Before the
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
Washington, D.C.

In the Matter of Development of a National Spectrum Strategy	Docket No. NTIA-2023-0003

COMMENTS OF 5G AMERICAS

5G Americas, the voice of 5G and beyond for the Americas, submits these brief comments and an attached white paper in response to the NTIA's Request for Comments ("*RFC*") in the above-referenced proceeding concerning the development of a National Spectrum Strategy.[1] 5G Americas is an industry trade organization composed of leading telecommunications service providers and manufacturers. The organization's mission is to facilitate and advocate for the advancement of 5G and beyond throughout the Americas. 5G Americas is invested in developing a connected wireless community while leading 5G development for all the Americas.[2]

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[1] *See* Development of a National Spectrum Strategy, 88 Fed. Reg. 16244 (Mar. 16, 2023) ("NSS RFC").

[2] Currently chaired by T-Mobile US, 5G Americas' Board of Governors includes Airspan Networks, Antel, AT&T, Ciena, Cisco, Crown Castle, Ericsson, Liberty Latin America,

5G Americas applauds NTIA for launching its National Spectrum Strategy. Your Strategy, along with an implementation plan that includes a spectrum pipeline, can provide investment certainty by identifying the specific frequency bands where regulatory and possible legislative action is planned. 5G Americas encourages NTIA to prioritize the lower range of frequencies in the mid-band range, as they will benefit users the most. Lower range mid-band such as spectrum in the range of 3 – 8 GHz will help with coverage layer for both 5G and 6G.

To assist NTIA in this important work, 5G Americas submits its recently published white paper, *Mid-Band Spectrum Update*.[3] As NTIA can appreciate, mid-band spectrum, from 1 – 6 GHz, is particularly valuable for the mobile industry. Mid-band spectrum provides a balance of speed, capacity, coverage, and penetration for cellular wireless networks. Other ranges, such as Millimeter wave (mmWave) and other high bands, will also play a key role in servicing capacity demands, where offloading requirements from the mid-band spectrum can occur when and where needed. But because mid-band spectrum works exceptionally well for densely populated metropolitan areas where connectivity demand is high, adequate amounts of spectrum in that range is imperative for U.S. connectivity and economic goals.[4]

The attached white paper provides an overview of current and potential new mid-band and extended mid-band spectrum availability in the United States over the next several years, including technical characteristics and challenges of particular bands, as well as the policy and

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Mavenir, Nokia, Qualcomm, Samsung, Shaw, Telefónica, VMware, and WOM. *Board of Governors*, 5G Americas (last visited Apr. 17, 2023).

[3] 5G Americas, *Mid-Band Spectrum Update* (2023), https://www.5gamericas.org/wp-content/uploads/2023/03/Mid-Band-Spectrum-Update-2023-Id.pdf.

[4] *See* NSS RFC at 16246 ("What factors should be considered in identifying spectrum for the pipeline?").

regulatory landscape facing them.[5] The paper addresses a number of bands, including 1300 – 1350 MHz, 1780 – 1850 MHz, 3100 – 3450 MHz, 4400 – 5000 MHz, 7125 – 8500 MHz, 10 – 10.5 GHz, 10.7 – 12.2 GHz, 12.2 – 12.7 GHz, and 12.7 – 13.25 GHz. The amount and the type of spectrum impacts the network's capabilities, and these mid-band and extended mid-band ranges can deliver the combination of capacity and coverage necessary to meet smartphone users' expectations as connectivity demand increases, as well as support 5G Advanced and 6G use cases as those technologies are deployed.

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April 17, 2023

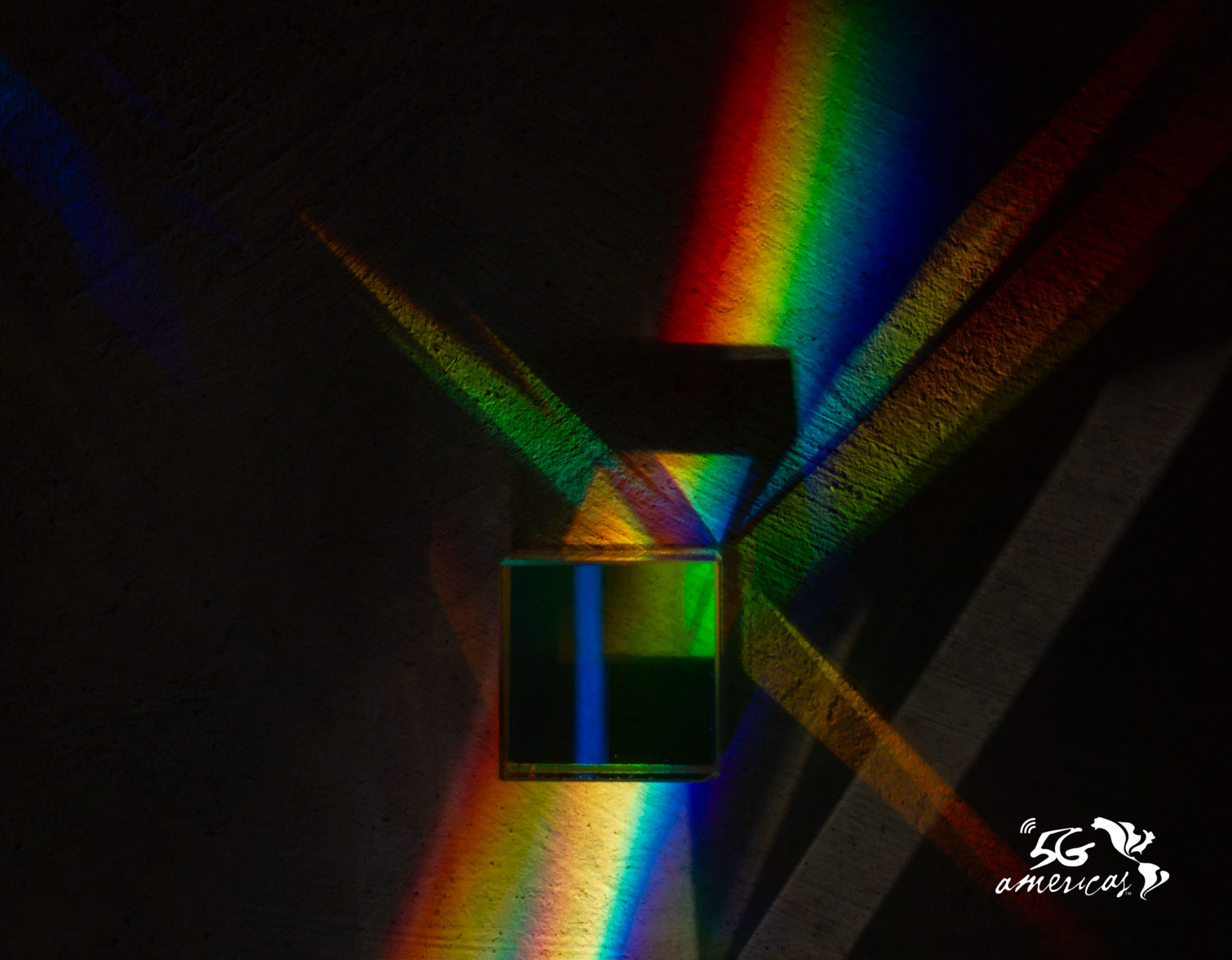
Attachment: 5G Americas *Mid-Band Spectrum Update* (March 2023)

[5] *See* NSS RFC at 16247 ("Are there any specific spectrum bands or ranges to be looked at that have high potential for expanding and optimizing access?").

