defined the capabilities of 5G networks in the IMT-2020 standard. For now, we can imagine what a two-order of magnitude improvement in traffic capacity could look like and then match it up to use cases like immersive VR and 8k eMBB. The end use cases may be off, but the functionality is likely directionally right.

Near term use cases for mid-band spectrum on 5G will include improved mobile broadband, Mobile Virtual Network Operator (MVNO) offload, private networks, and FWA. CBRS is available now for use cases and more will be available following the PAL auction. Intra and inter-band carrier aggregation with other mid-band spectrum assets as they come on line will further complement these initial use cases.

[16] J.P. Morgan estimates.

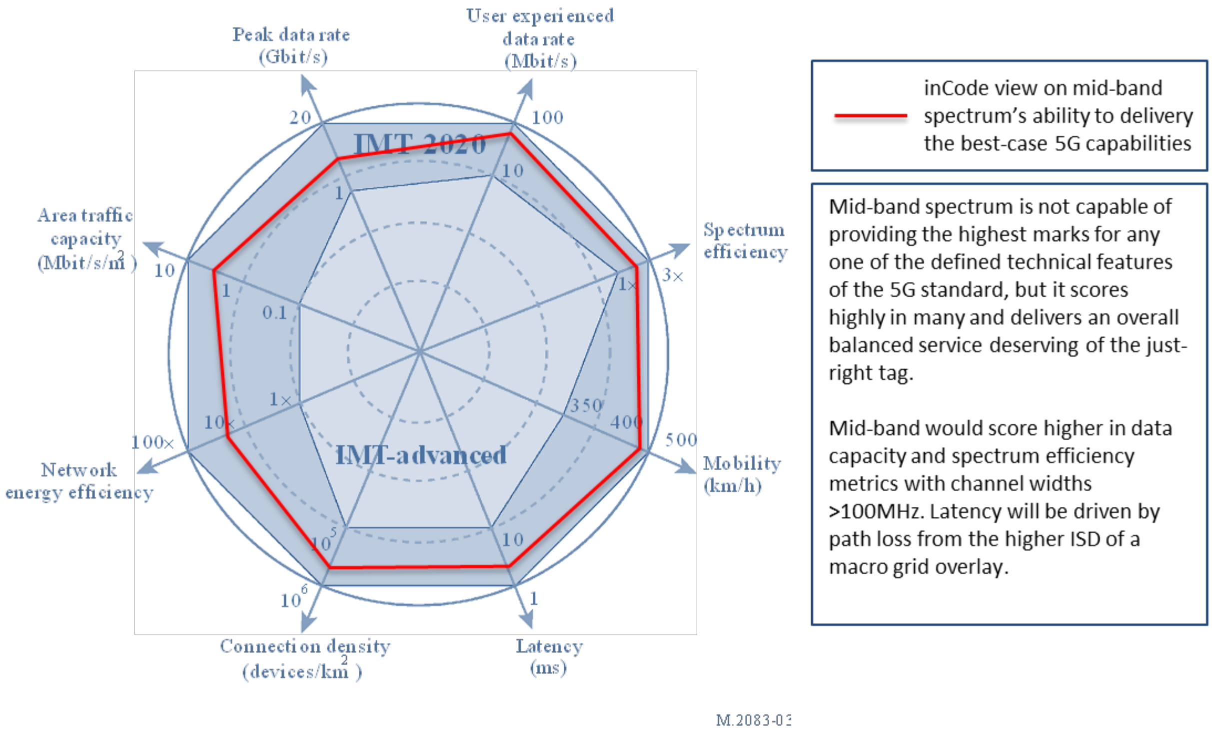

Figure 4. Enhancement of key capabilities from IMT-Advanced to IMT-2020 with a perspective on mid-band's ability to deliver the capability.

