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5G Americas is pleased to submit this cover letter and attached *5G Spectrum Vision* White Paper to NTIA in the proceeding on developing a Sustainable National Spectrum Strategy. NTIA's press release on its request for comments on developing this Strategy states the "strategy must accomplish several goals, including increasing spectrum access, improving spectrum sharing, enhancing spectrum management, and leveraging ongoing research and development activities."[1] 5G Americas,[2] whose mission is to advocate for and facilitate the advancement of 5G and the transformation of LTE networks across the Western Hemisphere, comments today primarily on the importance of increasing spectrum access in order to leverage the substantial amount of R&D that has been done by the wireless industry.

The attached *5G Spectrum Vision* White Paper outlines the spectrum inventory opportunities for 5G across the world. The White Paper reviews 5G spectrum considerations in the Americas, Europe, East Asia, and Australia. This review is followed by a discussion of the characteristics of different bands and the challenges of and opportunities in using different bands for 5G. The paper also makes recommendations on mechanisms for spectrum clearing, spectrum sharing, and necessary industry and regulatory actions toward more licensed spectrum for 5G in North America, including in the mid-band of 3450 – 3550 MHz. The 3.4 – 3.8 GHz band is becoming a key band for 5G globally. All or a significant portion of the 3.7 – 4.2 GHz band

[1] Press Release, NTIA, *NTIA Seeks Comment on Development of a National Spectrum Strategy* (Dec. 20, 2018).
[2] 5G Americas is currently chaired by T-Mobile USA, and its Board includes AT&T, Cable & Wireless, Cisco, CommScope, Ericsson, Intel, Kathrein, Mavenir, Nokia, Qualcomm, Shaw, Sprint, Telefonica and WOM.

should be made available as soon as possible for licensed flexible deployment. At the same time, 5G spectrum opportunities below 3 GHz must continue to be considered. Likewise, licensed use of the spectrum in the range 7 – 24 GHz must also continue to be explored. For the U.S. to lead in 5G, it is imperative that the U.S. make sufficient, internationally-harmonized spectrum available for exclusively-licensed use.

As the President recognized in his National Spectrum Strategy Memorandum,[3] it is imperative that America be first in 5G wireless technologies.[4] 5G will become a critical tool utilized across the national economy to drive productivity, innovation, and opportunity to a far greater degree than 4G. Leading countries around the world recognize the strategic imperative of 5G. America was first in 4G because it made new spectrum available to mobile operators, which gave significant momentum to 4G network technology development inside the U.S. and gave birth to the applications sector. For operators, the availability of new low-band spectrum in the U.S., coupled with previously assigned spectrum enabled America to be first in 4G, both in terms of first to deploy, but also the deepest market penetration and most intense customer use. Similarly, being first in 5G will require the U.S. government to make new spectrum available for commercial use, in low-, mid-, and high-band spectrum. 5G will cover a range of use cases, from enhanced consumer broadband, to industrial Internet of Things (IoT), to ultra-reliable, low-latency applications that are mission critical, like autonomous vehicles and remote surgery. Since 5G will cover a range of use cases, it will require spectrum in a range of bands, low-, mid-, and high.

5G Americas has published several white papers on what applications are optimal for which frequency bands across the low-, mid- and high-band range.[5] 5G will encompass a range of new applications, including enhanced mobile broadband, massive machine-type communications, often referred to as the Internet of Things, and applications where low-latency and reliability are mission-critical. It is imperative that the U.S. lead on all development paths of 5G, but the low-latency, ultra-reliable applications are seen by many to be of particular strategic importance in advancing national goals. Relative to ultra-reliable, low-latency critical applications, the U.S. being first to 5G can have profound economic and national security effects. Ultra-reliable low latency 5G is one of the enabling technologies in the fourth industrial revolution. Typical industrial automation use cases requiring ultra-reliable low latency performance include factory, process, and power system automation. Use cases involve communication transfers enabling time-critical factory automation that are required in many industries, such as metals, semiconductors, pharmaceuticals, electrical assembly, and food and

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[3] Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future, 2018 Daily Comp. Pres. Doc. No. 00730 (Oct. 25, 2018) ("Presidential Memorandum").
[4] *Id.* at Section 1, p. 2.
[5] *See* 5G Americas, *5G Spectrum Recommendations* 24-25, Table 15 (April 2017), available at http://www.5gamericas.org/files/9114/9324/1786/5GA_5G_Spectrum_Recommendations_2017_FINAL.pdf

beverage.[6] Traditionally, industrial control systems are mostly based on wired networks, because earlier wireless technologies could not meet the industrial latency and reliability requirements. Replacing the currently-used wires with radio links can bring substantial economic benefits, including reduced cost of manufacturing, installation, and maintenance; higher long-term reliability as wired connections suffer from wear and tear in motion application; and inherent deployment flexibility.

Being first to deploy ultra-reliable low latency and other 5G use cases will not only improve the global competitiveness of the wireless industry, an outcome the Presidential Memorandum seeks,[7] but the global competitiveness of the entire U.S. economy. The President's Memorandum states it is the policy of the United States to use spectrum to meet not just our economic goals, but our national security, science, safety, and other Federal mission goals now and in the future.[8] 5G use cases can help meet those goals in a variety of ways. Public safety and disaster response communications require robust and reliable communications in case of natural disasters such as earthquakes, tsunamis, floods, and hurricanes.[9] The use cases may require accurate position location and quick communication exchanges between users and systems. The efficiency gains in user battery consumption and network communications are critical in these use cases. 5G will bring public safety organizations enhanced and secured communications with real-time video and the ability to send high-quality pictures in real-time.

Urgent health care is another important area of both public safety and science. 5G will enable remote diagnosis, treatment and patient monitoring.[10] 5G devices will measure vital signs such as ECG, pulse, blood glucose, blood pressure, and temperature. The remote treatment and response based on monitored data can be life-critical for a patient, requiring immediate, automatic or semi-automatic response. 5G can facilitate remote surgical consultations and remote surgery. In a mobile scenario, such as in ambulances or disaster situations in remote areas, surgeons require precise control and feedback communication mechanisms that are low latency, highly reliable, and secure. The "Tactile Internet", enabled by 5G, also has applications in patient care.

The Presidential Memorandum also notes that wireless technologies can, in addition to offering safety benefits and saving lives, reduce the cost of transportation incidents.[11] 5G's realization can empower several technological transformations in the transportation industry, including automated driving, road safety, and traffic-efficiency services.[12] These transformations

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[6] 5G Americas, *New Services & Applications with 5G Ultra-Reliable Low Latency Communications* § 2.2 (November 2018), available at http://www.5gamericas.org/files/1115/4213/2248/5G_Americas_URLLLC_White_Paper_Final__updateJW.pdf.
[7] Presidential Memorandum at Section 4(e).
[8] *Id.* at Section 1.
[9] 5G Americas, *supra* note 6, at § 2.6.
[10] *Id.* at § 2.7.
[11] Presidential Memorandum at Section 1.
[12] 5G Americas, *supra* note 6, at § 2.8.

will fully connect cars, allowing them to react to increasingly complex road situations by cooperating with other nodes rather than relying on their local information. These trends will require information to be disseminated among vehicles reliably within extremely short time duration. For example, in fully automated driving with no human intervention, passengers will benefit by the information received by the vehicle from roadside infrastructure or other vehicles. The typical use cases of this application are automated overtake, cooperative collision avoidance, and high-density platooning, which require stricter end-to-end latencies and high reliabilities.

To assist NTIA in its preparation of a long-term National Spectrum Strategy, 5G Americas attaches its recent white paper on *5G Spectrum Vision*.[13] As the President recognized, "access to spectrum is a critical component of the technological capabilities that enable economic activity and protect national security. Wireless communications and associated data applications establish a foundation for high wage jobs and national prosperity. While American industry continues to extract greater and greater value from spectrum, each technological leap also increases demands on its usage." The attached White Paper on *5G Spectrum Vision* addresses immediate needs and sets goals that will carry the U.S. well into the future, so that the Nation can build a long-term, sustainable spectrum access framework. In addition to bands that the FCC has proposed for flexible use in both the mid-band and high-band ranges, these goals include repurposing the 3450 – 3550 MHz band for shared commercial access. Only by maintaining the momentum behind making new mid-band spectrum available will the U.S. be able to lead globally in 5G, as well as keep pace with further U.S. demand for traffic capacity as 5G services are deployed and new innovative 5G applications are developed.

5G Americas hopes this *5G Spectrum Vision* White Paper will assist NTIA and the agencies on the President's Spectrum Strategy Task Force in developing and implementing a National Spectrum Strategy that improves the global competitiveness of the U.S., increases spectrum access, efficiency and effectiveness, and unleashes innovation broadly across diverse sectors of the economy.

Best regards,

Chris Pearson
President, 5G Americas

[13] 5G Americas, *5G Spectrum Vision* (February 2019), available at http://www.5gamericas.org/files/4015/4958/3330/5G_Americas_5G_Spectrum_Vision_Whitepaper.pdf.

5G Americas Whitepaper

5G SPECTRUM VISION

FEBRUARY 2019

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EXECUTIVE SUMMARY

While significant progress is being made by regulators in jurisdictions throughout the Americas, further action is required to accelerate the availability of spectrum for 5G deployments. It is critical that spectrum be made available in low-bands, mid-bands, and high-bands to accommodate the variety of use cases and performance requirements expected of 5G.

In this whitepaper, 5G Americas provides the following recommendations:

- Stakeholders must continue to consider spectrum identification and allocation opportunities below 3 GHz
- Administrations should take steps to accelerate domestic procedures necessary to introduce spectrum supporting the developing global 5G ecosystem
- In the U.S., commercial readiness of the Spectrum Access System (SAS) Environmental Sensing Capability (ESC) should be facilitated, Citizen's Broadband Radio Service (CBRS) spectrum availability for General Authorized Access (GAA) usage expedited, and the government should move towards the auction of the CBRS Priority Access Licenses (PAL) as soon as practical.
- Federal Communication Commission (FCC) should finalize the proposed rulemaking and allocation of all or a significant portion of the 3.70-4.20 GHz band for licensed flexible deployment by 2020
- Additional services like Point-to-Multipoint in the 3.70-4.20 GHz band should not be introduced
- More mid-band spectrum should be opened; for example, in the U.S., the 3.45-3.55 GHz band should be made available for licensed use by 2022
- Administrations should consider regulatory activities for the 6 GHz band in the U.S. and Europe as potential 5G spectrum bands
- Administrations should continue to look at spectrum opportunities for licensed use of spectrum in the 7-24 GHz range
- Administrations should take steps to accelerate domestic procedures necessary to introduce spectrum supporting the developing 5G global ecosystem in millimeter wave (mmW) band, for instance in 28 GHz
- The 3.5 GHz and mmW auctions in Canada should proceed without delay as planned in 2020 and 2021, respectively
- The inclusion of the 42 GHz band in the auction of 37 GHz, 39 GHz, 47 GHz bands in the U.S. should be recommended; this band is part of the 37.0-43.5 GHz "tuning range"
- Rulemaking and auction of the 26 GHz band should be finalized as soon as practical to take advantage of this band's global harmonization for 5G
- The FCC should quickly issue service rules for the remaining mmW bands including 32 GHz, 45 GHz and 50 GHz

1. INTRODUCTION

Continuous progress in 5G standardization and successful 5G trials around the globe have paved the way for early 5G commercial launches. Launches are expected to increase over the next few years in North America and major markets across Asia-Pacific and Europe. A big part of delivering on 5G promises - enhanced mobile broadband, massive internet of things connectivity, and ultra-reliable low latency communication - is for operators to have access to a sufficient supply of harmonized low band, mid band, and high band spectrum.

The encouraging news is that regulators across the world have recognized this need and are in various stages of making new spectrum resources available for 5G services. There have been considerable developments in the U.S. and other North American countries towards availability of new spectrum resources.

In the U.S., a recent Presidential Memorandum calls for a comprehensive national strategy for managing spectrum resources, and states that "…access to spectrum is a critical component of the technological capabilities that enable economic activity and protect national security. Wireless communications and associated data applications establish a foundation for high wage jobs and national prosperity. While American industry continues to extract greater and greater value from spectrum, each technological leap also increases demands on its usage."

This Memorandum addresses immediate needs and sets goals that will carry the U.S. well into the future, so that the nation can build a long-term, sustainable spectrum access framework.