MID-BAND SPECTRUM UPDATE

A 5G Americas White Paper

Mar. 2023



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Executive Summary

5G, the "fifth generation" of wireless cellular technology, offers a vast range of capabilities compared to the previous generations of mobile technology. The high capacity and low latency of 5G communications allow not only for enhanced wireless broadband with ultra-high speeds, but also for additional functionalities and a wide range of optimized services that take advantage of this new interface. 5G technology expands the value of mobile networks by enabling new mobile services into new industries and connecting devices and people across an array of new applications. It can also help close the digital divide where people do not have access to the latest technology or decent connectivity.

However, the increasing demand of data traffic and subscriber growth requires new levels of spectral efficiency and flexibility. Massive MIMO, adaptive antenna technology, and other spectral efficiency techniques continue to evolve to support operators with access to deliver a powerful 5G experience to its consumers nationwide. Yet, technology alone is not enough to meet the consumer demand for higher speeds and enhanced user experiences.

What's required is spectrum: the key ingredient for any wireless technology. The amount and type of spectrum available to a network can impact its capabilities, and 5G networks require access to multiple ranges of frequency bands—from low, mid to high. While low-bands are the foundation for every network, they do not meet all the service requirements for more advanced use cases, including those that require higher performance and capacity per user or higher densities of users. These use cases are better supported by spectrum in the mid-band or extended mid-band.

Worryingly, there are currently no bands in the spectrum pipeline in the United States as of March 2023. Because identification, allocation and repurposing of spectrum is a multiyear process, the lack of spectrum in the pipeline is a critical concern. A spectrum pipeline can provide investment certainty by identifying the specific frequency bands where regulatory and possible legislative action is planned. Such a pipeline can also ensure that spectrum considerations are receiving the proper attention to make spectrum available for commercial uses in the proper timeframe. Without such a plan, Congressman Frank Pallone Jr. stated that the "U.S. risks falling behind our counterparts by failing to replenish the commercial spectrum pipeline."

This white paper provides an overview of current and potential new mid-band and extended mid-band spectrum availability in the United States over the next several years, including technical characteristics and challenges, as well as policy and regulatory landscape. The realization of new bands in these spectrum ranges depends on several developments, including studies and solutions for coexistence with incumbent services[1].

1. Introduction

5G supports a myriad of use cases, typically ones that require higher throughput, lower latencies, and much higher capacity on an operator's network than compared to the past generations. For that reason, 5G continues to be the fastest growing generation of mobile connectivity technology in history. At the end of 2022, global 5G wireless connections surpassed 1.1 billion. Connections to 5G networks have, on average, doubled every year since its commercial inception in late 2018, according to 5G Americas and data from Omdia.

With 75 countries reporting 5G connections, 433 million global 5G connections were added from Q3 2021 to Q3 2022, almost doubling connections from 489 million to 922 million. Global 5G connections are forecasted to accelerate in 2023, approaching 2 billion and reaching 5.9 billion by the end of 2027.

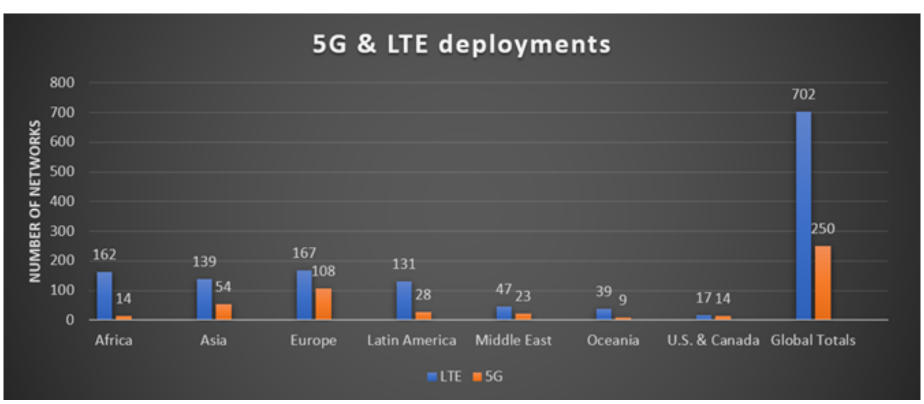
North America is a leader in the uptake of wireless 5G connections, with a total of 108 million 5G and 506 million LTE connections by the end of Q3 2022. 5G penetration of the population in the North American market is approaching 30 percent, as the region added 14 million 5G connections for the quarter–a gain of 15.47 percent over Q2 2022. Overall, a total of 137 million 5G connections is projected to come from North America by the end of 2022, bolstered by strong 5G smartphone shipments in the U.S.

Overall, the number of 5G commercial networks globally has reached 250, according to data from TeleGeography and 5G Americas. That number is expected to reach 397 by the end of 2025 representing strong 5G network investment growth in many regions throughout the world. The number of 5G and 4G LTE network deployments as of December 14, 2022, are summarized in Figure 1.1.

However, the growth of mobile connections has also led to extreme growth in demand for mobile data. At the end of 2022, total global demand for mobile network data traffic stood at 90 exabytes per month and is increasing at 40 percent annually, requiring new levels of spectral efficiency and flexibility for 5G and future networks. Past networks have been designed with low-band spectrum in mind, which do provide deep coverage, but falls short of providing the extreme capacity that is required by 5G. Mid-band spectrum is the sweet spot that provides a combination of higher capacity and coverage.

The rest of this paper discusses the current and potential new mid-band options available in U.S., coexistence considerations for mid-band, characteristics of mid-band spectrum and how can we evolve it towards best coverage and what tools are available to maximize the use of this spectrum.

Figure 1.1[2]: 5G & LTE Global deployments (Dec 2022)



2. Mid-Band Spectrum Overview

5G networks require access to multiple ranges of frequency bands from low, mid to high. Access to all three frequency ranges is essential for because they allow operators to optimize their networks based on environmental and network coverage, and capacity targets. High-band frequencies (mmWave) offer large bandwidths that can carry sizeable swaths of data with very low latency. However, high-band spectrum does not provide the of miles of coverage supported by low-band spectrum. While low-band spectrum offers better coverage and penetration, it lacks the greater bandwidth available in the millimeter wave bands.

Mid-band spectrum is tailor-made for 5G deployments by offering a sweet spot between coverage and capacity. Mid-band spectrum usually refers to the frequencies between 1 GHz and 7 GHz[3]. Mid-band spectrum provides stable coverage and much higher capacity than low-band spectrum for 5G connectivity, and can support a significant amount of data over long distances. In this way, the mid-band 5G deployments balance both connection speed and range, making it suitable for urban, suburban and rural areas. For example, in the 2.5 – 4.2 GHz portion of the mid-band, 5G can deliver speeds ranging from 100–900 Mbps to a single connected wireless client–speeds greater than that provided to many homes served via cable and fiber[4]. Because of the favorable propagation characteristics, mid-band deployments can support service beyond urban centers and inside buildings with a reliable Quality of Service (QoS).