Source: Rec. ITU-R M.2083-0: IMT Vision - "Framework and overall objectives of the future development of IMT for 2020 and beyond"

The chart above depicts the expected increase in capabilities of the 5G network (IMT 2020) vs the 4.5 G network (IMT 2015). Peak data rates from 1-10 Gbps, high density IoT and single-digit latency are hallmarks of 5G. Improved traffic density and lower power consumption will also spur innovation in the realm of the possible with 5G networks. Mid-band spectrum is able to deliver all of these 5G capabilities at a high level, but maybe not as good as high and low band counterparts. High band spectrum with its 400MHz channels scores well for bandwidth, area capacity, and spectral efficiency, but lower for energy efficiency. Low band spectrum doesn't score well for capacity, but does well with the coverage metrics like Mobility. Mid-band spectrum balances both capacity and coverage metrics.

ITU had a use case view of the future of 5G that started with the overall objectives as simplified by the pillars of eMMB, Ultra Reliable Low Latency Communications (URLLC), and massive Machine Type Communications (mMTC), Figure 5. This way of defining the experience first helped shape how to design the technology.

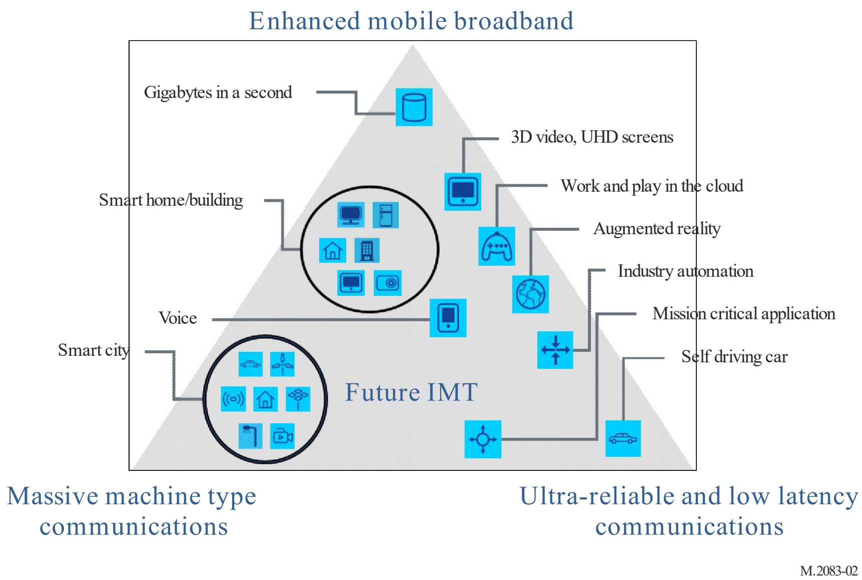

Figure 5. Usage scenarios of IMT for 2020 and beyond

Source: M.2083 : IMT Vision - "Framework and overall objectives of the future development of IMT for 2020 and beyond"

5G use cases need capable spectrum, often in 100MHz and greater blocks. Mid-band spectrum isn't required for 5G, but it helps. Mid-band spectrum can support 5G capabilities up to 5-7km inter-site distances on 20, 40, and 100MHz wide channels. Cell edge spectral efficiencies of 3-9b/s/Hz can deliver gigabit speeds with up to single digit latency as determined by the path loss. This combination enables a multitude of eMBB, FWA, AR, and VR use cases, Figure 6.