Other promising recent regulatory actions in the U.S. include finalization of the CBRS rule changes, release of 3.70-4.20 GHz and 6 GHz Notices of Proposed Rulemaking (NPRMs), auction of the 28 GHz band, and planned or contemplated auctions of the 24 GHz, 37 GHz, 39 GHz and 47 GHz bands. These actions will clearly enhance the U.S. 5G spectrum position by providing greater licensed, unlicensed, and shared spectrum resources for 5G. Regulations for other potential spectrum bands, including 26 GHz, 32 GHz, 42 GHz, 45 GHz and 50 GHz, are also necessary to maintain the momentum behind spectrum auctions and ensure that spectrum availability will keep pace with further demands for traffic capacity as 5G services are deployed and new innovative 5G applications are developed.

In other countries in the Americas, regulators are also in the process of making spectrum available for 5G services. In Canada, for example, 5G technology is expected to be deployed initially in the 600 MHz band, which is scheduled to be auctioned in March 2019. Recent public consultations in Canada have also identified 3.45-3.65 GHz, 3.65-4.2 GHz, 26.5-28.35 GHz, 37-40 GHz and 64–71 GHz as potential 5G bands. Auctions and public consultations for 5G are also underway and/or planned in several Latin American countries including Argentina, Brazil, Colombia, Mexico and Peru.

This paper reviews 5G spectrum considerations in the Americas, Europe, East Asia, and Australia. This is followed by a discussion of the characteristics of different bands and challenges and opportunities in using different bands for 5G. Subsequently, the paper identifies bands that have a potential to be used for 5G services. This paper also makes recommendations on mechanisms for spectrum clearing, spectrum sharing, and necessary industry and regulatory actions towards more licensed spectrum for 5G.

2. GLOBAL PROGRESS ON 5G SPECTRUM

The regulatory activity described in selected countries and regions in this section is not exhaustive but provides informative data examples on the status of spectrum considerations.

2.1 UNITED STATES

There has been an extensive push towards allocation of spectrum for 5G broadband services in the U.S.; progress has been made both below and above 24 GHz. Initially the focus was on spectrum above 24 GHz, but since 2017 the FCC has increased its efforts to identify mid-band spectrum suitable for 5G applications.

2.1.1 SPECTRUM BELOW 24 GHZ

On August 3, 2017, the FCC released a Notice of Inquiry (NOI) seeking input on potential opportunities for additional flexible access—particularly for wireless broadband services—in spectrum bands between 3.7 and 24 GHz (mid-band spectrum). In particular, the Commission sought public comment on expanding access in three specific mid-band spectrum ranges: 3.70-4.20 GHz for possible mobile use and 5.925-6.425 GHz and 6.425-7.125 GHz for flexible (mobile or fixed) use. The FCC also asked whether there are other bands that would be suitable for commercial use in the range 3.7 GHz to 24 GHz.[1]

On July 13, 2018, the FCC issued the 3.7 to 4.2 GHz band Notice of Proposed Rulemaking (NPRM). The NPRM proposes to add mobile allocation to the 3.70-4.20 GHz band and seeks comment on various proposals for expanding flexible use in the band, including whether to transition all or part of the band through a market-based mechanism, auction mechanisms, or other alternative mechanisms. The 3.70-4.20 GHz NPRM also requests: input on the future of the incumbents, including appropriate protections for existing satellite operators, relocation options for services and potentially sun-setting or grandfathering the existing fixed microwave point-to-point licenses in the band; potentially allowing point-to-multipoint use on a shared basis in a portion of the band; and what service and technical rules should be changed or adopted if the Commission decides to expand flexible use or allow point-to-multipoint use in the band.

[1] *FCC Opens Inquiry* into *New Opportunities in Mid-Band Spectrum*,, FCC Press Release, Aug 3, 2017

The U.S. Department of Commerce's National Telecommunications and Information Administration (NTIA) has identified 100 MHz of spectrum in the 3.45-3.55 GHz range for study as potential broadband wireless spectrum. This spectrum, could increase the availability of mid-band spectrum for 5G use.

On March 23, 2018, the FCC released the Sixth Further Notice on the 4.9 GHz band (4.94-4.99 GHz). This 50 MHz of contiguous spectrum, which was allocated to public safety use in 2002, has been lightly-utilized. In this FNPRM, the FCC sought comments on alternatives to stimulate expanded use of, and investment in, the 4.9 GHz band. The Commission's goal is to ensure that public safety continues to have priority in the band while possibly opening up the band to additional uses, including more prominent mobile use.

On October 24, 2018, the FCC issued the 6 GHz NPRM, which proposes to make the 5.925-6.425 GHz and 6.525-6.875 GHz spectrum available for unlicensed operations under rules consistent with the existing Part 15 rules for unlicensed device operations.

2.1.2 SPECTRUM ABOVE 24 GHZ

There has been significant progress in the U.S. towards making spectrum above 24 GHz available for 5G. These bands have traditionally been used for fixed and satellite services.

The FCC has been driving this process since 2014 through multiple NOIs, NPRMs, and FNPRMs, leading to Report & Orders. As a result, multiple bands including 24 GHz (24.25-24.45/24.75-25.25 GHz), 37 GHz (37.6 - 38.6 GHz), 39 GHz (38.6 - 40 GHz), and 47 GHz (47.2 - 48.2 GHz bands were designated for Upper Microwave Flexible Use Service (UMFUS) and the 64-71 GHz spectrum for unlicensed use.

Auction of the 28 GHz band started in November 2018 and was underway in January 2019. The 24 GHz band's auction is expected to start after conclusion of the 28 GHz band auction. Furthermore, the FCC Chairman has announced an intention to auction the 37/39/47 GHz bands in fourth quarter of 2019.

The FCC has also proposed a number of bands including 26 GHz (25.25-27.5 GHz), 32 GHz (31.8-33.4 GHz), 42 GHz (42-42.5 GHz), 50 GHz (50.4-51.4 GHz) for flexible use service, and 70 GHz (71-76 GHz), and 80 GHz (81-86 GHz) for fixed services.

In February 2018, FCC adopted a new NPRM called "Spectrum Horizons" to make the spectrum above 95 GHz more readily accessible for new innovative services and technologies.

For more information on the various US notices, see the Appendix D Additional Resources.

2.2 CANADA

Canada has also been active in identifying and designating new spectrum for 5G broadband services. In June 2018, Innovation, Science and Economic Development Canada (ISED) released a document entitled

Spectrum Outlook 2018 to 2022,[2] which outlined its plans to make additional spectrum resources available to support commercial mobile services, including 5G services, in several bands through 2022. Priority 1 bands identified in the document included the 600 MHz, 3500 MHz, 26 GHz, 28 GHz, 37-40 GHz, and 64-71 GHz bands.

2.2.1 SPECTRUM BELOW 24 GHZ

In March 2018, ISED released SLPB-003-18, *Technical, Policy and Licensing Framework for Spectrum in the 600 MHz Band*, which set out its decisions on an August 2017 consultation on the 614-698 MHz frequency band. In total, 70 MHz of spectrum was made available for flexible use, of which 30 MHz was set aside for new entrants. Although not initially identified as a 5G band during the consultation process, there is a high likelihood that 5G will be deployed given the imminent availability of 5G equipment and devices in this band. An auction for the 600 MHz band is scheduled to take place in March 2019.

A consultation[3] on revisions to the 3.5 GHz band was also released in June 2018 to accommodate flexible use for fixed and mobile 5G services. The consultation proposed reallocating 25 MHz of spectrum in the 3.45-3.475 GHz band from radiolocation service to mobile service on a primary basis. Together with a 2014 decision to allocate the 3.475-3.650 GHz band for flexible use, this proposal would enable 200 MHz of spectrum for 5G services across the entire 3.45-3.65 GHz band.

The consultation also sought preliminary comments on potential changes to the 3.40–3.45 GHz band and the 3.65–4.20 GHz band (referred to as the 3800 MHz band) to support 5G technologies. Specifically, ISED asked for comments on potential interest in sharing spectrum between radiolocation and other services in the 3.40-3.45 GHz band. It also asked for comments on how to optimize the use of the 3.80 GHz band in the future, given that many countries around the world are making changes to their regulatory rules to facilitate commercial mobile or flexible use in this band. While ISED's decisions on the consultation are still pending, they have stated that a 3.5 GHz auction is scheduled to take place in 2020.

2.2.2 SPECTRUM ABOVE 24 GHZ

In June 2017, ISED issued SLPB-001-17, *Consultation on Releasing Millimeter Wave Spectrum to Support 5G,*[4] seeking comments on making millimeter wave (mmW) spectrum available to support the deployment of 5G in the 28 GHz (27.50-28.35 GHz) and 37-40 GHz frequency bands for flexible fixed and mobile use, and the 64-71 GHz frequency band for license-exempt use. Subsequently, ISED released an addendum[5]

[2] SLPB-003-18, *Spectrum Outlook 2018 to 2022*, ISED, June 2018, https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11403.html.
[3] SLPB-004-18, *Consultation on Revisions to the 3500 MHz Band to Accommodate Flexible Use and Preliminary Consultation on Changes to the 3800 MHz Band*, ISED, June 2018, https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11401.html.
[4] SLPB-001-17, *Consultation on Releasing Millimetre Wave Spectrum to Support 5G,* ISED, June 2017, http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11298.html.
[5] SLPB-005-18, *Addendum to the Consultation on Releasing Millimetre Wave Spectrum to Support 5G,* ISED, June, 2018, https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11399.html.

to SLPB-001-17 in June 2018, initiating a consultation on releasing mmW spectrum in the 26.5–27.5 GHz band (26 GHz band) in addition to the bands identified in the initial mmW Consultation. Since the 26 GHz and 28 GHz bands are adjacent, this would provide a total of 1.85 GHz of contiguous mmW spectrum available to support the deployment of advanced communication systems, such as 5G wireless networks and systems. ISED also sought comments of the importance of harmonizing the band plan for the 26.5-28.35 GHz band with the U.S. While a decision on this consultation has not yet been made, an auction of the 26.5-28.35 GHz and 37-40 GHz bands is expected to take place in 2021.

2.3 LATIN AMERICA

5G Americas publishes a frequent comprehensive review of spectrum allocation and utilization in Latin America.[6] That analysis is focused on the region's progress in both allocating and assigning licenses in a range of bands commonly used globally for mobile services. A summary has been included in the appendix and is taken directly from the report reviewing various spectrum allocations and the activity of upcoming auctions in the region as of July 2018. This provides a view of the allocation of sub-3 GHz spectrum in the region.

Similarly, with respect to mid-band spectrum, the Latin American region has significant work ahead to pave the way for the fullest possible use of 5G technologies. Among the major economies in the region, Chile has part of the 3.5 GHz spectrum band assigned to fixed wireless services and is in the process of defining the conditions for a future auction of the spectrum in this band for 5G services. Colombia has a co-primary allocation for mobile in the 3.5-4.2 GHz band, while Argentina has a secondary allocation to mobile in the 3.3-3.4 GHz band. Brazil is considering in the near term identifying and allocating 3.5 GHz and 28 GHz for mobile broadband. Costa Rica joined with Colombia, Canada and the U.S. at WRC-15 to identify the mid-band spectrum at 3.6 -3.7 GHz for mobile broadband. Nonetheless, this relatively limited amount of regional activity stands in sharp contrast to the status of these bands in the U.S., Canada and Europe.

With respect to high-band spectrum, some of the larger jurisdictions in the region are well-positioned to move forward with high-band spectrum needed for 5G. As Table 2.1 shows, the larger economies generally support mobile as a co-primary allocation across a range of frequencies, from 25 GHz to 96 GHz. Moreover, there is good alignment in allocations with the work ongoing in preparation for WRC-19 with respect to these bands.

[6] *Reporte de anuncios de subastas y adjudicaciones de espectro*, 5G Americas. July 2018.

Table 2.1. Existing Co-Primary Allocations to Mobile Services in Selected Latin American Jurisdictions.