The higher performance and improved efficiency of 5G technology supports important use cases, especially when used in mid-band spectrum. For instance, 5G promises to close the digital divide in many areas where people do not have access to the adequate connectivity. Private 5G networks for industrial IoT is another use case where the unique capabilities of 5G along with the mid-band propagation characteristic allow for high reliability, low latency, high capacity and coverage, all with improved network security. These capabilities make mid-band spectrum useful for healthcare applications and medical equipment communications.

Around the world, regulators have been appropriately focusing on freeing up mid-band spectrum for 5G deployments. However, in the United States, the need for additional mid-band spectrum in the pipeline is acute. Chair of the U.S. Federal Communications Commission (FCC) Jessica Rosenworcel noted, “we need mid-band deployments at scale to foster invention in the new spectrum frontier.”[5]

2.1 Current and Potential New Mid-band and Extended Mid-band Spectrum

This section provides an overview of current and potential new mid-band and extended mid-band spectrum availability in the United States over the next several years, including technical characteristics and challenges, as well as policy and regulatory landscape. The realization of new bands in these spectrum ranges depends on several developments, including studies and solutions for coexistence with incumbent services.

2.2 1300 – 1350 MHz

Currently, 30 MHz of the 1300 – 1350 MHz band is targeted by the National Telecommunications and Information Administration (NTIA) & FCC for clearance[6]. The 1300 – 1350 MHz band is used by federal agencies for operating various types of long-range radar systems that perform missions critical to safe and reliable Air Traffic Control (ATC) in the national airspace, border surveillance, early warning missile detection, and drug interdiction. A multi-agency initiative is underway to explore the feasibility of altering the Federal Aviation Administration’s (FAA) long-range radars operating in the 1300 – 1350 MHz sub-band, which could include relocating them to another band.

Relocating these radars from the band would likely significantly improve the potential for sharing with commercial services. In fact, the federal agencies involved in the initiative propose utilizing funds from the Spectrum Relocation Fund to study the possibility of relocation consistent with the Spectrum Pipeline Act of 2015. Congress has allocated at least 30 MHz of low-band spectrum to be auctioned for license use by 2024, and that the national spectrum strategy should announce at least 100 MHz of low-band spectrum be auctioned by 2024. The 1300 MHz band would provide 50 MHz of spectrum for next-generation wireless services, and the proceeds of that auction will help the FAA and other incumbent users to modernize radar and related systems[7].

2.3 1780 – 1850 MHz

As of March 2012, more than twenty federal agencies utilized over 3,100 individual frequency assignments in the 1755 MHz – 1850 MHz band. Primary uses of the band included fixed point-to-point microwave, military tactical radio relay, air combat training systems, precision guided munitions, tracking telemetry and commanding, aeronautical mobile telemetry, video surveillance, unmanned aerial systems, and other Department of Defense (DoD) systems including electronic warfare, software defined radio, and tactical targeting networking technology.

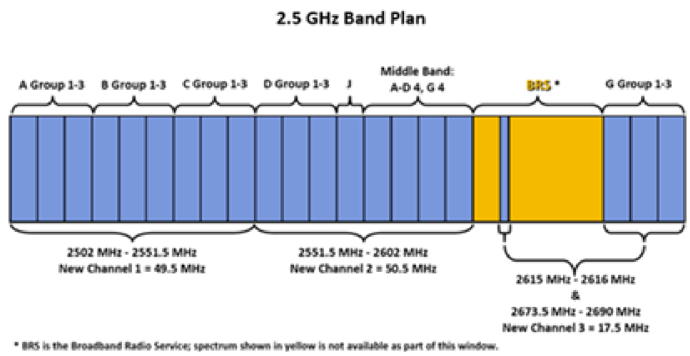
In 2014, the 1755 MHz – 1780 MHz band was auctioned for commercial use as part of the AWS-3 auction. After the auction, some systems operating over the entirety of the 1755 MHz – 1850 MHz band were re-tuned to operate solely in the 1780 MHz – 1850 MHz portion of the band. It is important to determine how to work with the federal systems in the 1780 – 1830 MHz segment if it is to be made available for future cellular use. The 1700 MHz band is 50 MHz directly adjacent to the AWS-3 spectrum that was auctioned in 2015, and offers great synergies with existing wireless offerings. Both commercial and government users share a solid understanding of the affected government systems which will help facilitate a smooth transition[8].

2.4 2.5 GHz band (2496 – 2690 MHz)

The FCC concluded Auction 108 at the end of August 2022 where a total of 63 bidders won licenses out of 83 qualified bidders, and 8,017 geographic overlay licenses were made available. The gross proceeds totaled $427M, and three blocks of spectrum (49.5 MHz, 50.5 MHz, and 17.5 MHz blocks) were licensed on a county basis. This contiguous mid-band spectrum will help further extend 5G service beyond most populated areas.

Auction 108 concerned overlay licenses, where licensees obtain the rights to geographic area licenses "overlaid" on top of the existing incumbent licenses. As with an ordinary flexible-use license, the overlay licensee may operate anywhere within its geographic area, subject to protecting the licensed area of incumbent licensees[9].

Figure 2.1: 2.5 GHz Band Plan[10]



2.5 3100 – 3550 MHz

The FCC and the NTIA have been working to create opportunities for commercial use in the 3100 – 3550 MHz spectrum range. The range has allocations for both federal and non-federal services. The DoD uses the entire band for operating high- and low-powered defense radar system on various platforms including shipborne, land-based, and aeronautical mobile radar systems for national defense purposes.

In July 2020, NTIA submitted a report[11] to Congress, pursuant to the MOBILE NOW Act[12], that examined the shared use of spectrum between federal incumbents and commercial wireless services in the 3100 – 3550 MHz band. While priority was enabling spectrum sharing in the upper 100 MHz portion of the band, other options for the entire band have been under consideration, including relocation of some incumbents.

After years of effort, an agreement was reached to relocate many federal incumbent systems below 3450 MHz to facilitate nationwide commercial service in the upper 100 MHz portion of the 3100 – 3550 MHz spectrum range (adjacent to CBRS). The 3450 – 3550 MHz band was auctioned in January 2022, but there is ongoing work[13] to open up more spectrum in the 3100 – 3450 MHz range for commercial use.

2.5.1 3100 – 3450 MHz

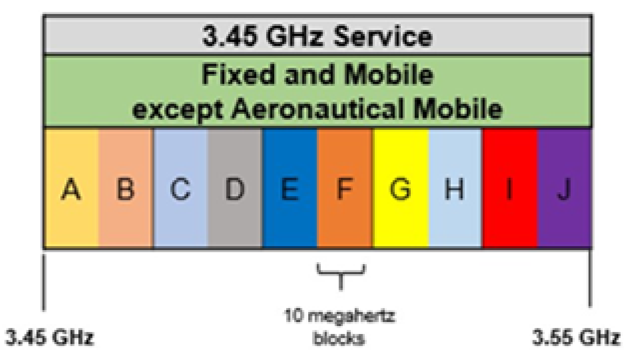
Currently this entire band is allocated on a primary basis to the federal radiolocation service. The lower portion of the band, 3100 – 3300 MHz, also has secondary allocations to federal and non-federal Earth exploration-satellite (active) and space research (active) services, as well as non-federal radiolocation service.