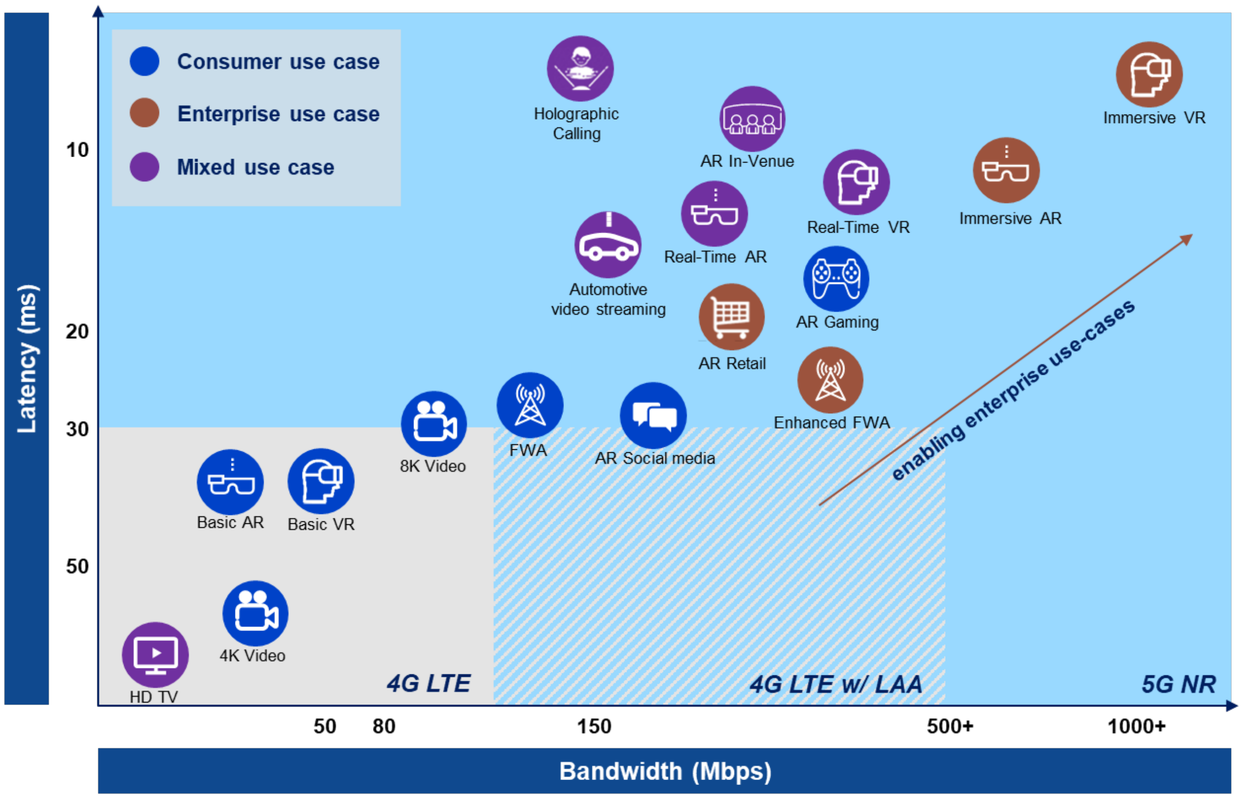

Figure 6. Latency and bandwidth requirements to deliver mobility use cases

Source: inCode analysis

Current 4G networks are able to support eMBB data sessions and basic AR/VR capability, but they lack the low-latency capabilities to drive these and related use cases forward. Mid-band spectrum is better suited for use cases requiring high mobile data usage over a wide area. The combination of wide spectrum channels and capable signal propagation eases network design and planning constraints when building for these types of use cases.

eMBB The eMBB use case shines with mid-band spectrum on 5G. It builds on top of what is already capable for improved mobile data services. Real world eMBB results in an urban environment show 300-500Mbps is capable now on B4 LTE with B46 licensed-assisted access (LAA), giving optimism to 5G FWA use cases on mid-band spectrum. The LAA unlicensed band support benefits eMBB and high data usage use cases. LAA provides support for up to two licensed plus three unlicensed carriers enabling speeds above 1 Gbps[17]. T-Mobile US is using LAA capabilities today to transmit 4G LTE signals over unused 5GHz Wi-Fi channels to widen its available bandwidth when aggregated with its existing spectrum, Figure 7. T-Mobile is using 2CA up to 5CA carrier aggregation profiles of combine 20MHz channels of its 1700MHz/2100Mhz AWS Band 4 spectrum with three 20MHz channels of U-NII band 5GHz LAA spectrum. Mobile devices connect to the cell site and send UL data using the B4 spectrum, and then get DL data from a combination of B4 and LAA.