Bands	Brazil	Mexico	Argentina	Colombia
25-29 GHz	25.25-29.5 GHz		25.5-27.5; 29.1-29.5 GHz	25.25-29.1 GHz
31 GHz	31-31.3 GHz	31-31.3 GHz	31-31.3 GHz	31-31.3 GHz
36-37 GHz	36-37 GHz	36-37 GHz		36-37.55 GHz
38-40 GHz	39.5-40.5 GHz	38-40.5 GHz		38-40.5 GHz
42-47 GHz	42.5-47 GHz	40.5-42.5; 43.5-47 GHz		42.5-47 GHz
47-50 GHz	47.2-50.2 GHz	47.2-50.2 GHz		47.2-50.2 GHz
50-52 GHz	50.4-52.6 GHz	51.4-52.6 GHz		50.2-52.6 GHz
55-59 GHz	55.78-59 GHz	55.78-59 GHz		54.25-58.2 GHz
59-64 GHz	59-64 GHz	59-64 GHz		59-64 GHz
64-71 GHz	64-71GHz	64-71 GHz		66-71 GHz
71-76 GHz	71-76 GHz	71-76 GHz		71-71.5 GHz
81-86 GHz	81-86 GHz	81-86 GHz		81-86 GHz

To date, other than Brazil, Chile, Colombia, Costa Rica, and Mexico, no other Latin American country has initiated plans to utilize these frequency bands for mobile services with proceedings such as planning to assign licenses. Brazil is considering an auction of 26 GHz and updated rules in 2020, and unlicensed access to the extended 60 GHz band (54 - 71 GHz). Relative to the WRC-19 agenda item on 5G (IMT 2020), Mexico is supporting 24.65 – 27 GHz for mobile broadband. Colombia and Uruguay have joined Brazil's Draft Inter-American Proposal to identify the 26 GHz band for mobile broadband at the WRC. Brazil also has a proposal to identify the 39 GHz band (37 – 43 GHz) for mobile broadband, as does Mexico. In

addition, Mexico supports identifying the 42 – 43.5 GHz, 47.2 – 48.2 GHz, and the 50.4-52.6 GHz bands for mobile broadband in the region at the WRC.

All nations in the region should now be focused on whether additional allocations to mobile will be needed for spectrum at 24 GHz and higher, taking into account harmonization with the larger markets in the region, as well as WRC-19 Agenda item 1.13. Nations may also consider taking steps to assign licenses, and in particular, seek to align spectrum regulations to U.S. decisions in the band, because equipment is already available in some of the bands identified by the U.S.

2.4 EUROPEAN UNION

The Radio Spectrum Policy Group (RSPG) is a high-level advisory group that assists the European Commission of the European Union (EU) in the development of radio spectrum policy.[7] The RSPG developed an opinion on spectrum bands for next generation wireless systems (5G) as agreed to in the RSPG Work Program for 2016. The opinion[8] was finalized in November 2016 and identified a strategic roadmap for 5G in Europe. In particular, the roadmap identified the following main building blocks for 5G spectrum:

- Mid-band spectrum at 3.4-3.8 GHz as a "primary" band, which will provide capacity for new 5G services
- High-bandwidth spectrum at 24.25-27.50 GHz as the "pioneer" millimeter wave band to give ultra-high capacity for innovative new services, enabling new business models and sectors of the economy to benefit from 5G
- The EU's Conference of telecom regulators (CEPT) also proposes a mobile broadband identification for 40.5-43.5 GHz. This is a priority band for CEPT and already identified for future harmonization in Europe. According to its draft European Common Position for WRC-19, CEPT considers that 40.5-43.5 GHz has good potential for future harmonisation in Europe[9]

2.4.1 FRANCE

Under France's 5G roadmap, its regulator ARCEP has allowed trials throughout 2018 in several French cities in the 3.4-3.8 GHz range. The roadmap will allow band plans of more than 300 MHz of contiguous spectrum by 2020. Additional reorganization is planned to extend the amount of spectrum to 340 MHz by the year 2026.[10] In May 2018, ARCEP released a public consultation on the 26 GHz band, and is also considering the 1.5 GHz (part of the L Band) for 5G.

[7] http://rspg-spectrum.eu/

[8] *Opinion on spectrum related aspects for next-generation wireless systems (5G),* http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf.

[9] Draft CEPT Brief on WRC-19 Agenda Item 1.13, Doc. CPG (18)073 ANNEX IV-13. 30 November 2018.

[10] *France to allocate 5G spectrum in September,* Nick Wood, Total Telecom. 26 June 2017. https://www.totaltele.com/497381/France-to-allocate-5G-spectrum-in-September.

2.4.2 GERMANY

Germany's federal network regulator Bundesnetzagentur (BNetzA) decided in May 2018 to award licenses in the 2 GHz and 3.5 GHz band, pursuant to its framework document from June 2017.[11] In early 2019, the 3.4-3.7 GHz band will be auctioned as national licenses in 10 MHz blocks. The 3.7-3.8 GHz band is also planned for auction in 2019, depending on demand for local/regional licenses. BNetzA also announced plans to develop an application procedure for auctions in 2019 of the 26 GHz (24.25 GHz-27.5 GHz) band for 5G. Other millimeter wave bands will be considered over time.

2.4.3 IRELAND

Ireland completed its 5G auction in 2017 for the 3.6 GHz band, which included 350 MHz in the 3.475-3.8 GHz band.[12] Three Ireland's CEO Robert Finnegan stated that the company wanted to acquire the optimum bandwidth for 5G of 100 MHz in the auction in a band that was internationally recognized as capable to support 5G use cases below 6 GHz.[13]

2.4.4 UNITED KINGDOM

The United Kingdom's Ofcom is taking a leading role internationally in identifying spectrum bands for 5G and has already auctioned 150 MHz of spectrum in the 3.4-3.6 GHz band as well as spectrum in the 2.3 GHz band.[14] Ofcom has already started the process of preparing for auctions in the adjacent the 3.6 – 3.8 GHz band.

In the millimeter wave band, Ofcom has said that it fully supports the identification of the 26 GHz band by the Radio Spectrum Policy Group and has started efforts to determine what actions are necessary to make this spectrum available for 5G.[15]

2.5 CHINA

In July 2017, China's Ministry of Industry and Information Technology (MIIT) approved the 4.8-5.0 GHz, 24.75-27.5 GHz and 37-42.5 GHz bands for China's 5G technology research and development testing.[16] This action follows MIIT approval of the frequency band 3.4-3.6 GHz in January of 2016 for 5G trials in both

[11] *Germany unveils 5G spectrum framework, plans auction in 2018,* Telecompaper. 29 June 2017. http://gtigroup.org/news/ind/2017-06-29/10751.html.
[12] *Irish 5G spectrum auction raises €78m,* Nick Wood, Total Telecom. 25 May 17. https://www.totaltele.com/497141/Irish-5G-spectrum-auction-raises-78m.
[13] *Five firms win Ireland's first 5G licenses in €78m auction*, John Kennedy, Silicon Republic. 22 May 2017. https://www.siliconrepublic.com/comms/5g-auctions-ireland.
[14] https://www.ofcom.org.uk/__data/assets/pdf_file/0021/97023/5G-update-08022017.pdf.
[15] *Ofcom updates 5G spectrum plans*, TeleGeography. 9 February 2017. https://www.telegeography.com/products/commsupdate/articles/2017/02/09/ofcom-updates-5g-spectrum-plans/.
[16] *Ministry of Industry and Information Technology approved the new 5G technology test frequency,* Radio Authority. 14 July 2017. http://www.miit.gov.cn/n1146285/n1146352/n3054355/n3057735/n3057743/c5730476/content.html?from=groupmessage&isappinstalled=0.

Beijing and Shenzhen. These tests were meant to verify various aspects of the 5G technologies and provide a foundation to facilitate early ecosystem development. In June 2017, MIIT's Radio Administration expanded the frequency range to 3.3-3.6 GHz, with 3.3-3.4 GHz limited to indoor use. It also issued a public consultation to seek comments on the spectrum use for 5G.[17] In March 2018, an MIIT official stated to local press that the government expected to issue commercial 5G licenses in the second half of 2019.

In December 2018, the MIIT provided China Unicom access to the 3.5 GHz to 3.6 GHz frequency band for a nationwide 5G trial rollout through June 2020. In exchange for the use of this spectrum, China Unicom will vacate spectrum in the 2.555 GHz to 2.575 GHz range that they were using for 5G trials. China Telecom will be given the 3.4 GHz to 3.5 GHz spectrum for 5G trials in mainland China. In exchange for the use of this spectrum, China Telecom will vacate the spectrum in the 2.635 GHz to 2.655 GHz range that they were using for 5G trials. China Mobile, the country's largest operator, has been approved to use spectrum in the 2.515 GHz to 2.675 GHz and the 4.8 GHz to 4.9 GHz ranges for its nationwide 5G trials. The 2.5-GHz spectrum includes frequencies to be re-farmed from China Mobile's existing TD-LTE spectrum.

2.6 JAPAN

Japan hopes to commercialize 5G services in time for the 2020 Olympics. The frequency ranges which currently have priority in Japan for 5G in the millimeter wave bands are 24.25-29.5 GHz, 37.0-40 GHz and 40.5-43.5 GHz, with 27.5-29.5 GHz receiving priority attention. Japan's leading operators have been testing 5G; particularly in the 28 GHz and 39 GHz bands. In mid-band spectrum, Japan is currently considering 3.6-4.2 GHz and 4.4-4.9 GHz for 5G.18 Japan has already allocated spectrum in the 3.5 GHz band.[18] [19]

2.7 SOUTH KOREA

On June 18, 2018, South Korea completed its auction of 5G spectrum with 280 MHz bandwidth of 3.5 GHz spectrum and 2400 MHz bandwidth of 28 GHz spectrum awarded to three operators. On December 1, 2018 all three national carriers launched 5G services in South Korea (SK Telecom, Korea Telecom (KT) and LG U Plus). A national broadband plan was published early 2017 and indicates the possibility of extending the 28 GHz band by up to 2 GHz to provide access to a total of 3 GHz, 26.5 – 29.5 GHz. There is interest in more spectrum for 5G in the longer term, though it is not yet decided which frequency band.[20]

[17] *China issues plan to use 3300-3600 MHz, 4800-5000 MHz for 5G*, Monica Alleven, FierceWireless. 7 June 2017. http://www.fiercewireless.com/wireless/china-issues-plan-to-use-3300-3600-mhz-4800-5000-mhz-for-5g.
[18] *Japan's Radio Policy to realize 5G in 2020*, Presentation by Kuniko Ogawa, Director for Land Mobile Communications Division, Ministry of Internal Affairs and Communications, Japan. 28 June 2016. https://www.gsma.com/spectrum/wp-content/uploads/2016/08/MIC_Spectrum-for-5G-MIC-Kuniko-OGAWA.pdf.
[19] *Japan released 3.5G TDD licenses – 3.5 G TDD-LTTE commercialization is accelerating*, GTI Group. 12 December 2014. Gtigroup.org http://www.gtigroup.org/news/ind/2014-12-25/5208.html.
[20] *K-ICT Spectrum Plan*, Ministry of Science, ICT and Future Planning (MSIP) of Korea. January 2017. http://blog.naver.com/with_msip/220917986508.

2.8 AUSTRALIA

In December 2018, Australia concluded an auction for 3.6 GHz,[21] and the commercialization of 5G services in Australia is expected to begin in 2019. Australia plans to allow access to both the 3.6 GHz and 26 GHz bands. In February 2016, the Australian Communications and Media Authority (ACMA) released a paper on 5G and Mobile network developments - Emerging issues.[22] It recognized that supporting international harmonization played a critical role in leveraging the economies of scale achieved and the resulting benefits for Australia arising from lower device costs. The ACMA also issued a discussion paper seeking comment on whether and how to proceed with making the 3575-3700 MHz band (ACMA also is interested in examining spectrum from 3400-3700 MHz) available for mobile broadband services.[23]

2.9 TAIWAN

5G can be expected to be commercialized in Taiwan in 2020. In May 2018, the telecom regulator for Taiwan, the NCC, revealed plans to auction 5G licenses no later than the end of 2019, although the specific frequencies are still up under discussion, with the mid-band spectrum in the 3.4 GHz-3.6 GHz bands held by Chunghwa Telecom and the Taiwanese military.

NCC is reportedly considering low-band spectrum for 5G, including the 700 MHz band and 800 MHz band, while the 28 GHz band is also expected to receive further consideration.

2.10 HONG KONG

Hong Kong's Communications Authority (CA) has announced its intention to auction the 3.5 GHz band (3.4 GHz-3.6 GHz) band by 2020 to support 5G technology, Hong Kong operators have requested to have low-band and high-band spectrum additionally made available.

In August 2018, the CA and Hong Kong's Commerce and Economic Development Bureau initiated a joint consultation into the assignment of 5G-suitable spectrum in the 3.3 GHz and 4.9 GHz bands, with a 100 MHz available in each band. A major operator was granted a temporary permit in May 2018 to test 5G in the 26 GHz-28 GHz range. Press reports have suggested that this high-band spectrum could be made available as early as April 2019.