The DoD operates high-powered defense radar systems on fixed, mobile, shipborne, and airborne platforms in this band. Some operations are limited to specific areas, others are nationwide. Coexistence with these systems can be challenging. There are ongoing efforts involving government and industry (the National Spectrum Consortium [NSC][14]) to further explore dynamic spectrum sharing technologies that could be used in this band. In addition to a lighter spectrum utilization, 3300 – 3450 MHz band would benefit from existing ecosystems (3GPP bands n77 and n78).

2.5.2 3.45 GHz band (3450 – 3550 MHz)

The 3450 – 3550 MHz band was auctioned for commercial 5G use in January 2022. This band is allocated on a primary basis to the federal radiolocation service, and to the non-federal fixed and mobile except for aeronautical mobile services on a nationwide basis. There is also allocation to federal Aeronautical Radionavigation Service (ground-based) in the 3500 – 3550 MHz range.

Figure 2.2: 3.45 GHz Band Plan[15]



The DoD operates high-powered defense radar systems on fixed, mobile, shipborne, and airborne platforms in this band. These radar systems are used in conjunction with weapons control systems and for the detection and tracking of air and surface targets. The DoD also operates radar systems used for fleet air defense, missile and gunfire control, bomb scoring, battlefield weapon locations, ATC, and range safety. The shipborne radars operate at over twenty ports and along the entire Atlantic, Pacific, and Gulf coasts. Some of the airborne systems operate nationwide, while other systems are limited to four locations. The ground-based radars operate at over one hundred locations, with many located near high-population areas. DoD also uses this band for testing and training infrastructure and activities.

Coexistence with Federal Use

Generally, non-federal systems have unencumbered operations in the entire band across the contiguous United States territory, except in some specific areas (military training facilities, test sites, shipyards) defined as Cooperative Planning Areas (CPAs) and Periodic Use Areas (PUAs). In CPAs and PUAs, federal systems will be allowed to continue operating in the band, but will require coordinated, shared spectrum usage. PUAs overlap with 23 of the 33 identified CPAs. These CPAs employ episodic use where the DoD will occupy all or part of the band. It is estimated that the total area of all CPAs covers about 13 percent of the continental United States, and includes 19 percent of the total population. Non-federal systems will not be precluded from operations in CPAs and PUAs, but coordination will be required prior to commercial access to those areas via a DoD online portal.

Last year the FCC held Auction 110 for the 100 MHz of spectrum in the 3.45 GHz band. Prior to auction, the DoD and NTIA had identified radar locations that need protection and coordination with wireless services. These were defined under Cooperative Planning Areas (CPAs) and Periodic Use Areas (PUAs).

Cooperative Planning Areas (CPAs)

CPAs are geographic locations in which non-federal operations shall coordinate with federal systems in the band to deploy non-federal operations in a manner that shall not cause harmful interference to federal systems operating in the band. Operators of non-federal stations may be required to modify their operations to protect federal operations against harmful interference and, where possible, to avoid interference and potential damage to the non-federal operators' system. Non-federal operations may not claim interference protection from federal systems.

Periodic Use Areas (PUAs)

PUAs are geographic locations in which non-federal operations in the band shall not cause harmful interference to federal systems operating in the band for episodic periods. During these times and in these areas, federal users will require interference protection from non-federal operations. PUAs are required to provide quiet environments to test and calibrate radar equipment, to support large-scale military exercises, or for short durations, high-power radar operations.

Processes for activating a PUA and any restrictions on commercial operations when the PUA is activated will be documented in operator-to-operator agreements for each location. Operators may agree to alternate arrangements (technical restrictions) in lieu of activating a PUA. DoD operations requiring the activation of PUAs currently typically range between 28-60 days per year. PUA activation rates are based on DoD mission requirements and are subject to change due to new or altered requirements.

The DoD later released the “DoD 3450 – 3550 MHz Workbook” to provide potential bidders in Auction 110 (commercial flexible-use licensees) with information about potential impacts to frequency blocks and market areas from DoD incumbent users. The DoD 3450 – 3550 MHz Workbook was meant to allow the sharing of CPA and PUA for coordination with incumbent DoD operations. Many aspects of the incumbent spectrum uses involve sensitive, non-public information that was redacted for public use, however some of the redacted information was made available to parties that were cleared for receiving Controlled Unclassified Information (CUI).

The workbook provided information on the encumbered census tracts for each of the ten 10 MHz segments within the 3450 – 3550 MHz band. These included impacted census tracts, the state associated with the census tract, and the latitude/longitude coordinate of the center of the census tract. Two different CPA/PUA groups were specified based on 5G equipment at 100-meter-tall commercial use antenna towers and 100 feet tall commercial use antenna towers. The total number of encumbrances from each antenna height as well as the encumbrances from each individual CPA/PUA were listed. The workbook information along with CUI helped the auction bidders be better prepared for participating in the auction.

2.6 C-Band (3700 – 3980 MHz)

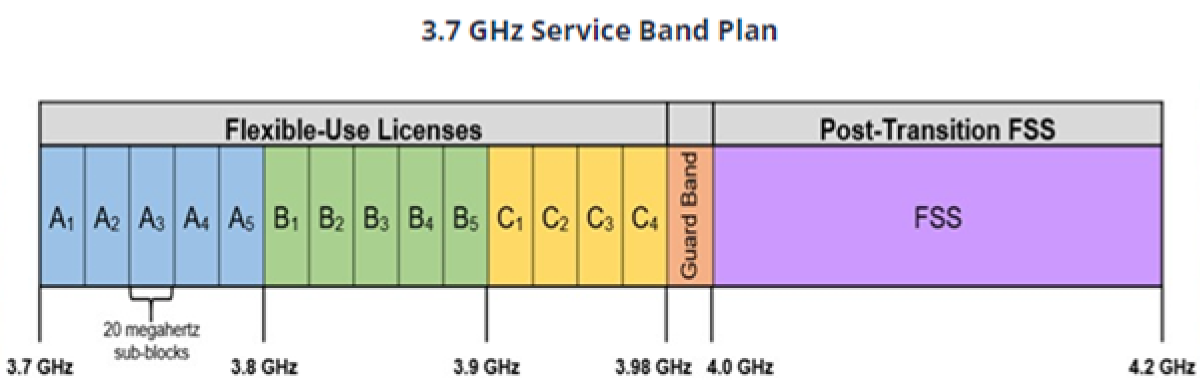
The 5G deployments in the C-band in the U.S. were launched in January 2022. In its first phase, 5G C-band is deployed only in the 3700 – 3800 MHz frequency range. The C-band second phase will have an additional 180 megahertz of spectrum (3800 – 3980 MHz), available for use no later than December 2023.