[17] Source: LAA, Ericsson - https://www.ericsson.com/en/portfolio/networks/ericsson-radio-system/radio-system-solutions/licensed-assisted-access

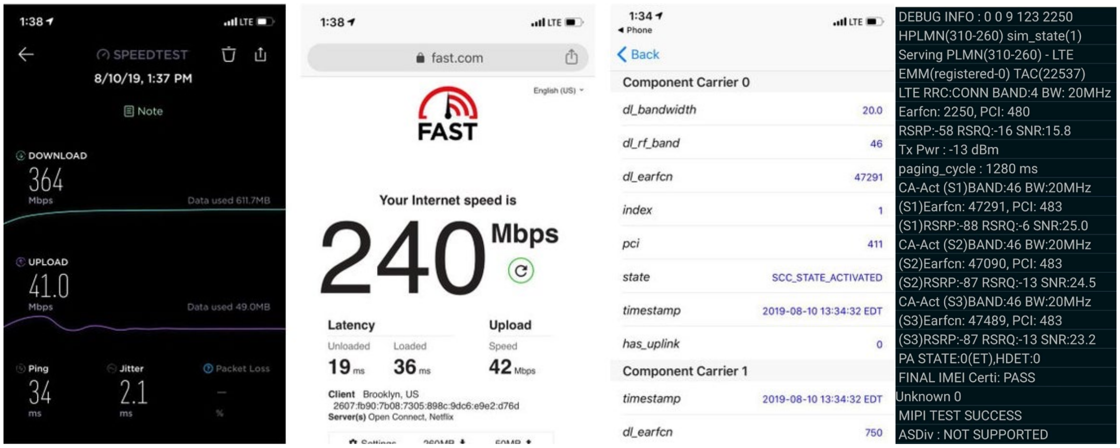

Figure 7. Urban eMBB use case on 20MHz of B4 LTE and 60MHz of B46 LAA

Source: Ookla, T-Mobile LAA profile in NYC demonstrating 300Mbps mobile broadband with 4CA of 20MHz of B4 and 60MHz of B46.

T-Mobile LAA on LTE today provides 300-500Mbps mobile broadband speeds on a 4CA to 5CA carrier aggregation profile with U-NII band B46 spectrum and its licensed bands. 5G NR on Rel.16 works to move LAA capabilities up to 1 Gbps with greater carrier aggregation and improved spectral efficiency.

FWA, is another use case where high bandwidth over a wide area is needed. We can look at rural, suburban, and urban FWA use cases with targeted DL bandwidth of 50, 100, and 300 Mbps, respectively, to evaluate the suitability of mid-band spectrum for this application.

> **Rural FWA** deployments are typically low-density RAN buildouts on macro towers with line-of-sight (LoS) top-down deployments. Delivering a 50Mbps DL product with 50-75ms latency can be done on 4G LTE with low band TDD spectrum today with indoors CPE given a couple 10MHz channels. This approach is more challenged with higher adoption rates, CPE shift from the edge to the center of the home, or the served location is at the cell edge. Mid-band spectrum on 5G can help provide wider channels with improved spectral efficiency for better cell edge performance. CPE should be mounted outdoors to prevent excessive path loss. 40-60MHz of mid-band spectrum should be sufficient.

> **Suburban FWA** is a medium-density RAN build but still on macro towers with LoS. Competitive FWA offers should be able to provide a 100Mbps product with 50ms latency. Mid-band spectrum with 3-5b/s/Hz cell edge spectral efficiency and 2-3 simultaneous attached users (SAU) per sector translates to a need for 100MHz of mid-band spectrum minimum. This is achievable in the US with just over 500MHz of mid-band spectrum available for use in the next few years. If the operator has ~20-40MHz of spectrum available from existing holdings then ~60-80MHz of new spectrum would be needed to enable this use case pending available carrier aggregation profiles. Mid-band spectrum on 5G is the best approach here as mmWave would be too expensive to build out in suburban areas.