[21] *Australia's 5G Auction Concludes*, the ACMA. 12 December 2018. https://www.acma.gov.au/theACMA/australias-5g-auction-concludes.
[22] 5G and Mobile Network Development, the ACMA. Consultation closed: 14 March 2016. http://www.acma.gov.au/theACMA/5g-and-mobile-network-developments.
[23] *Future use of 1.5 GHz and 3.6 GHz bands*, ACMA. Oct. 2016. http://www.acma.gov.au/theACMA/future-use-of-the-1_5-ghz-and-3_6-ghz-bands.

3. BAND CHARACTERISTICS

Wireless innovation, next-generation technologies, and the emergence of 5G will drive demand for cutting edge services and applications – all of which means that technology alone will not fulfill the traffic demand and the need for more wireless broadband spectrum is acute. A combination of spectrum across low-bands, mid-bands, and high-bands will optimize wireless broadband deployments and address the variety of expected 5G use cases.

3.1 LOW-BANDS, MID-BANDS & HIGH-BANDS

Depending upon frequency bands, the technology will perform differently and some bands will be better suited for certain use cases than others.

For instance, lower frequency bands, such as those below 2 GHz, are an excellent fit for coverage and mobility and are valuable for high aggregation of low bandwidth users, such as interactive communications and massive Machine Type Communications (mMTC). Low-band spectrum is also well suited for indoor penetration. In terms of capacity, some 5G use cases will rely on significantly higher peak data rates for faster connections and low latency, and this will require wider channels than are available in the lower bands.

Higher frequency bands, such as those in the millimeter waves (mmW), are optimal for short range, low latency, and very high capacity transmissions for enhanced mobile broadband (eMBB), but with a more limited range and with limited indoor penetration.

Mid-band spectrum offers a balance of these capabilities, complementary to mmW in urban and suburban settings and extending the availability of 5G beyond densely populated areas. Mid-band deployments typically use a smaller number of macro base stations - in contrast to the larger number of small cells required to support mmW 5G deployments.

Indeed, U.S. FCC Chairman Pai recently observed, “As the world goes wireless, as consumers rely ever more heavily on their mobile devices, we need to keep up and that means in part looking at spectrum bands ‘in the middle,’ where the FCC historically hasn’t focused.”[24]

[24] *Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*, Statement of FCC Chairman Ajit Pai. GN Docket No. 17-183, FCC 17-104. 3 August 2017.

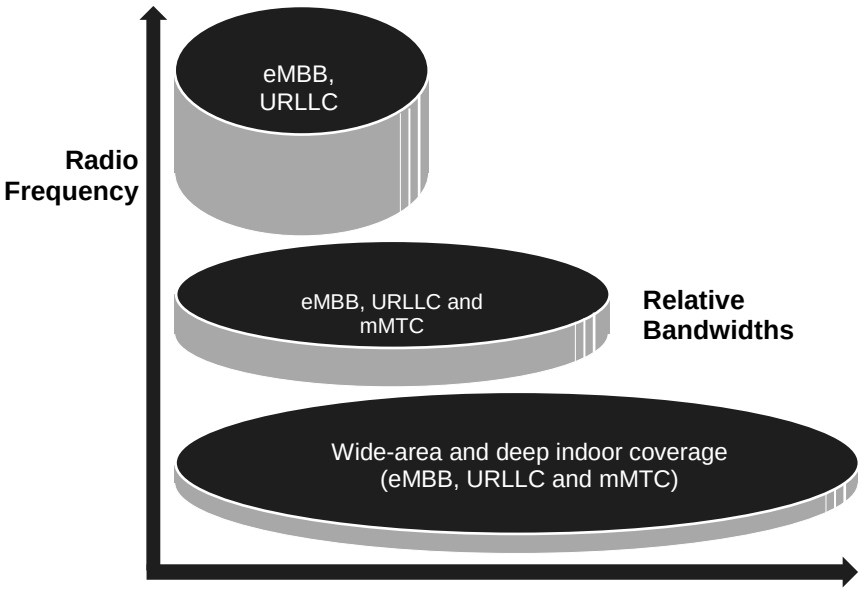

Figure 3.1. Relative Radio Frequency Propagation Range.

3.2 UNLICENSED BANDS

There is a significant amount of spectrum available in the unlicensed bands. This has been utilized for a variety of purposes such as WiFi, Point-to-Point Transport and Low Power Instrumentation and Automation. 3GPP Release 13 specified the functionality necessary for LTE networks to utilize the unlicensed 5 GHz spectrum as a peak throughput booster and hot spot capacity relief mechanism.

When compared with the total allocation of licensed spectrum for mobile networks, the amount of unlicensed spectrum is significantly greater. Unlicensed bands are generally shared with licensed operations and unlicensed devices usually operate with no protection from interference and must protect uses operating under a primary allocation. Regulations generally limit the power for devices operating on an unlicensed basis and may include other technical limits to facilitate sharing. Due to the unlicensed nature of the spectrum, it is necessary that all potential users of the spectrum share the resources and hence there are regulations that limit the allowed transmit power, radiation patterns, duty cycles, and access procedures to ensure that all users can be served by the resource. Accordingly, reliability and performance of services running on shared, unlicensed spectrum are not assured. In most circumstances, the unlicensed spectrum works well but in certain circumstances (for example, high demand scenarios such as a public sports venues), the results can be less than satisfactory.

4. OPPORTUNITIES AND CHALLENGES WITH DIFFERENT BANDS FOR 5G

Each spectrum range has specific characteristics as previously explained that make it more suitable for certain deployment scenarios. While the low range of spectrum has very good propagation aspects that make it feasible for large area coverage, low-band has limited capacity due to the lack of available spectrum and component design considerations. The mid-range of spectrum provides a type of coverage more feasible for urban deployment due to increased capacity. The high-range of spectrum is more limited in coverage but could provide very high capacity due to the amount of unused spectrum and wider channelization available at these frequencies.

In the following subsections, the characteristics of potential new licensed 5G spectrum below and above 24 GHz are reviewed.

4.1 SPECTRUM BELOW 24 GHZ

Among the frequencies below 24 GHz, there are currently two upcoming bands in the U.S. that are most likely to provide licensed spectrum for 5G deployments in the relatively near term: CBRS (3.55-3.70 GHz); and C-Band (3.70-4.20 GHz). Other bands that have been highlighted by the FCC as having a potential for 5G mobile broadband use are the 6 GHz bands (5.925-6.425 GHz and 6.425-7.125 GHz). The FCC is seeking comments on its proposed use of the 6 GHz band for unlicensed use.

4.1.1 3.55-3.7 GHZ (CBRS) BAND

The 3.55- 3.7 GHz band, referred to as the Citizens Broadband Radio Service (CBRS) -- due to the name of the FCC rule section that was modified to allow its use for broadband -- has a three-tier structure. This structure, combined with the limited amount of available spectrum and low transmit output power, offers limited opportunity as sufficient 5G mid-band spectrum solution to the U.S. mobile service providers.

The recent 2018 Report and Order made significant changes to the Priority Access License (PAL) framework, such as: increasing the size of PAL license areas from census tracts to counties; extending the license terms to ten years; and making such licenses renewable. The changes will likely make the CBRS PAL licenses more attractive for mobile service providers.

However, there are still limitations on the use of the CBRS spectrum including: reduced base station transmit power compared with traditional licensed mobile bands; and the potential to lose access to channels due to dynamic incumbent operations which will remain in the 3.5 GHz band on a primary basis. Moreover, an individual organization is only eligible to purchase up to 40 MHz of PAL spectrum and efficiency of spectrum allocation is lost due to the three-tier dynamic sharing structure. This generally leaves the U.S. with less mid-band spectrum than what most other major countries are making available for 5G

services. The total CBRS licensed spectrum is insufficient to meet long-term 5G mobile wireless broadband requirements.

The situation in Canada is drastically different. A public consultation issued by ISED in June 2018 proposed revisions to the 3.45-3.65 GHz band to accommodate flexible use for fixed and mobile service. Unlike the U.S., a three-tiered framework for coordinating shared use was not put forward. Instead, ISED proposed adopting a band plan with 20 unpaired licensed 10 MHz blocks. As most of this band (3.475-3.65 GHz) is currently used for fixed wireless Internet services, incumbent licensees will be required to reduce their spectrum holdings and transition to different frequencies in the new band plan. An auction for this band is expected to take place in 2020, following a second consultation on the technical, policy and licensing framework.

The U.S. NTIA's review and possible repurposing of an additional 100 MHz at 3.45-3.55 GHz from government use to commercial broadband could help mitigate the shortage in the U.S. of internationally harmonized mid-band spectrum.

4.1.2 3.70 – 4.20 GHZ C-BAND DOWNLINK

The band 3.70-4.20 GHz band holds significant promise for terrestrial mobile, as it overlaps and is adjacent to 3.5 GHz spectrum that is being made available for 5G services in many countries globally. The 3.70-4.20 GHz band is also adjacent to the CBRS band discussed above. International efforts are well underway to make mid-band spectrum available for 5G operations, and the 3.70-4.20 GHz band is becoming globally harmonized. Several countries already have designated this band or a portion of it for wireless mobile broadband.

The 3.70-4.20 GHz band is important to fill the gap between low-band and high-band spectrum because the band provides a balance of capacity and coverage along with a large contiguous spectrum block. Therefore, it has the potential to accommodate the wide bandwidth demands required for new 5G use cases and performance. Designating the band for licensed wireless use is critical to ensure 5G global competitiveness.

Currently the C-Band is utilized for satellite downlink and fixed services. These uses will need to be addressed as part of the process to enable this band for terrestrial 5G. Co-channel sharing between terrestrial and satellite operations in the same area will be challenging, if not impossible. Therefore, the band must be generally repurposed – particularly in urban areas. The FCC in its recent 3.70-4.20 GHz Notice of Proposed Rulemaking (NPRM) has proposed several ways forward. It is critical that the entire 500 MHz, or at least a significant portion of the 500 MHz be repurposed for licensed terrestrial use. Licensed wireless use in this band will help meet the demand for additional capacity for wireless networks providing 5G technologies, harmonizing the band with international designations, and complementing the mmW spectrum already (or soon to be) available for mobile wireless broadband.

The 3.70-4.20 GHz band is also being considered for commercial mobile or flexible use in Canada. As in the U.S., this band is primarily used for C-Band satellite downlink services and shares similar repurposing challenges. Although this band was included in the same consultation[25] as the 3.45-3.65 GHz band, it is at an earlier stage in the consultation process and a decision on any future consultations is still pending.

4.1.3 5.925-6.425 GHZ AND 6.425-7.125 GHZ (6 GHZ) BAND

The 6 GHz band has the potential of delivering a 1200 MHz swath of "mid-band" spectrum for 5G services if appropriate sharing mechanisms with fixed service incumbents are developed.

On October 24, 2018, the FCC issued the 6 GHz band NPRM which proposes to make the 5.925-6.425 GHz and 6.525-6.875 GHz bands available for unlicensed operations. The NPRM included four new "U-NII"[26] bands with attributes described in Table 4.1.

Table 4.1. Attributes of U-NII Bands 5-8.

Band	Frequency Range (MHz)	Bandwidth (MHz)	Access Point Max. EIRP	Use Restrictions	AFC System
U-NII-5	5975 – 6425	500	4 W	Indoor/Outdoor	Yes
U-NII-6	6425 – 6525	100	1 W	Indoor Only	No
U-NII-7	6525 – 6875	350	4 W	Indoor/Outdoor	Yes
U-NII-8	6875 – 7125	250	1 W	Indoor Only	No
Total	5975 - 7125	1,150			

In the U-NII-5 and U-NII-7 bands, unlicensed devices would only be allowed to transmit under the control of an Automated Frequency Control (AFC) system to protect existing point-to-point microwave links and Fixed Satellite Services (FSS). In the U-NII-6 and U-NII-8 bands, unlicensed devices would be restricted to indoor use and would operate at low power, without an AFC system.

In Europe, the focus for the introduction of unlicensed operation in the 6 GHz band is limited to 5.925-6.425 GHz. The European Commission adopted a mandate to CEPT to study the feasibility and identify harmonized technical conditions for coexistence basis of the 5925-6425 MHz band for Wireless Access Systems including Radio Local Area Networks (WAS/RLANs). At the 44th Plenary meeting (28 February-3 March 2017), the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) agreed to task Working Group Frequency Management (WG

[25] *Consultation on Revisions to the 3500 MHz Band to Accommodate Flexible Use and Preliminary Consultation on Changes to the 3800 MHz Band*, SLOB-004-18. June 2018. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11401.html.
[26] The FCC term "U-NII", for Unlicensed National Information Infrastructure, dates from the early days of the commercialization of the Internet in the 1990s, when Internet Protocol-based technology was described by policymakers as National Information Infrastructure. U-NII-1 through U-NII-4 are the unlicensed bands in the 5 GHz range.