The 5G C-band has been the subject of many discussions involving the FCC, the FAA, and the aviation and wireless industries. More than 60 countries have 5G networks deployed in C-band spectrum and safely operated for years without any reported cases of radio altimeters interference. A detailed analysis of coexistence between C-band (5G) and radio altimeters, including inconsistencies and flaws in the aviation industry studies, is available in the 5G America’s paper released in July 2021[17].

Since January 2022, the FAA has cleared more than 90% of aircraft models for low-visibility landings in 100% of identified airports in the U.S[18].

In January 2023, The FAA proposed an airworthiness directive requiring airplanes in the U.S. to install 5G C-band tolerant radio altimeters or compatible radio frequency (RF) filters by February 2024[19]. The FAA estimates that approximately 180 airplanes would require radio altimeter replacement and 820 airplanes would require addition of radio altimeter filters to comply with the proposed modification requirement. The FAA estimates that the total price-tag to make these modifications to airplanes is $26 million[20].

Figure 2.3: 3.7 GHz Band Plan[16]



In a parallel effort, lab tests, flight tests and simulation-based analysis have been developed under the Joint Interagency - 5G Radar Altimeter Interference (JI-FRAI) project involving the DoD and the aviation and wireless industries. JI-FRAI project is focused on radio altimeters used by military aircrafts – many of such altimeters are also used in civil aviation. As one outcome of this effort, NTIA published a report[21] on characterization of the 3-D aerial radiation patterns emission spectra of 5G base station transmitters Substantial conclusions:

- Measured 5G power emissions are consistent with numerical simulation data and manufacturers' engineering specification sheets. The power radiated above horizon is significantly less than in the 5G base station main antenna beams directed toward UEs at ground level.
- 5G base station transmitters incorporate effective bandpass filtering in their output stages, providing very reduced unwanted emissions at the radio altimeter band, significantly reducing the likelihood of interference.
- The contribution of more distant 5G base stations to the aggregate interference at the radio altimeter rapidly fades to insignificance.

2.7 4400 – 5000 MHz

Current mobile standardization (3GPP band 77 [3300-4200 MHz] and 3GPP band 79 [4400-5000 MHz]) is the basis for various 5G deployments and possible deployments worldwide in parts of these two frequency bands. Some examples of such countries are Japan and China above 4.4 GHz.

The 4400-4500 MHz band is a federal band used for fixed and mobile services. The band supports fixed Line of Sight (LOS) and transportable-fixed point-to- point microwave systems, drone vehicle control and telemetry systems. In addition to the military systems, the civilian federal agencies also have systems in the band for nuclear emergencies and law enforcement activities.

Other federal applications in the 4500-4800 MHz band include trans-horizon radio communications, air-to-ground operations for command and control, telemetry to relay data, and various range systems. Non-federal use includes fixed-satellite services (FSS) (s-E)[22].

The 4800-4940 MHz band is used by the military at test ranges and naval ports around the U.S. Radio astronomy observations at selected locations are authorized in the 4800-4940 MHz band. The 4990 – 5000 GHz has federal allocation for radio astronomy and space research (passive).

The 4400-4500 MHz band is a sub-band of the larger 4400-4940 MHz federal government band. Many systems authorized to operate in the 4400-4500 MHz band typically have a tuning capability from 4400-4940 MHz.

2.7.1 Adjacent Services

In the United States, the 4940-4990 MHz band is a non-federal band and is allocated to the mobile service on a primary basis.

The 4200-4400 MHz band is a shared band internationally reserved for radio altimeters installed on aircraft. A nominal 20 MHz guard band should be achieveable if incumbent equipment in that band is upgraded to meet new performance requirements within reach of the state of the art.

2.7.2 Challenges

Radio altimeters are used on federal (military and civilian), and non-federal aircraft. Some altimeters have very poor selectivity. Some challenges include achieving realistic scenarios and information on the individual receiver selectivity performance for currently deployed radio altimeter models, focusing on out-of-band receiver blocking performance to assess realistic potential interference from commercial mobile use in adjacent bands to altimeters.

2.7.3 Activities

Activities include development of revised Minimum Operational Performance Standards (MOPS) for altimeters that would permit adjacent operations to the altimeter band unrestricted.

The 4800-4990 MHz is a WRC-23 agenda item (AI1.1) that reflects the growing worldwide interest on the 4.4-5GHz spectrum range for International Mobile Telecommunications (IMT) (5G). Studies will be performed in the ITU-R to determine the appropriate mechanism to ensure coexistence with incumbents in the band.

2.8 7125 – 8500 MHz

This entire band has only federal allocations for different services. Figure 2.4 shows the allocations for this band, where it is observed that fixed service has primary allocation in almost the whole band, with secondary allocation only for 7250 – 7300 MHz and 7900 – 8025 MHz. Other primary allocations exist in parts of the band for fixed, mobile and meteorological satellite services in both communication directions, as well as for space research

(Earth-to-Space) and Earth exploration-satellite service (Space-to-Earth). Other parts of the band have secondary allocations for the mobile-satellite service.

This band is also used for fixed-satellite and mobile-satellite service. Federal agencies operate the Defense Satellite Communications Systems (DSCS) series of geostationary satellites (s-E) in this frequency band. Federal agencies also operate the Wideband Gapfiller Satellite (WGS) in this band. Fixed-satellite use 7250 – 7750 MHz for downlink and 7900 – 8400 MHz for uplink; this includes support for DSCS and the WGS.

Non-federal usage includes unlicensed use for ultra-wideband devices under Part 15.501-525 rules utilizing primarily the 7750-8750 MHz frequency range. These devices include personal item tracking devices, mobile phones and other personal consumer electronics, including wearables, wall-penetrating radars, and automotive applications thereby crossing several consumer sectors.

In addition, non-federal operations in space research (s-e) in the 8400-8500 MHz is also allocated. The federal agencies use of this band is mostly for fixed point-to-point microwave communication systems. This includes the FAA use of this band for fixed point-to-point microwave communications networks to connect remote long-range aeronautical radionavigation radars to ATC centers. However, the use of the band for fixed assignments in the 7125 – 8500 MHz has been declining.

The feasibility of introducing flexible use in this band looks promising, but more study is needed to characterize its use and to determine the most appropriate technical and operational conditions for using the band. Currently, spectrum occupancy measurements taken in three cities in the U.S. indicate generally low usage of the band.

Coexistence with the incumbent services may be difficult. Studies are needed to determine the most appropriate technical and operational conditions for using the band.

This band has been indicated among the main priorities for FCC action beyond the year 2022 as part of the effort towards mid-band spectrum for 6G[24,25]. Federal agencies have been collecting information about their operations in this band with a report due back to NTIA. Information about spectrum usage in this frequency range is essential for determining the most suitable portions of this band for commercial operations and the conditions for using the band.