> **Urban FWA** use cases are typically high density RAN builds, often with small cells and non-line-of-sight situations. Offering a 300Mbps+ product with 5-10ms latency requires wide channels and a densified network site plan. mmWave spectrum with 3-7b/s/hz cell edge spectral

efficiency and 4-5 SAUs per sector translates to a required range of 300-500MHz total mmWave spectrum width less what can be aggregated from existing holdings. This is very likely with a mmWave 5G deployment, but the sites would need to have a <250m ISD to allow for handoffs without downgrading to 4G. This could be done with mid-band spectrum given the right channel width holdings or augmented with three B46 LAA channels. A mid-band build in an urban area would be at a lower cost than then much denser mmWave network build. Operators with owners economics on existing dense fiber networks in urban areas can offset some of the build cost for mmWave networks.

4. Business Model Considerations

4.1. Cost Considerations

The two main categories associated with mid-band spectrum deployment are getting the spectrum, and putting it to use. Each of these and their associated drivers go in the business model when planning for deployment

Spectrum acquisition costs, $/MHz-pop or licensing costs, will be a key entry cost for mid-band spectrum deployment. However, the largest cost could be cell site densification to support mid-band spectrum pending the operator's existing grid. The existing tower grid for US operators average 12km between their macro tower sites outside of urban centers. This ISD drops to 0.6km for tower sites in and around urban centers on average. The 12km ISD works for 600MHz, 700MHz, Cellular, AWS, and PCS frequencies, but B41 2.5GHz would require densification to maintain higher data rates in rural deployments. The B41, CBRS B48 3550-3700, and higher mid-band spectrum should have ISDs in the 1-4km range depending on the cell edge performance needs. Some densification may be needed outside of urban centers, but existing sites in most urban centers should have adequate ISDs to provide both coverage and capacity on mid-band spectrum. Densification provides the added benefit of more spectrum reuse opportunities for efficient radio resource use for cell area covered pops.

Transmit power regulation on mid-band spectrum is a key factor in setting the grid size. CBRS has class B base stations for outdoor use which have a maximum Equivalent Isotropically Radiated Power (EIRP) of 47 dBm or about 50 watts. Unlicensed U-NII WiFi mid-band spectrum for outdoor point-to-point and point-to-multipoint is governed by FCC Part 15 rules[18] and maxes out at 30dBm or about 1 watt. Current licensed spectrum in the 2GHz range is allowed to transmit at a higher EIRP of up to 62 dBm. This translates to about 6-7km lower ISD for CBRS implying densification needs for macro towers.

Any densification needed for mid-band spectrum is far less than the densification needed for mmWave spectrum deployments. Spectrum starting in the 24GHz and 28GHz frequencies will need ISDs on the order of city blocks, or <200m, as seen with Verizon's 5G April 2019 launch in downtown Chicago.

4.2. Mid-band Deployment Cost Drivers

There are many variables to consider when evaluating the operational and business costs of mid-band spectrum deployment. We'll look at a few key primary and secondary drivers for mid-band spectrum deployment cost variability.