FM) to study the technical and regulatory feasibility of harmonized introduction of low power WAS/RLANs in the band 5925-6425 MHz. The related compatibility studies (with the Fixed Service and Fixed Satellite Service (uplink) are to be conducted in System Working Group Spectrum Engineering 45 (SE 45).

The European Telecommunications Standards Institute (ETSI) has created a technical report, ETSI TR 103 524 V1.1.1 (2018-10)[27] in support of the ECC Work Item SE45_1 covering the band 5.925 GHz to 6.425 GHz. In addition, the report contains a request to consider additional frequencies for unlicensed or license exempt use of spectrum up to 6.725 GHz.

To date, there have been no public consultations in other parts of North America on designating 6 GHz spectrum for unlicensed use, but interest is growing in Canada. The 6 GHz band was discussed in ISED's *Spectrum Outlook 2018 to 2022* document but considered a low priority band and, as such, no plans were made as of January 2019 for a public consultation for this band.

4.1.4 12 GHZ BAND

The 12 GHz (12.2-12.7 GHz) spectrum band is allocated to FSS and Broadcasting on a co-primary basis, but, is widely used for Direct Broadcast Satellite (DBS) services. Fixed service (FS) is also permitted, provided it does not interfere with the satellite services. Multichannel Video Distribution and Data Service (MVDDS) was authorized in the U.S. under the FS allocation.

Over the last few years, incumbent satellite licensees have made requests to convert the spectrum for 5G mobile broadband use. Mobile operators have argued that incumbent satellite licensees should not be rewarded for allowing the spectrum to be fallow by giving them mobile rights. Other satellite entities (Boeing, OneWeb) have opposed those requests. To date, there has not been any ruling on this matter, however, protection of DBS and satellite downlink would probably severely limit the use of this band for 5G mobile services.

There have been no public consultations in Canada or in Europe on releasing the 12 GHz band for 5G services at this stage.

4.2 SPECTRUM ABOVE 24 GHZ

Multiple mmWave bands have been identified in the U.S. by the FCC for broadband, including 24 GHz, 28 GHz, 37 GHz, 39 GHz, and 47 GHz bands, and are expected to be auctioned over the next couple of years. The auction of the 28 GHz band began in November of 2018. The auction of the 24 GHz band will begin in early 2019, after a required six-week rest period. The additional mmW bands at 37, 39 and 47 GHz will be auctioned later in 2019. Through these auctions a significant amount of mmW spectrum will become

[27] *Wireless access systems including radio local area networks (WAS/RLANs) in the band 5 925 MHz to 6 725 MHz*, ETSI TR 103524 v1.1.1. October 2018. https://www.etsi.org/deliver/etsi_tr/103500_103599/103524/01.01.01_60/tr_103524v010101p.pdf.

available for 5G broadband use. The FCC is also considering a number of additional bands for flexible use, including 32 GHz, 42 GHz, and 50 GHz. Each of these bands have their own specific characteristics and issues.

4.2.1 24 GHZ BAND

The 24 GHz band consists of a lower (24.25-24.45 GHz) and upper segment (24.75-25.25 GHz) resulting in 700 MHz of spectrum which has the lowest propagation losses compared to other mmW bands under consideration. The upper segment of the 24 GHz band is shared with FSS uplink. Sharing with FSS is manageable since the number of existing and future FSS earth stations has been limited by the FCC and the sharing mechanisms could be like the sharing of broadband wireless with FSS earth stations in the 28 GHz band.

The main issue with the 24 GHz band is its proximity to the Earth Exploration Satellite Service (EESS) band which needs protection from the 24 GHz band emissions. This issue has been studied in the International Telecommunication Union (ITU) and different government agencies in other countries to determine the need for more stringent Out-of-Band Emission (OOBE) requirements on broadband services in the band. The overall propagation losses in this band are less than other mmW bands despite the local peak in atmospheric absorption in this band, which is about 0.15 dB/km more than 28 GHz band.

Another potential drawback is the 300 MHz gap in the U.S. rules for flexible commercial use between the lower and upper segments of this band. However, that does not seem to pose a significant problem as the planned equipment for the mmW bands are expected to handle non-contiguous spectrum.

In Canada, ISED is currently monitoring developments in the 24 GHz band to determine when, and for which services, these bands should be made available.

4.2.2 28 GHZ BAND

The 28 GHz band offers 850 MHz of contiguous spectrum that is among the most internationally harmonized with potential for a robust ecosystem. Although WRC-15 omitted 27.5-28.35 GHz from a list of mmW bands that it invited ITU-R to study for mobile service, several countries like South Korea, Japan, Sweden, Finland, the U.S. and Singapore support or plan to have mobile use in the band.

The key issue in this band is sharing with FSS gateway earth stations. However, the studies by different industry groups have concluded that the impact of FSS uplink on the 5G receivers can be minimized by carving out a relatively small area around each earth station from the mobile broadband service area.

The other shortcoming is lack of opportunity for auction participants to gain access to the 28 GHz band spectrum for major markets. In the U.S., most of the top 50 -100 markets licenses are held by incumbents or have already been acquired in secondary market deals. The FCC 28 GHz spectrum holdings being

auctioned in 2018/2019 consist mainly of the spectrum in smaller markets. Nonetheless, the 28 GHz auction was ongoing as of January 2019 and had netted over $700 million in proceeds to date.

In Canada, two consultations on releasing millimeter wave spectrum for 5G services have been issued in recent years). The first consultation[28] in June 2017 sought comments on developing a flexible use model for fixed and mobile services in the 27.5-28.35 GHz band and adopting the same band plan as the U.S. Comments were also solicited on whether unlicensed use should be implemented across the entire 28 GHz band. The second consultation[29] in June 2018 proposed extending the flexible use licensing model to include the adjacent 26.5-27.5 GHz band, providing 1.835 GHz of contiguous flexible use spectrum. Harmonization with the U.S. band plan was also opened up for renewed comments. Decisions on both consultations are still pending but a spectrum auction for the combined 24.5-28.35 GHz band is expected to take place in 2021.

4.2.3 37 GHZ BAND (37-38.6 GHZ)

This band is one of the least encumbered by incumbents as there are no U.S. Federal or non-Federal services in the band.

The entire 37 GHz band is allocated in the U.S. to the fixed and mobile services on a primary basis for Federal and non-Federal use. Portions of the 37 GHz band are also allocated to the Space Research Service (SRS) (space-to-Earth) on a primary basis for Federal use (37-38 GHz) and to the Fixed-Satellite Service (FSS) (space-to-Earth) on a primary basis for non-Federal use (37.5-38.6 GHz). The use of this FSS downlink allocation is limited to individually licensed earth stations and is also subject to other limitations. The lower band segment will be fully available for use by both Federal and non-Federal users on a coordinated co-equal basis. Non-Federal users, identified as Shared Access Licensees (SAL), will be authorized by rule. Federal and non-Federal users' access to the lower portion had not been determined as if January 2019. The third FNPRM proposed a few coordination mechanisms, but a fully developed dynamic sharing mechanism requires further study along with government and industry collaboration.

In addition to the uncertain status of sharing in the lower 600 MHz of the band, the 37 GHz band (like the 24 GHz band), is adjacent to a passive services band (36-37 GHz), where passive sensors in the Earth Exploration Satellite Service (EESS) and SRS (Space Research Systems) are located and would be impacted by the necessary protection requirements of those services.

[28] *Consultation on Releasing Millimetre Wave Spectrum to Support 5G,* June 2017. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11298.html.
[29] *Addendum to the Consultation on Releasing Millimetre Wave Spectrum to Support 5G,* June 2018. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11399.html

The ITU-R's Task Group 5/1 sharing studies are focusing on determination of additional isolation needed to protect EESS (passive) services. It should be noted that the EESS (passive) operations in 36-37 GHz already share co-frequency with active fixed and mobile services.

In Canada, the 37-40 GHz band has the same primary allocations as the U.S. and was included in the June 2017 consultation, as noted previously. To benefit from the ecosystem that develops in the U.S. and simplify coordination of fixed and mobile services along the Canada-U.S. border, ISED proposed adopting the same band plan as the U.S. for the entire 37-40 GHz range.

4.2.4 39 GHZ BAND (38.6-40.0 GHZ)

This band is currently allocated for fixed, fixed satellite (space-to-Earth), and mobile services on a primary basis for non-Federal use in the U.S. There are co-primary Federal FSS (space-to-earth) and MSS (space-to-Earth) allocations in the 39.5-40.0 GHz band, limited to military systems.

The non-Federal satellite earth stations in the 39 GHz band are authorized on a first-come, first-served basis that will entitle them to protection from terrestrial transmissions subject to certain conditions.

The issues with the band include the current licenses' format and band sharing with the FSS earth stations. The current licenses include unpaired blocks of 50 MHz channels, previously 2x50 MHz Frequency Division Duplex (FDD), in both Partial Economic Area (PEA, previously EA) and Rectangular Service Area (RSA) geographic licensing areas. The Fourth *Spectrum Frontiers* R&O is addressing the transition to a contiguous spectrum band plan with 100 MHz Time Division Duplex (TDD) blocks.

The band sharing with FSS in the 37.5-40.0 GHz band has been addressed through requiring only a limited number of individually licensed earth stations in each PEA. Since the sharing mechanism requires the mobile services to be protected from the earth station transmissions, relatively large exclusion zones (many times that of the 28 GHz band) need to be carved out of the mobile service areas.

4.2.5 47 GHZ BAND (47.2-48.2 GHZ)

The 47.2-50.2 GHz frequency bands are allocated to the Fixed, Fixed Satellite, and Mobile Services on a co-primary basis in all three ITU Regions. It is important to note that ITU Regions 1 and 2 (Region 2, for the Americas, Region 1 for Europe, the Middle East, and Africa) utilize different portions of the 47.2-50.2 GHz bands for high density FSS applications and that the spectrum for high density applications in Region 3 (Iran and Asia Pacific) are in frequency bands other than 47.2-50.2 GHz.

The second *Spectrum Frontiers* FNPRM established UMFUS service rules in the 47.2-48.2 GHz band and ruled that UMFUS licenses will be issued in that band with both fixed and mobile rights. There are no Federal allocations in this band, but, sharing between terrestrial operations and a limited number of FSS earth stations per PEA licenses in uplink bands (similar to the 28 GHz band) is required. The other issue

for this band is that internationally it is part of the 47.2-49.2 GHz band which needs to protect the adjacent EESS and Space Research operations.

4.2.6 64-71 GHZ BAND

This 7 GHz of spectrum is available in the U.S. for unlicensed use under the technical standards of the FCC's Part 15 for the 57-64 GHz frequency band with slight modifications.

There are no authorized non-Federal operations in this band. The only service allowed is Inter-Satellite Service (ISS), but there are currently no active satellite licenses in this band. The band has been designated for Federal and non-Federal fixed, Radiolocation, Radio Navigation-Satellite, and Earth Exploration-Satellite. Any use of the 66-71 GHz band by the land mobile service is subject to causing no interference to, and accepting interference from, the space radiocommunication services in this band.

Greater propagation losses compared to lower frequency licensed mmW bands could make this band less desirable for mobile broadband, but at the same time the propagation of the much shorter wavelength of this band range facilitates larger antenna arrays that could compensate for the loss in range. There is no abnormal high attenuation due to water absorption losses like the adjacent 60 GHz band.

The 64-71 GHz band is also being considered for unlicensed use in Canada and was included in the June 2017 consultation on releasing millimeter wave spectrum for 5G services. As mentioned, a decision on this consultation is pending. Most of the band, 66 – 71 GHz, is under study for possible identification for mobile broadband under the WRC-19 agenda item. Several countries are considering identifying the band for 5G under this study item.

4.2.7 70 / 80 GHZ BANDS (71-76 GHZ AND 81-86 GHZ)

In the second mmW FNPRM, the FCC declined to authorize mobile use in the 70 GHz and 80 GHz bands (referred to by some as the E Band) under UMFUS rules, while reserving the right to revisit this issue as mobile use deploys in other millimeter wave bands, technology develops, and as further thought is given to mobile/fixed coexistence.