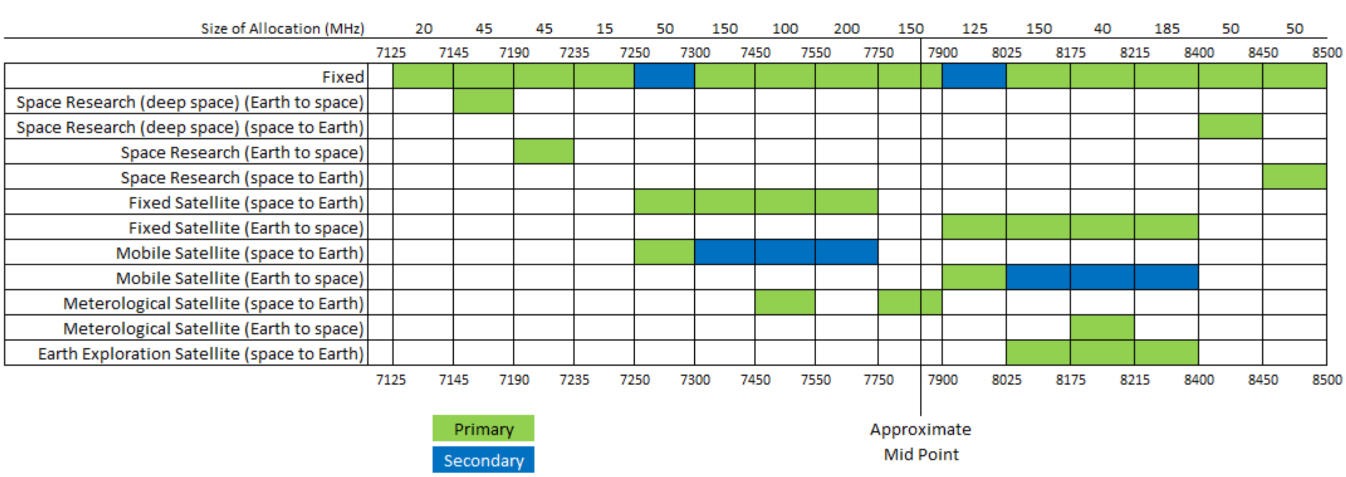
2.9 10 – 10.5 GHz

In ITU Region 2 covering the Americas, the frequency band 10-10.5 GHz is allocated to the radiolocation service on a primary basis, as well as to the fixed and mobile services via ITU footnotes 5.480 and 5.481 to numerous countries. Among the systems deployed in this range are high-powered ground and airborne systems that are operational worldwide. In the U.S. this band is used by the federal for weapons control radar systems onboard aircraft. The earth exploration-satellite service (EESS) (active) is also allocated on a primary basis in 10-10.4 GHz in Region 2. The National Oceanographic and Atmospheric Administration uses this band for radar systems onboard meteorological satellites.

10-10.5 GHz band is one of the candidate bands for WRC-23.ITU will consider agenda item 1.2 at WRC-23. This agenda item will consider identification of the frequency band 10.0-10.5 GHz for IMT, including possible additional allocations to the mobile service on a primary basis, in accordance with Resolution 245 (WRC-19).

Coexistence with adjacent EESS passive and in-band EESS active services is challenging.

Figure 2.4: 7.125 – 8.5 GHz Allocations[23]



2.10 10.7 – 12.2 GHz

This band is used for fixed-satellite service (s-E) on a primary basis in the 10.7-11.7 GHz band for non-federal use. The band 11.7 -12.2 GHz band is used for fixed-satellite service (s-E) as a primary service on a non-federal basis. The band 11.7-12.2 GHz band is the downlink that is paired with the uplink in the 14.0-14.5 GHz band. Federal agencies operate communications satellite Earth stations for voice, data, and video signals using commercial geostationary satellites. These federal agencies operate Earth stations that receive voice, data, and video signals. The National Oceanographic and Atmospheric Administration uses the 10.7-10.8 GHz band for passive sensing of the Earth from space using numerous sensing instruments such as radiometers, imagers, sounders, and temperature and water vapor profilers.

Coexistence with the above services seems challenging but requires further examination.

2.11 12.2 – 12.7 GHz

This band currently is used by the following services:

- Direct Broadcast Satellite (DBS), which operates under the primary broadcasting satellite service allocation.
- Multi-Channel Video and Data Distribution Service (MVDDS), which operates under a co-primary fixed service allocation.
- Non-Geostationary-Orbit Fixed-Satellite Service (NGSO FSS) (space-to-Earth), which also have co-primary allocation.

While these three services are co-primary, MVDDS and NGSO FSS are allocated on a non-harmful interference basis with respect to DBS, and therefore operate under some technical conditions, which include reduced Effective Isotropic Radiated Power (EIRP) and equivalent power flux density limits for MVDDS transmissions.

In 2021, the FCC released a NPRM[26] seeking input on the feasibility of allowing flexible-use services in the 12.2 – 12.7 GHz band while protecting incumbents from harmful interference. DBS has tens of millions of individual homes and businesses as subscribers throughout the U.S., with relatively small dish antennas as receivers, which can be deployed anywhere. Co-channel coexistence of high-power systems with such an incumbent is very challenging, as already indicated in some filings to the FCC. Currently, it is unclear if the FCC will consider some relocation from the band for making part of it available for flexible-use services.

Fixed one-way service called “MVDDS” is authorized in the 12 GHz band under stringent technical rules meant to protect the primary incumbent DBS/BSS and the co-primary NGSO FSS (non-geostationary-satellite service). The U.S.-licensed DBS providers use the band throughout the U.S. to provide DBS directly from geostationary-orbit (GSO) satellites to relatively small dish antennas at tens of millions of individual homes and businesses. DBS service had over 22 million combined subscribers as of the third quarter of 2020.

Coexistence of terrestrial systems with DBS is difficult. Studies are needed to determine the most appropriate technical and operational conditions for using the band. Coexistence of the existing 12 GHz services including MVDDS with mobile broadband is discussed in the latest 12 GHz NPRM, but no ruling on a sharing mechanism has been made yet. FCC Chairwoman Rosenworcel has stated that this will be a complex proceeding and “we are trying to identify if having these services coexist is viable”[27].

2.12 12.7 – 13.25 GHz

On October 22nd 2022, the FCC released an Notice of Inquiry (NOI) to explore repurposing of up to 550 MHz of extended mid-band spectrum for next-generation services. With this order, the FCC has extended the temporary freeze on applications within the band.

This band is used by fixed and fixed-satellite service (s-E) and mobile on a non-federal primary basis between 12.7-13.25 GHz basis in the U.S. From an international perspective, the 12.7-12.75 GHz is allocated for FSS, Mobile except aeronautical mobile and fixed-satellite service (E-s) in Region 2. From 12.75-13.25 GHz, the band is also allocated for fixed, mobile except aeronautical mobile, fixed-satellite service (E-s) in Region 2 and space research (deep space)(s-E). The National Science Foundation uses this band for the radio astronomy research of various spectral lines, including the research of the formaldehyde line and quasars.