[18] eCFR Part 15

4.2.1. Primary drivers for mid-band deployment cost variability

1. **Spectrum band** – Propagation and path loss characteristics vary by frequency. Migration from 600MHz to 2.5GHz to 3.5GHz to 24GHz bands drops the ISD by 59%, 22%, and 75%, sequentially. A cell site grid set up for 2.5GHz can more easily colo 3.5GHz radios than mmWave radios. Mid-band spectrum would need 2-3x densification over low band, while mmWave would need 10-12x densification over low band spectrum[19]. Each band has its corresponding transmit power requirements for base stations. Lower power means more cells sites are needed.
2. **Channel width** - Impacts the number of sites needed for densification. Depends on cell edge traffic throughput requirements. Ranges from 5MHz FDD up to 100Mhz TDD wide channels. FDD vs TDD impacts the asymmetry of a band where paired spectrum cannot respond to DL/UL asymmetry. Aim for 100MHz of mid-band spectrum to deliver many of the 5G use cases. CBRS will have up to 70MHz available for PAL with flexible use provisions for additional channels. The C-band 3.7-4.2GHz could free up 200MHz channels for operators pending release details. inCode's view is it will take a combination of low, mid, and high band spectrum to deliver the full capabilities of 5G, but many use cases will benefit from having at least 100 MHz of mid-band spectrum available for use. These 100MHz and wider channels make massive multiple-input and multiple-output (MIMO) possible.
3. **Carrier aggregation profiles** – CA profiles supported by 3GPP and the operator control what frequencies are available for signal modulation. Greater intra-band and inter-band CA aggregation creates wider channels and lowers the deployment costs.
4. **Spectral efficiency** - Cell edge vs cell best-case differs greatly due to path loss. Cell edge can vary from 1b/s/Hz to 7b/s/Hz now while 7-11b/s/Hz is achievable closer to the cell site. Holding other factors constant, moving from 2.5GHz spectrum to 24GHz spectrum increases the spectral efficiency 57% due to supporting higher orders of modulation on wider channel widths. Low band spectrum blocks typically have lower channel widths where side guardbands are a higher percentage of the overall channel width. Lower spectral efficiency means more cell sites are needed for a given level of service.

4.2.2. Secondary drivers for mid-band deployment cost variability

1. **Indoor vs outdoor antennas -** Mid-band spectrum will struggle with in-building penetration due to its power and propagation characteristics. Best to plan for outdoor antenna mounts for fixed wireless applications and use LAA profiles for mobility use cases. Mid-band spectrum fairs better than mmWave when it comes to going through windows and walls. Millimeter wave spectrum is blocked by the thin, reflective coating on low emissivity, or low-e, glass preventing indoor usage of 5G devices on these bands. Even 2.5GHz spectrum struggles to get into buildings. The 3.5GHz CBRS spectrum can get 50Mbps with outdoor mounted antennas in a rural deployment, but this number drops to less than 10Mbps when the CPE is placed indoors. Indoor CPE path loss is further hindered by CPE placement, often in the center of the structure to aid the WiFi signal emitted from the CPE. Mobile UEs have the same problem and require increase radio resource allocation to maintain a given DL/UL bit rate
    a. A correctly installed outdoor CPE is directed to the best serving cell site, leading to a lower link budget path loss and increasing the value of mid-band and mmWave TDD spectrum. Macro sites above the canopy or small cells below the canopy can be LoS to outdoor antennas. This is the recommended approach.

[19] Ericsson

   b. Outdoor antennas deliver a large gain in signal quality as a result of the 10dB difference in antenna gain and the avoidance of 10–15dB in wall or window attenuation losses suffered by indoor devices.
   c. Another contributor to signal attenuation in indoor devices is the deep indoor loss, as the device is likely to be placed in a hidden location or interior location to provide optimum Wi-Fi coverage. This could contribute another 5dB in path loss.
   d. An indoor CPE is comparable to a smartphone in terms of spectrum efficiency. An outdoor antenna / indoor CPE combo is 2-3x more efficient. For the same data consumption rate, around 2-3x as many HHs can be served using outdoor rather than indoor units. And consequently, 2-3x as much spectrum is needed to serve indoor-only FWA households.
2. **LoS vs nLoS** – Line of sight is preferred, but not always possible. Outdoors non-line of sight (nLoS) benefits from beamforming and more capable phase array antennas. Multi-path MIMO improvements also benefit the higher ISD of mid-band spectrum
3. **Urban vs rural** – Area traffic capacity support improves two orders of magnitude with the migration to 5G. Mid-band spectrum propagates this benefit over a broader area. Urban areas are better positioned to benefit from 5G, but it requires densification. Urban clutter reflectance makes RF planning easier for mid to high bands because of beam forming and steering capabilities.
4. **DL loading** – Site densification varies with DL loading. Densification is required once DL loading approaches 100%. RF resource blocks get depleted at the site due to traffic increase and more users and traffic equals more required resource blocks.
5. **Busy hour traffic hours** – Sets the triggers for bandwidth management and service expectations. Determines worse-case capacity scenarios and minimum planning thresholds.
6. **Device and handset compatibility and availability** – Business cases on mid-band spectrum should consider UE availability for a given spectrum band. Baseband compatibility for 2.5GHz devices is more available than CBRS and C-band device due to Sprint's presence in that band for many years. There are 100s of 2.5GHz SKUs, but only 10s of CBRS SKU's in the market today[20]. The Google Pixel3 and Samsung S10 support CBRS.