Currently, multiple systems including Federal and non-Federal Fixed, FSS, Mobile, Mobile Satellite Switching System (MSS) (space-to-Earth), Broadcasting Satellite Service (BSS) and SRS have allocations or operate in different segments of these bands.

Band sharing between Federal and non-Federal users, and among different types of non-Federal uses (fixed and satellite) is coordinated through third-party database systems. Licensees may operate a link only after the link is both registered with a third-party database and coordinated with NTIA. Based upon information available from the third-party database managers, as of June 10, 2016, there were approximately 12,000 registered fixed links in the 70 GHz and 80 GHz bands.

Similarly, the 70/80 GHz bands are not being authorized for 5G mobile services in Canada in the near term. Instead, they are being prioritized for backhaul services to satisfy the immediate demand with a potential release in mid-2020.

5. IDENTIFICATION OF FUTURE 5G BANDS IN NORTH AMERICA

This section addresses some spectrum ranges that the FCC and NTIA could assess as potential future bands for 5G in North America, serving a wide variety of use cases. This list is not exhaustive and other bands can certainly be considered. Potential pairings and duplex directions (TDD or FDD) are not discussed for all the bands and are for further study. Given the incumbency in the bands, sharing of the bands with the incumbents in addition to clearing would need to be studied in order to obtain access for 5G systems.

5.1 LOW-BAND

The low-bands considered for 5G include the 470-512 MHz T-Band, 1300-1350 MHz and 1780-1830 MHz bands and 1675-1695 MHz bands which are explained in the following sections 5.1.1 to 5.1.3.

5.1.1 470-512 MHZ T- BAND

According to the FCC's licensing records, there are 925 public safety entities that hold licenses in the T-Band. These systems are licensed in eleven metropolitan areas where T-Band spectrum is allocated for land mobile radio (LMR) use: Boston, MA; Chicago, IL; Dallas/Fort Worth, TX; Houston, TX; Los Angeles, CA; Miami, FL; New York, NY/NE NJ; Philadelphia, PA; Pittsburgh, PA; San Francisco/Oakland, CA; and Washington, DC/MD/VA.[30]

The Middle-Class Tax Relief and Job Creation Act of 2012 (The Act) requires that within 9 years of the Act's enactment, therefore, by February 22, 2021, the FCC must take certain steps to begin the auction and relocation process, but public safety incumbents are not required to relocate at that time. Specifically, by the 9-year deadline, the FCC must "reallocate" T-Band public safety spectrum and "begin a system of competitive bidding. The Act states that "relocation shall be completed not later than 2 years after the date on which the system of competitive bidding is completed. Therefore, the exact timing of the relocation deadline will depend upon the conclusion of the T-Band competitive bidding process.

There have been, and will likely be in the future, legislative efforts to keep the T-Band for land mobile services in the U.S. The legislation would only impact use in those 13 areas and only addresses the public safety use. A portion of the spectrum in those areas is for private land mobile use and that wasn't

[30] *Public Safety T-Band Fact Sheet*, FCC. July 2016. https://transition.fcc.gov/pshs/docs/T-Band_FactSheet_July2016.pdf.

addressed. The limited and fragmented available spectrum would undermine its utility for commercial services.

As it pertains to other 450 MHz spectrum blocks, the 450 MHz Alliance[31] was recently created to promote the allocation of the 450 MHz spectrum worldwide for mobile broadband, and to grow and facilitate coordination of the 450 MHz ecosystem to maximize commercial benefits for stakeholders. Its members include traditional wireless industry companies such as wireless carriers and equipment manufacturers, as well as companies representing various vertical markets for machine-to-machine communication.

5.1.2 1300-1350 MHZ AND 1780-1830 MHZ BANDS

The AIRWAVES bill introduced in the previous Congress (proposed legislation and not yet law) asks NTIA to report on relocating federal operations in the 1300-1350 MHz and 1780-1830 MHz bands.[32] [33] [34] [35]

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 exploring the feasibility of making changes to the Federal Aviation Administration's (FAA) long-range radars operating in the 1300-1350 MHz sub-band that could include relocating them to another band. While it is too early in the process to reach conclusions, relocation of these radars from the band would likely significantly improve the potential for sharing with commercial service. In fact, the federal agencies involved in the initiative are proposing to utilize funds from the Spectrum Relocation Fund to study the relocation possibility consistent with the Spectrum Pipeline Act of 2015.

More than 20 federal agencies as of March 2012 were utilizing more than 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 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, providing important experience working with these agencies on reallocating and sharing such spectrum-based systems. After the auction, some systems operating over the entirety of the 1755 MHz–1850 MHz band are being re-tuned to operate solely in the 1780 MHz–1850 MHz portion of the

[31] 450 Alliance website. https://450alliance.org/about-us/.
[32] *The Airwaves Act*, Policy Brief, CTIA. https://www.ctia.org/news/the-airwaves-act-policy-brief.
[33] NTIA. 1 March 2014. https://www.ntia.doc.gov/files/ntia/publications/compendium/1300.00-1350.00_01MAR14-1.pdf.
[34] *Sizing Up Spectrum Sharing Prospects*, Glenn Reynolds, Chief of Staff, and Peter Tenhula, Deputy Associate Administrator, Office of Spectrum Management, NTIA. 16 November 2016. https://www.ntia.doc.gov/blog/2016/sizing-spectrum-sharing-prospects.
[35] *The Next Wave of Spectrum Reallocation: The Value of Additional Mid-Band Spectrum Reallocations,* Coleman Bazelon for CTIA. 14 November 2017. https://docs.house.gov/meetings/IF/IF16/20171116/106636/HHRG-115-IF16-20171116-SD005-U5.pdf.

band. Therefore, 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.

5.1.3 1675-1695 MHZ BANDS

The Geostationary Operational Environmental Satellites (GOES) series of satellites operate in this band transmitting weather and other meteorological data to earth station receivers for further processing and distribution. In addition, Federal agencies use the 1675-1683 MHz portion of this band to transmit meteorological data from radiosondes to ground stations for weather forecasting.[36] [37]

NTIA assessed that the Federal spectrum usage in the 1675-1685 MHz sub-band is much less than that in the 1685-1695 MHz sub-band. This will be further reduced when the radiosonde receive stations are migrated to the 400 MHz band. When the radiosonde receives stations complete their planned migration to the 400 MHz band, opportunities may exist to accommodate wireless broadband, contingent upon the successful completion of a feasibility study.

5.2 MID-BAND

In addition to mid-bands in 3.45-3.55 GHz, 3.70-4.20 GHz for possible mobile broadband use and 5.925-6.425 GHz and 6.425-7.125 GHz for more flexible use as discussed in previous sections, the following bands represent possible candidate mid bands for 5G.

5.2.1 2.70-2.90 GHZ AND 2.90-3.11 GHZ BANDS

The band 2.70-2.90 GHz is used by Federal agencies for operating various types of radar systems that perform missions critical to safe and reliable air traffic control and accurate weather monitoring in the United States. The Federal Government uses the band 2.90-3.10 GHz for operating various types of radar systems that perform missions critical to safe and reliable maritime navigation and accurate weather monitoring in the United States. Several years ago, NTIA assessed that the Federal spectrum usage in the 2.90-3.10 GHz band is much less than in the 2.70-2.90 GHz band. This indicates that potential sharing opportunities may exist in the 2.90-3.10 GHz band, contingent upon the successful completion of feasibility studies,

[36] *Quantitative Assessment of Spectrum Usage*, Penny Pritzker, Secretary and Lawrence Stickling, Assistant Secretary for Communications & Information, US Dept. of Commerce. November 2016.
https://www.ntia.doc.gov/files/ntia/publications/ntia_quant_assessment_report-no_appendices.pdf.
[37] Compendia 1675-1695 Spectrum Bands, NTIA. 1 September 2014.
https://www.ntia.doc.gov/files/ntia/publications/compendium/1675.00-1695.00_01SEP14.pdf.

including the impact of proposed wireless broadband systems on federal systems that would likely remain operating in the 2.70-3.10 GHz band. [38] [39]

5.2.2 3.45-3.55 GHZ BANDS

NTIA is considering this band for potential broadband wireless use. In the United States, military radar systems currently operate in the 3.45-3.55 MHz band and Amateur radio has an allocation in this band. DOD plans to submit a proposal under the Spectrum Pipeline Act to carry out a comprehensive radio-frequency engineering study to determine the potential for introducing advanced wireless services in this band without harming critical government operations. Expectations are that the result of this hard work will be a "win-win," situation enabling the continuing growth of the U.S. wireless industry while protecting radars that are vital for national security.

This spectrum is immediately below the CBRS band and the potential for international spectrum harmonization could lead to the creation of a global market for equipment that includes the 3.45-3.55 GHz band, and help bring services to market quicker, and at lower cost point.

5.2.3 4.94-4.99 GHZ BANDS

The 4.94-4.99 GHz band is allocated exclusively for non-Federal fixed and mobile (except aeronautical mobile) services. The band is also allocated to the space research (passive) and Earth exploration-satellite (passive) services on a secondary basis. In 2002, the Commission allocated the 4.94-4.99 GHz (4.9 GHz) band for fixed and mobile use and designated the band for public safety broadband communications. Since then, the band has experienced relatively light usage compared to the typical use of other public safety bands. As a result, the FCC has proposed several rule changes and sought comment on alternatives with the goal of promoting increased public safety use of the band while opening up the spectrum to additional uses that will encourage a more robust market for equipment and greater innovation. The FCC proposed rules on channel aggregation, aeronautical mobile use, frequency coordination, site-based licensing, regional planning, and technical rule changes with the goal of promoting increased use of the band. The FCC also sought comment on alternatives such as expanding eligibility, spectrum leasing, sharing, and re-designating the band for commercial use. [40] [41]

[38] *Quantitative Assessment of Spectrum Usage*, Penny Pritzker, Secretary and Lawrence Stickling, Assistant Secretary for Communications & Information, US Dept. of Commerce. November 2016. https://www.ntia.doc.gov/files/ntia/publications/ntia_quant_assessment_report-no_appendices.pdf.
[39] Compendium 2700-2900 Spectrum Bands, NTIA. 1 March 2014. https://www.ntia.doc.gov/files/ntia/publications/compendium/2700.00-2900.00_01MAR14-1.pdf.
[40] Compendium 4940-4990 GHz Spectrum Bands, NTIA. 1 March 2014. https://www.ntia.doc.gov/files/ntia/publications/compendium/4940.00-4990.00_01MAR14.pdf.
[41] *4.9GHz Proposed Rule*, Federal Register, FCC. 7 May 2018. https://www.federalregister.gov/documents/2018/05/07/2018-09416/49-ghz-band.

5.3 HIGH-BAND

The 26 GHz, 32 GHz, 42 GHz, 50 GHz, 70 GHz and 80 GHz bands have emerged as potential 5G bands in regional and international forums leading to the World Radiocommunication Conference 2019 (WRC-19) and could also be considered for North America.[42] Global harmonization can indeed promote global interconnection, roaming, and interoperability in these various bands.

5.3.1 7.125-8.4 GHZ BANDS

The 7.125-8.4 GHz band is allocated to federal use, but it may not be fully utilized and could be an excellent growth band for point-to-point microwave operations. The FCC could work with NTIA to adopt a non-Federal allocation in the 7.125-8.4 GHz band that would permit commercial point-to-point deployment. Because the band already has a Federal fixed allocation, coordination with incumbent fixed links is expected to be relatively straightforward.[43]

5.3.2 26 GHZ (25.25-27.50 GHZ) BANDS

This band is part of the spectrum frontiers proceeding and the FCC has sought comment on its use for UMFUS. However, the FCC has taken no action on the band yet. The 26 GHz band could be suitable for flexible fixed and mobile use, as the FCC has proposed. It is adjacent to the 24 GHz and 28 GHz bands, which the FCC has already found suitable for fixed and mobile use. The amount of spectrum potentially available (over two gigahertz) could make this band a useful addition to 5G and is a priority band for 5G in several regions around the world, including Europe.

In the Federal column of the U.S. Table of Allocations, the entire 25.25-27.5 GHz band has primary allocations for Fixed (FS), Mobile (MS), and Inter-Satellite (ISS) services, with Inter-Satellite limited to space research and Earth exploration-satellite applications, along with transmissions of data originating from industrial and medical activities in space. The 25.5-27.0 GHz band has a primary allocation for both Federal and non-Federal Space Research service (SRS) (space-to-Earth), with non-Federal Earth Exploration-Satellite Service (EESS) subject to case-by-case electromagnetic compatibility analysis. Suitable sharing or protection arrangements with incumbents in the band need to be worked out.