In the 13.25-13.75 GHz band, federal agencies operate airborne Doppler navigation radars and shipborne radiolocation point defense weapon systems, including search radars, tracking radars, and missile and gun fire-control radars in this band. The National Aeronautics and Space Administration (NASA) uses this band for active sensor systems used in joint programs with the Centre National d’Etudes Spatiales (CNES) for space-based observations and measurements of surface topography, ocean winds and precipitation. In addition, NASA uses this band for space-based precipitation radars in the Tropical Rainfall Measurement Mission (TRMM), Global Precipitation Mission (GPM), and terrestrial precipitation radars. NASA also uses this band for spacecraft communications downlinks involving space research, tracking and data relay satellite system (TDRSS) and to provide communications to the space shuttle and other spacecraft.

In Region 2, the 13.25-13.75 GHz band is used for Earth exploration-satellite (active), aeronautical radionavigation and space research on a primary basis. Coexistence with NASA's active sensor systems is challenging and requires further study.

5G Americas also submitted comments and reply comments to the recent NOI published by the FCC for exploration of this range for commercial use. 5G Americas supports that the Commission has begun its review of a band of upper mid-band spectrum in a globally-harmonized range for next-generation wireless broadband. We, like others in the mobile industry, view upper mid-band spectrum as a complement to the "work horse" of low mid-band. 5G Americas urges the Commission to progress its review of the 3.1 – 3.45 GHz band this year, as well to initiate a proceeding on 4.4 – 4.94 GHz and 7.125 – 8.5 GHz. When the Commission does propose rules for the 12.7 GHz, it should propose flexible, exclusively-licensed, high-power use, in order to maximize the benefits of 5G-Advanced and 6G applications in the band for the American people[28].

3. Current and Planned Mid-band Deployment Status in the U.S.

All of the service providers in the U.S. have been heavily focused on acquisition of mid-band spectrum for 5G with the multiple auctions held by the FCC. Details on all of the bands available as of today as well as future status are examined in the following sections.

3.1 2.5 GHz – n41 (2496 – 2600 MHz)

T-Mobile's Ultra Capacity 5G, which is largely based on the 2.5 GHz spectrum, covers 260 million people[29]. B41 is primarily in use by T-Mobile in the U.S. T-Mobile as part of the most recent Educational Broadband Service (EBS) auction (Auction 108), acquired around 90% of all licenses in the band.

3.2 CBRS – n48 (3550 – 3700 MHz)

As per the OnGo Alliance, there are over 240,000 CBSDs across the U.S. currently broadcasting wireless signals on the CBRS spectrum via private and fixed wireless networks, spanning various sectors including enterprise IT, industrial IoT, smart cities, rural broadband, transportation, hospitality, retail, and real estate[30].

3.3 C-band (3700 – 3980 MHz)

To make mid-band available to consumers, C-band clearance is being done on an accelerated timeline in U.S., where 100 MHz in top 46 PEA's, is now already available. The rest of 180 MHz is set to be cleared nationwide, by December 5th, 2023.

AT&T is planning on using a single tower climb to more effectively deploy both C-band and 3.45 GHz. At the 3rd Quarter earnings of 2022, AT&T discussed that their deployments on mid-band 5G spectrum covering 100 million people, updating end of year target to more than 130 million people[31].

Verizon now covers more than 175 million people and plans for more 5G coverage using C-band soon. The ongoing C-band rollout is 13 months ahead of the original schedule and continues to accelerate[32].

3.4 3.45-3.55 GHz (3450 – 3550 MHz)

AT&T has stated that they have already started deployment of 40 MHz of nationwide 3.45 GHz spectrum. AT&T was the biggest winner in Auction 110, acquiring 1,624 licenses.

4. Maximizing Utility for 5G Mid-band Spectrum

Mid-band spectrum holds the key for 5G deployments with ever-increasing data traffic and subscriber growth. The performance targets on networks require new levels of spectral efficiencies and flexibility. This section will look at how to evolve mid-band towards best coverage and capacity.

4.1 Mid-band Coverage and Capacity

As the demand for new use cases that requires higher speeds and enhanced user experience grows, this requires the network to support substantially higher network capacity. While legacy networks in the past have used spectrum below 3GHz, the physical characteristics of bands above 3 GHz requires a re-thinking of how to improve both coverage and capacity.

The increasing demand of data traffic and subscriber growth requires new levels of spectral efficiency and flexibility. Massive MIMO technology offers operators with access to larger bandwidth of mid-band spectrum to deliver a powerful 5G experience to its consumer nationwide.

A massive MIMO system is one that contains a large number of antennas, typically much greater than eight. Massive MIMO solutions are targeted towards improvement of spectral efficiency and offer enhanced coverage and capacity. This is achieved through using multi-antenna technologies such as beamforming, null forming and spatial multiplexing, that takes advantage of specific channel and antenna array properties.

4.2 Beamforming

The purpose of beamforming is to amplify transmitted/received signals in a specific direction. Massive MIMO enables beamforming in both vertical and horizontal directions. Having a much higher number of antennas elements enables sharper beams, which helps concentrate energy in one direction more than the other and provide higher SNR to end user. To target these beams and find the right direction towards a user requires channel estimation which can be done using the following two techniques:

4.2.1 Closed Loop/Codebook

Closed loop/codebook based where gNB transmits Reference signals (CSI-RS) in downlink and a UE measure on CSI-RS and reports Precoding Matrix Index (PMI), this works for both FDD and TDD. Downlink transmissions are based on PMI and standardized precoding tables.

4.2.2 Reciprocity

In this case the UE transmits sounding reference signals (SRS) in uplink, different UEs are identified by using different UE specific SRS configuration. Downlink transmission based on SRS measurements, this works well for TDD and not for FDD:

- Coverage and capacity enhancements
- Expanded beamforming capability
- Use low-bands as supplemental UL for mid-band
- Optimization/improvement of coexistence and sharing mechanisms

4.3 Uplink (UL) and Downlink (DL) Decoupling

To maximize the spectrum usage for mid-bands ranging in 3 – 6 GHz, it is possible to decouple the UL and DL. TDD bands are typically deployed with a frame configuration which is more downlink centric and due to the propagation characteristics at higher frequency are limited in coverage compared to FDD low & mid-bands.

The coverage imbalance between DL and UL is typically much larger due to the imbalance of power between downlink and uplink. The decoupling of DL and UL can be a key enabler to maximize the usage for mid-band spectrum, where implementation of such can extend the footprint of mid-band.

Implementation of such will be beneficial for 5G deployments as the operators will be able to leverage existing FDD spectrum uplink coupled with TDD downlink to extend the footprint and improve the usability of mid-band TDD. This will provide much higher capacity and an improved user experience.

5. Mid-band Spectrum Pipeline Update

A spectrum pipeline provides investment certainty by identifying frequencies bands where regulatory and possible legislation action is planned. A spectrum pipeline assures that spectrum considerations are receiving proper attention with the objective to have spectrum available in the proper timeframe. In the U.S., the House Subcommittee on Communications and Technology of the Committee on Energy and Commerce held a hearing[33] titled "5G and Beyond: Exploring the Next Wireless Frontier." The Committee Chairman Frank Pallone, Jr. stated that "we risk falling behind our counterparts by failing to replenish the commercial spectrum pipeline". For instance, China has already made triple the mid-band spectrum available for 5G compared to the United States, which delivers the best of both worlds when it comes to wireless broadband: faster speeds, less buffering, and access to a signal indoors. It's not enough simply to make our airwaves available for commercial use—we must also place radio waves in the hands of innovators to benefit the public. In assessing the current state of spectrum allocation in the U.S., the limited availability compared to other services could hinder the ability of mobile wireless networks to keep up with projected growth and increased demand. Especially In the lower mid-band, the range of radio frequencies between 3 to 8 GHz[34].