4.3. Mid-band Spectrum Revenue Benefit

Revenue benefits from mid-band spectrum 5G services will likely be driven by eMBB use cases at first followed by cross-sell and up-sell to experience-based benefits enabled by 3GPP Rel.16. To date, the US market has not successfully monetized 5G. Mainly because it is still seen as more-capable eMBB, but still unproven. SK Telecom has been successful at monetizing 5G based on the experience benefit it provides to gaming packages. Mid-band spectrum for 5G can drive some of this experience benefit by completing the low / mid / high band mosaic for service delivery and ensure service continuity for coverage, capacity, and latency needs. CBRS is called the Innovation Band. New business models and revenue follow innovation.

[20] https://www.gsmarena.com

Conclusion

In conclusion, mid-band spectrum for 5G is justified in having the just-right Goldilocks moniker. It is at the sweet spot of coverage and capacity for 5G deployments. The challenge will be getting enough 2.5-8GHz spectrum out into the US market in time for the 5G use cases to benefit. Many 5G use cases will need a combination of >100MHz spectrum channels, single-digit latency, and wide area coverage. Mid-band spectrum in the US is capable of meeting these criteria pending its availability schedule. The FCC is working with the industry to secure the deployment of additional mid-band spectrum to close this gap in the US spectrum portfolio. Companies should pursue mid-band spectrum acquisition to complement their existing spectrum portfolios.

Abbreviations

3GPP	3rd Generation Partnership Project
5G	5th generation cellular network technology
AR	Augmented Reality
AWS	Advanced Wireless Services
BRS/EBS	Broadband Radio Service / Education Broadband Service
BTA	Basic Trading Area
CA	Carrier Aggregation
CBA	C-Band Alliance
CBRS	Citizens Broadband Radio Service
CPE	Customer Premises Equipment
DL	Downlink
EDGE	Enhanced Data rates for GSM Evolution
EIRP	Equivalent Isotropically Radiated Power
eMBB	enhanced Mobile Broadband
ESC	Environmental Sensing Capability
FAST	Facilitate America's Superiority in 5G Technology
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FWA	Fixed Wireless Access
GAA	General Authorized Access
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HH	Households
HSPA	High Speed Packet Access
IMT	International Mobile Telecommunications
IoT	Internet of Things
ISD	Inter-Site Distance
ITU	International Telecommunication Union
LAA	License Assisted Access
LoS	Line of sight
LTE	Long-Term Evolution
MIMO	Multiple-Input and Multiple-Output
mMTC	massive Machine Type Communications
mmWave	Millimeter Wave
MSO	Multiple-System Operator
MVNO	Mobile Virtual Network Operator
nLoS	Non-line of sight
NPRM	Notice of Proposed Rulemaking
NR	New Radio
PAL	Priority Access License
PCS	Personal Communications Service
PEA	Partial Economic Area
Pop	Population
RAN	Radio Access Network

SAS	Spectrum Access System
SAU	Simultaneously Attached Users
SKU	Stockkeeping unit
SMR	Specialized Mobile Radio
TDD	Time Division Duplex
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications Service
U-NII	Unlicensed National Information Infrastructure
URLLC	Ultra Reliable Low Latency Communications
V2X	Vehicle to everything
VR	Virtual Reality

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