[42] *In the Matter of Use of Spectrum Bands Above 24 GHz For Mobile Radio Services,* FCC's Third Report and Order, Memorandum Opinion and Order, and Third Further Notice (draft). 8 June 2018; *In the Matter of Use of Spectrum Bands Above 24 GHz For Mobile Radio Services*, FCC's Report & Order and FNPRM, 14 July 2016; *In the Matter of Use of Spectrum Bands Above 24 GHz For Mobile Radio Services*, FCC's Second Report and Order, Order on Reconsideration, and Memorandum Opinion and Order, 22 November 2017.

[43] *In the Matter of Expanding Flexible Use in Mid-Band Spectrum between 3.7 and 24 GHz,* Comments to FCC by CTIA. GN Docket No. 17-183. 15 November 2017. https://ecfsapi.fcc.gov/file/111532275964/171115%20CTIA%20Mid-Band%20Reply%20Comments%20FINAL.pdf.

5.3.3 32 GHZ (31.8-33.4 GHZ) BANDS

FCC has specifically sought comment on its use for UMFUS. This is in the same procedural position as 26 GHz. There are no current non-Federal licensees in the 32 GHz band. In the United States, the entire 32 GHz band is allocated for the Federal Radio Navigation Service and the 32.3-33.4 GHz band is allocated for the non-Federal Radio Navigation Service. A co-primary Space Research (deep space) (space-to-earth) allocation in the 31.8-32.3 GHz band, and an ISS allocation in the 32.3-33 GHz band also exist in the band and are adjacent to 31.3-31.8 GHz, which is a globally allocated passive band, where no transmissions are authorized in order to protect radio astronomy observations. There are two challenges to authorizing the 32 GHz band for 5G services. First, the 32 GHz band is not currently allocated for mobile use. Second, the FCC noted that the amount of usable spectrum in the 32 GHz band appears to be significantly curtailed by the need to protect the existing Federal and deep space research systems in the 32 GHz band, as well as operations in the adjacent 31.3-31.8 GHz passive band. The relevant coexistence issues will need to be sorted out.

5.3.4 42 GHZ (42.0-42.5 GHZ) BANDS

The 42.0-42.5 GHz band (42 GHz band) consists of 500 megahertz, allocated to non-Federal fixed and mobile services on a primary basis, and it contains no current Federal allocation or service rules. The adjacent 42.5-43.5 GHz band is allocated to the Radio Astronomy Service (RAS) on a primary basis for Federal and non-Federal use and to the Federal fixed, fixed-satellite (Earth-to-space), and mobile except aeronautical mobile services on a primary basis. In its Third Report and Order, Memorandum Opinion and Order, and Third Further Notice, the FCC sought comments on including the 42 GHz band in the Part 30 UMFUS Rules. This would enable the use of this band together with the existing 37 GHz and 39 GHz bands. International consideration of this band for mobile use, and the availability of 500 megahertz of unassigned spectrum all support the conclusion that this band is suitable for flexible use.

5.3.5 45.5-47.5 GHZ BANDS

This band lacks studies in the ITU's Task Group on terrestrial services for the 5G agenda item, TG5/1, so it is too soon for 5G Americas to make a recommendation. However, some Administrations have indicated they support further examination and may bring studies on 45.5 – 47.2 GHz into the meeting to prepare for the WRC in early 2019, given the band is in the same tuning range as the FCC's band 47.2-48.2 GHz.

5.3.6 50 GHZ (50.4-52.6 GHZ) BANDS

The 50.4-51.4 GHz portion of the band includes primary Federal and non-Federal allocations for fixed and mobile services, as well as primary Federal and non-Federal allocations for fixed-satellite (Earth-to-space)

and mobile satellite (Earth-to-space) services. As in the case of other bands shared between terrestrial and fixed-satellite services (for example, 24.75-25.25 GHz, 37.5-40 GHz and 47.2-48.2 GHz), sharing in the 50.4-51.4 GHz band, where an FSS allocation already exists, should be feasible with minimal impact on terrestrial operations.

5.3.7 SPECTRUM BANDS ABOVE 95 GHZ

In February 2018, the FCC adopted a new NPRM in a proceeding called "Spectrum Horizons" to enable use of bands above 95 GHz and empower innovators to test new ideas. The range above 95 GHz can be explored for longer term options.[44]

The NPRM seeks comment on:

- proposed rules to permit licensed fixed point-to-point operations in a total of 102.2 GHz of spectrum
- making 15.2 gigahertz of spectrum available for unlicensed use
- creating a new category of experimental licenses to increase opportunities for entities to develop new services and technologies from 95 GHz to 3 THz with no limits on geography or technology

6. MECHANISMS FOR CLEARING SPECTRUM

For the most part, the potential 5G spectrum bands have a combination of Federal and non-Federal incumbents. Services like Federal and non-Federal radiolocation and radio navigation are incumbents in some of potential 5G bands. In addition, satellite systems also are present in some of those bands.

A licensed framework for mobile terrestrial service is preferred as it can create a robust ecosystem with greater security, and promote investment and innovation (such as deployment of new interfaces like 5G New Radio) and encourage rapid deployment of 5G facilities.

Considering incumbents in the band is of a primary concern for the introduction of mobile service. Aspects to be considered are the type of incumbent services, geographic location of the incumbent, how often the spectrum is used by the incumbent, the type of service and other factors. Microwave services will require different considerations than satellite services or radio astronomy. Radio astronomy systems are generally located in remote areas that are naturally separated from the population centers where mobile service is most densely deployed. In some cases, incumbent services do not fully utilize the existing spectrum, or the existing uses can be transitioned to a more spectrally efficient technology. For instance, analog technology could be evolved to digital; or the service could be transitioned from one platform to another. As a further example, mobile services have the capability to support functionality used by the broadcast auxiliary

[44] *In the Matter of Spectrum Horizons*, FCC's NPRM. 28 February 2018.

services or fiber could be used for video distribution rather than by satellite. In some cases, relocation, transition and repacking spectrum are not suitable mechanisms for spectrum access. In these cases, spectrum sharing can be the preferred means for the introduction of mobile services. For example, the FCC established a regulatory framework in the 28 GHz band that allowed the deployment of terrestrial mobile service while supporting existing and future satellite gateways in the band. In this case, sharing was possible by restricting the conditions by which satellite gateways could be deployed. In another example, the FCC established the Citizens Broadband Radio Service (CBRS) in the 3.55-3.70 GHz band for wireless broadband service. The incumbent in the band of primary consideration are government radars, specifically the high-powered, shipborne naval radars. In this case it was not optimal to clear the spectrum; therefore, the FCC established a spectrum sharing framework that serves to support incumbent use of the band while allowing some limited access for mobile services.

As described in the summary, there is not a single solution for the introduction of mobile service in potential 5G spectrum band. Many aspects must be considered to determine whether the band can be cleared or whether its' only suitable solution is spectrum sharing.

Section 6.1 describe various mechanisms for clearing spectrum including relocation, transition and repacking. In section 6.2 various sharing mechanisms that can be considered given the right regulatory constraints such as exclusion zones, light licensing, dynamic spectrum sharing and contention-based protocol are explained.

6.1 MECHANISMS FOR CLEARING SPECTRUM FOR MOBILE LICENSED USE

There are many models that can be collectively considered in the clearing of spectrum for mobile licensed use. In the following sections, models for relocation, transition and repacking are explained.

6.1.1 RELOCATION

There are two main approaches that could be considered for relocating incumbents. The first approach is through government requirements and the second is a market-based approach.

The first approach would mandate through regulations that incumbents are required to relocate to another band. This approach is also applicable for satellite incumbents with equipment capable of operation in multiple bands. Incumbents of the mandatory relocation could be compensated, for example, through an auction of the licenses.

A second approach for relocating incumbents is a more market-based approach where relocation would be voluntary for the incumbent to move their operations to other frequencies or other locations. Incumbents could also decide to terminate their operations instead of relocating. There are several ways that a market-based approach has been, or could be conducted. For instance, when it comes to satellite in the 3.70-4.20

GHz band in the U.S., it may be possible to relocate earth station downlink operations to more remote geographical areas, subject to interference protection from new entrants, and utilize fiber or other technologies for backhaul. This is a critical component to the success of this band for 5G considering that there are a significant number of earth stations in urban/suburban areas that would conflict with the success of deployment by mobile services in this band. It is possible that this type of relocation could be mandated or executed through a market-based approach where there is direct engagement by the incumbent with a new entrant to clear spectrum for the introduction of new services.

Another market-based approach is where the regulator provides incentives for the incumbent(s) to relocate their services/traffic to new frequencies. Incentives could include the ability for the incumbent to take part in an auction and benefit from the sale of its license as was done in the U.S. in the 600 MHz Incentive Auction. In this case the FCC conducted a first-of-its-kind auction that compensated TV broadcasters that relinquished their licenses.

The benefit of these market-based approaches is the voluntary nature of cooperation between the incumbents and the new entrant, which could mean less industry opposition and delays as FCC decisions are appealed, and the expectation that spectrum access is expedited. However, there is also a level of uncertainty that is avoided when relocation is mandated; specifically, the uncertainty of when the spectrum would be made available, what spectrum is available and under what terms. In some cases, there may need to be widespread agreement among the incumbent community to ensure that spectrum access, sufficient to support competition among service providers with sufficient bandwidth, would be possible.

6.1.2 TRANSITION

The focus of this model is to consider how alternative transmission platforms (for example, fiber or fixed service) can be used to clear spectrum for mobile licensed use. For example, off-the-shelf equipment running on a commercial LTE network has the capability of delivering high-definition video in real-time. The very high uplink and downlink speeds that LTE enables have already provided an alternative to services currently allocated in bands for electronic news gathering and similar applications. It is expected that 5G will expand the opportunity to support new use cases as a substitute for some existing services utilizing spectrum that could be better served for wireless broadband. When it comes to satellite, for instance in the 3.70-4.20 GHz band in the U.S., it may be possible to transition the video distribution services supported by satellite to other platforms. For instance, the ubiquitous nature of fiber, especially in the urban/suburban areas, with its capabilities for increased capacity, improved availability and redundancy make it a prime candidate for video distribution. An additional alternative or as a complement to fiber is microwave.

6.1.3 REPACKING

Repacking is the process by which existing services are required to relocate their operations to another portion of the same frequency band. The relocated operations will have to modify their existing facilities (for

example, antennas) to transmit on a different frequency. The benefit of repacking is that fragmented spectrum can be cleared by moving operations to another portion of the spectrum. What remains ideally is contiguous spectrum that is no longer fragmented, and incumbents are now operating in adjacent frequencies, which provides cost-savings. For example, on April 13, 2017 the FCC formally closed the 600 MHz incentive auction and began the congressionally-mandated 39-month period during which time some TV stations will need to transition to new channel assignments. The repacking process allowed the introduction of mobile services in the vacated spectrum and with repacking, co-existence is easier. Another example is the possible opportunity for repacking in the 3.70-4.20 GHz band.

The Commission currently authorizes FSS earth stations on a "full-band, full-arc" basis. This licensing structure allows earth stations to coordinate both across the entire 500 MHz frequency band and the entire geostationary arc visible from their location, regardless of whether they are using, or have plans to use, those frequencies and satellite positions. However, if the basis for coordination could be better served using other means as in fiber and microwave, it may be possible to repack satellite operations towards the upper part of the 3.70-4.20 GHz band, which could facilitate the introduction of licensed mobile service and provide synergies with the CBRS band in the adjacent 3.55-370 GHz band.

6.2 MECHANISMS FOR SPECTRUM SHARING

Exclusive licensed spectrum is still considered the most suitable for reliable delivery of 5G services but sharing may be acceptable under some circumstances. Spectrum sharing typically involves co-frequency coordination between services with similar access rights and can facilitate access to spectrum that is underutilized. Spectrum sharing can also facilitate access to spectrum in cases where spectrum clearing is not possible in a timely manner or when the incumbents are not planning to relocate so spectrum sharing is required. Spectrum sharing to allow the introduction of licensed mobile service on a primary basis, in some cases, can be facilitated by designating the incumbent services on a secondary basis. This option is best considered when the incumbent has limited operations and therefore interference would likely be minimal to begin with.