There are currently no bands in the pipeline. Because the process for identification, allocation and repurposing of spectrum is a multiyear process, the lack of spectrum in the pipeline is a critical concern. There are two frequency ranges that have received some attention and may eventually be included in the mid-band spectrum pipeline: 3.1-3.45 GHz and 7-15 GHz. First, FCC Chairwomen Jessica Rosenworcel remarked at the Mobile World Congress 2022 35 that "we will turn our sights to working with our federal partners to open up the next tranche of mid-band spectrum in the 3.1-3.45 GHz band" Furthermore, "I believe for 6G we [FCC] need to start planning now to identify spectrum in the 7-15 GHz range that can support faster speeds and wider coverage. I also believe it's not too early to harmonize these efforts across the world. That's how we will help ensure this next-generation effort can reach everyone, everywhere."

FCC Commissioner Carr recently cited 36 that he foresees the lower 3000 MHz band, 4800 MHz, 7125 – 8400 MHz, and spectrum above 95 GHz (including terahertz bands that could be useful in 6G) as main priorities for FCC action beyond the year 2022. From an international perspective, these frequencies are also primarily allocated to fixed, mobile, FSS and mobile-satellite services (MSS).

Conclusion and Recommendations

The amount and the type of spectrum impacts the network's capabilities. 5G networks require access to multiple ranges of frequency bands from low, mid to high. All three frequency ranges are essential for 5G deployments as they allow operators to optimize their networks based on environmental and network coverage and capacity targets. However, 5G deployment challenges over the last few years have made it quite evident that mid-band spectrum offers the unique combination of capacity and coverage necessary to satisfy smart phone users expectations for availability of 5G and beyond everywhere. With exponential growth of mobile data consumption and proliferation of new bandwidth hungry smart phone applications, it is vital that regulatory bodies ensure availability of timely licensed mid-band spectrum beyond what's already been allocated.

There are currently no bands in the spectrum pipeline in the U.S. A spectrum pipeline provides investment certainty by identifying frequencies bands where regulatory and possible legislative action is planned. A spectrum pipeline assures that spectrum considerations are receiving proper attention with the objective of having spectrum available in the proper timeframe.

A spectrum pipeline should prioritize the availability of lower range of frequencies in the mid-band range, as they will benefit the industry the most. Lower range mid-band such as spectrum in the range of 3 – 8 GHz will help with coverage layer for both 5G and next G's. The FCC and NTIA in conjunction with industry should create a spectrum pipeline.

The paper has identified and discussed several potential mid-bands and extended mid-bands that need to be tapped into to support current and future 5G and beyond applications. Making these bands available for deployment depends on several developments, including studies and solutions for coexistence with incumbent services as mentioned in the following:

The key challenge to allocation of new mid-band spectrum is that none of the potential bands are clear and all have incumbents with unique system characteristics and coexistence challenges. Coexistence with incumbents has also been the key challenge with mid-bands that have already been allocated including 3.45 GHz, CBRS, and C-band.

Coexistence mechanisms already developed for some bands like the 3.45 GHz band may help in developing coexistence mechanism for some new bands which have incumbents with the same or similar system characteristics like 3.1-3.45 GHz band. Other new and extended mid-bands may need new approaches.

Potential new mid-bands currently are mainly used by federal systems - each with unique characteristics and coexistence requirements. As experienced in the CBRS band case, development of suitable coexistence mechanisms for new bands is often a lengthy process. To jump start this process for new mid-bands, it's critical that the coexistence characteristics of the incumbent systems become available as early as possible. This information can greatly help industry and academic research groups in developing appropriate coexistence mechanisms for these bands.

Among potential mid-band spectrum below 7 GHz, the frequency range 4400 – 5000 MHz seems to have been least discussed for mobile broadband use in the U.S. This contrasts with the growing worldwide interest in this frequency range as reflected in the inclusion of the 4800-4990 MHz in ITU WRC-23 agenda items. Considering the favorable propagation characteristics of mid-band frequencies below 7 GHz, it's recommended that actionable studies begin immediately to allow the introduction of commercial services in this frequency range.

The feasibility of introducing flexible-use in the 7125 – 8500 MHz band looks promising; it's recommended that actionable studies begin immediately to allow the introduction of commercial services in this frequency range.

For the wireless industry to continue to provide these considerable, widespread positive effects to the American economy, it is necessary to provide mobile network operators access to dedicated, licensed spectrum[37].

The extended mid-band in the range of 8.5 – 16 GHz will help complement the lower mid-band spectrum and should be assessed for the mobile wireless industry.

Acronyms

ATC: Air Traffic Control

CBRS: Citizens Broadband Radio Service

CNES: Centre National d'Etudes Spatiales

CPA: Cooperative Planning Areas

CUI: Controlled Unclassified Information

DBS: Direct Broadcast Satellite

DoD: Department of Defense

DSCS: Defense Satellite Communications Systems

E-s: Earth-to-space

EESS: Earth exploration-satellite service

EIRP: Equivalent Isotropic Radiated Power

ESC: Environmental Sensing Capability

FAA: Federal Aviation Administration

FCC: Federal Communications Commission

FDD: Frequency Division Duplex

FSS: Fixed-satellite services

GPM: Global Precipitation Mission

GSO: Geostationary-satellite orbit

IMT: International Mobile Telecommunications

IoT: Internet of Things

ITS: Institute for Telecommunication Sciences

LOS: Line of Sight

LTE: Long Term Evolution

MIMO: Multiple Input Multiple Output

MOPS: Minimum Operational Performance Standards

MSS: Mobile-satellite services

MVDDS: Multi-Channel Video and Data Distribution Service

MWC: Mobile World Congress

NASA: National Aeronautics and Space Administration

NOI: Notice of Inquiry

NPRM: Notice of Proposed Rule Making

NTIA: National Telecommunications and Information Administration

PMI: Precoding Matrix Index

PUA: Periodic Use Areas

S-e: Space-to-Earth

SAS: Spectrum Access System

SNR: Signal to Noise Ratio

SRS: Sounding reference signals

TDD: Time Division Duplex

TDRSS: Tracking and data relay satellite system

TRMM: Tropical Rainfall Measurement Mission

UE: User Equipment

UL: Uplink

WGS: Wideband Gapfiller Satellite

Acknowledgments

5G Americas' Mission Statement: 5G Americas facilitates and advocates for the advancement of 5G and beyond throughout the Americas.

5G Americas' Board of Governors members include Airspan Networks, Antel, AT&T, Ciena, Cisco, Crown Castle, Ericsson, Liberty Latin America, Mavenir, Nokia, Qualcomm Incorporated, Samsung, Shaw Communications Inc., T-Mobile USA, Inc., Telefónica, VMware and WOM.

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