The CSMAC 5G Subcommittee Report [45] provides the following insight on the spectrum sharing mechanisms:

> *"Critical components in determining the appropriate sharing framework will be the degree of protection and the type of services involved. Spectrum sharing can be difficult for some of the 5G services especially the ones that require low latency and high quality of service (QoS). 5G networks may also use different access mechanisms for different services. For example, Non-Orthogonal Multiple Access (NOMA) may be used for mMTC, and the sharing framework should*

[45] Commerce Spectrum Management Advisory Committee, 5G Subcommittee. 17 November 2017. https://www.ntia.doc.gov/files/ntia/publications/5g_subcommittee_final_report_2017.pdf.

consider these aspects too, which are unique to 5G. Propagation at frequencies greater than 6 GHz can be more directional which may allow spectrum sharing at shorter separation distances with management of interference in the angular domain, for example, using beamforming. Incorporating directional information in a location-based sharing framework may be considered if the directional information is fixed. However, this is often not the case for Point-to-Multipoint systems. The utility and benefit of dynamic beamforming coordination decreases in this framework."

6.2.1 EXCLUSION ZONES

Exclusion zones are based on interference protection of a specific geographical area. Exclusion zones can be particularly useful if the incumbent operation is unlikely to receive harmful interference from the introduction of other spectrum uses or if the number of operations to protect is limited. For instance, when the operation of the incumbent is in a remote area and relocation does not make sense, interference protection is possible using a defined geographical exclusion zone. Another example is within the CBRS band where defined exclusion zones preclude operation of Citizen's Band radio Service Devices (CBSD) within those zones. In this case, exclusion zones are enforced and maintained by the spectrum database manager, or SAS. With the SAS, spectrum is managed and assigned on a dynamic, as-needed basis across three tiers of the CBRS access. An extension of the exclusion zone concept is the *protection* zone. A protection zone defines coordination requirements.

Every effort should be made to make exclusion zones as small as possible. A good example is in the CBRS band where NTIA reduced the size of exclusion zones from their original estimates.

6.2.2 LIGHT LICENSING

In 2005, the FCC released rules that defined a regulatory framework around the concept of light licensing for fixed services in the 71-95 GHz bands. These rules would no longer require traditional frequency coordination among non-Federal Government users and would improve the process of coordination with incumbents in the band and allow ease in the register and licensing of individual fixed service links. The regulatory framework recognized that networks in these frequency ranges would need minimal frequency coordination because of the increased path losses in that mmW frequency.

Consequently, the shorter range of the links would facilitate co-existence and allow a high degree of frequency reuse. Under this approach, the Commission was able to issue an unlimited number of non-exclusive nationwide licenses. To utilize light licensing for these bands, licensees must register for individual links using Database Managers (using a link registration system). The registered links must be coordinated with NTIA, which has developed an automated coordination mechanism that will allow non-Federal Government users and the Database Managers to determine whether a given non-Federal Government link has any potential conflict with Federal Government user. This light licensing regulatory framework

recognizes first-in-time protection rights and full interference protection for links that have been registered and approved.

6.2.3 DYNAMIC SPECTRUM SHARING

A database-driven spectrum sharing approach could be used to manage exclusion zones and protection requirements and facilitate access to spectrum, when the nature of incumbents and new entrants justify such an approach. Under this framework, the database is responsible for determining the available spectrum, depending on the location of the user and the proximity of the user to other uses in the band. There are two primary database approaches for managing spectrum access: Spectrum Access System (SAS) and Licensed Shared Access (LSA). The LSA specification supports two tiers of usage and the SAS specification supports an additional tier of generally authorized spectrum access. As an example, SAS is planned for deployment in the 3.55-3.70 GHz band. There are three tiers of service that share spectrum in the band. The SAS is designed to protect each subsequent tier of service with the priority for protection starting in Tier 1 (government radars and grandfathered satellite earth stations). A database-driven sharing approach could likewise be used to manage protection of FSS earth stations in the 3.70-4.20 GHz. The viability would depend on numerous factors, including the size of the required exclusion or protection zones around the earth stations and the concentration of earth stations in urban and suburban areas.

6.2.4 CONTENTION-BASED PROTOCOL

A contention-based protocol is another technique that can support uncoordinated spectrum access. For example, 3GPP's License-Assisted Access and IEEE 802.11 use a technique where radio transmitters first detect or listen to the communication radio channel before they transmit. The transmitter will wait until the radio channel is clear before it transmits. The "Listen-before-Transmit" is an example of a -contention-based protocol.

According to Section 90.7 of the FCC rules, a contention-based protocol is defined as:

> *Contention-based protocol. A protocol that allows multiple users to share the same spectrum by defining the events that must occur when two or more transmitters attempt to simultaneously access the same channel and establishing rules by which a transmitter provides reasonable opportunities for other transmitters to operate. Such a protocol may consist of procedures for initiating new transmissions, procedures for determining the state of the channel (available or unavailable), and procedures for managing retransmissions in the event of a busy channel. Contention-based protocols shall fall into one of two categories:*
>
> *(1) An unrestricted contention-based protocol is one which can avoid co-frequency interference with devices using all other types of contention-based protocols.*
> (2) *A restricted contention-based protocol is one that does not qualify as unrestricted.*

7. RECOMMENDATIONS

Significant progress towards the allocation of spectrum below and above 24 GHz for broadband services has been made in several countries including the U.S. However, there are several suggested recommendations for additional actions that can be taken by administrations to secure the success of 5G.

7.1 SUMMARY OF RECOMMENDATIONS FOR BANDS BELOW 24 GHZ

- Continue to consider spectrum identification and allocation opportunities below 3 GHz
- Administrations should take steps to accelerate domestic procedures necessary to introduce spectrum supporting the developing global 5G ecosystem
- In the U.S., facilitate commercial readiness of the SAS/ESC, expedite CBRS spectrum availability for General Authorized Access (GAA) usage, and move towards the auction of the CBRS Priority Access Licenses as soon as practicable
- Proceed with the 3.5 GHz auction in Canada without delay as planned in 2020
- Propose the FCC finalize the rulemaking and allocation of all or a significant portion of the 3.70-4.20 GHz band for licensed flexible deployment by 2020
- Do not introduce additional services like Point-to-Multipoint in the 3.70-4.20 GHz band
- Open more mid-band spectrum. For instance, in the U.S. the band 3.45-3.55 GHz should be made available for licensed use by 2022
- Administrations should to consider regulatory activities taking place in the 6 GHz band by the U.S. and Europe as potential 5G spectrum bands
- Administrations should continue to look at spectrum opportunities for licensed use of spectrum in the range 7-24 GHz

7.2 SUMMARY OF RECOMMENDATIONS FOR BANDS ABOVE 24 GHZ

- Administrations should take steps to accelerate domestic procedures necessary to introduce spectrum supporting the developing 5G global ecosystem in mmW band, for instance in 28 GHz
- Proceed with the 28 GHz auction in Canada without delay as planned in 2021
- Recommend the inclusion of the 42 GHz band in the auction of 37 GHz, 39 GHz, 47 GHz bands in the U.S. This band is part of the 37.0-43.5 GHz “tuning range”
- Finalize rulemaking and auction of the 26 GHz band as soon as practicable to take advantage of this band’s global harmonization for 5G
- The FCC should quickly issue service rules for the remaining mmW bands including 32 GHz, 45 GHz and 50 GHz

7.2.1 RECOMMENDATION DETAILS

The following section provides details regarding 5G Americas' recommendations for specific spectrum bands.

7.2.1.1 37.0-43.5 GHZ

5G Americas recommends that parts or all of the 37.0-43.5 GHz be made available for IMT. In the United States, the Commission has decided to make 37.0-40.0 GHz available for UMFUS (which includes IMT). 37.6-40.0 GHz is designated as licensed and 37.0-37.6 GHz as shared. ITU-R studies have concluded that sharing between IMT and other incumbent services operating within the 37.0 to 43.5 GHz frequency range is feasible.

7.2.1.2 47.2-50.2 GHZ

5G Americas proposes a global identification for IMT in 47.2-50.2 GHz. The 47.2-50.2 GHz band is also being considered for IMT identification at WRC-19. A global identification would allow each country to assign spectrum for IMT consistent with their domestic use and priorities, while still facilitating the benefits of economies of scale for businesses and consumers. In the U.S., the Commission has decided to make 47.2-48.2 GHz available for UMFUS and has reserved the identifications at 48.2-50.2 GHz for exclusive FSS use.

7.2.1.3 50.4-52.6 GHZ

5G Americas recommends that the entire 50.4-52.6 GHz band be identified for UMFUS. There are already primary fixed and mobile service allocations throughout the 50.4-52.6 GHz band, but there are currently no FCC service rules for this band. In the 1st FNPRM in the Spectrum Frontiers proceeding, the Commission proposed to authorize fixed and mobile operations throughout the 50.4-52.6 GHz band in accordance with the Part 30 UMFUS rules. The FCC has not yet decided to allow flexible use of the entire band and instead is focused on the sub-band 50.4-51.4 GHz. 5G Americas recommends that the FCC take action in the rest of this band to allow introduction of UMFUS (including IMT). The 50.4-52.6 GHz band is also being considered for IMT identification at the WRC-19.

7.2.2 MORE LICENSED MID-BAND SPECTRUM NEEDED

Based on the current proposals from the C-Band Alliance and the FCC in the 3.70-4.20 GHz and 6 GHz band proceedings, the amount of licensed spectrum proposed, 180 MHz, represents only 15 percent of the amount of unlicensed spectrum proposed in the 5925-7125 MHz band. The FCC has not identified additional licensed mid-band spectrum. 5G Americas recommends that the FCC note the current imbalance of licensed to unlicensed spectrum at mid-band and take necessary steps to balance the regulatory framework to create a longer-term spectrum pipeline for licensed mid-band spectrum.

7.2.3 OTHER ADMINISTRATIONS

While significant progress is being made by regulators in other jurisdictions in the Americas, further action is required to ensure the timely availability of spectrum for 5G deployments. For example, the proposed timelines for the 3.5 GHz and mmW auctions in Canada are significantly lagging compared to similar auctions in other developed countries (for example, U.S., Germany, Ireland, UK, South Korea). In addition, the 3.5 GHz and 28 GHz ecosystems are developing rapidly and will be ready for 5G deployments well in advance of the proposed auctions in 2020 and 2021, respectively. As such, Canada cannot afford to delay these important auctions. Canada's ISED should also accelerate public consultations on other potential 5G spectrum bands, such as the L-band for flexible use and the 6 GHz band for unlicensed use.

8. CONCLUSION

Regulatory steps towards allocating 5G spectrum, as well as recent early limited 5G deployments, are an excellent indication of 5G becoming a commercial reality. Nonetheless, investment in, and the success of 5G is largely contingent on the availability of a sufficient supply of harmonized low-band, mid-band, and high-band spectrum.

This paper reviewed relevant recent activities in various regions and provides information on the status of global spectrum considerations. This is followed by an explanation of the characteristics of different bands, and challenges and opportunities in using different bands for 5G, and in particular, bands that have a potential to be used for 5G services for North America. The report also covers mechanisms for spectrum clearing, spectrum sharing, and necessary industry and regulatory actions toward availability of more licensed spectrum for 5G in North America. The report also presented specific calls to action or recommendations on needed attention from the various administrations and regulations that will help make 5G a success.

APPENDIX

APPENDIX A. UPCOMING AND RECENT AUCTIONS IN LATIN AMERICA

As of December 2018, it is estimated that the average spectrum awarded per country for broadband in Latin America is 363.8 MHz. For the remaining available spectrum, 700 MHz, AWS and 2600 MHz are the most frequently mentioned as planned to be awarded by the countries. Presently, LTE has been implemented on some combination of 700 MHz, 800 MHz, 900 MHz, AWS, 1800 MHz, 1900 MHz and 2500 MHz in Latin America countries.

With the addition of 700 MHz in Mexico, Peru and the British Virgin Islands, a total of 18 regional jurisdictions have assigned 700 MHz spectrum to carriers.

Although WRC-15 identified the 1427-1518 MHz band for IMT in Region 2, Latin American countries have not yet moved to implement that WRC-15 decision. In Brazil, 1427-1429 MHz was previously allocated to

mobile as a primary use. Regulatory action to allocate the 1427-1518 MHz band for mobile use and to assign it to service providers will be an important contribution to low-band spectrum in support of 5G.

Table A.1. Upcoming and Recent Auctions in the Latin Americas Region.

Country	Type of Auction/Award	Status
Argentina	700 MHz, 1900 MHz and AWS	Assigned, remaining capacity to be assigned of 90 MHz
Argentina	2600 MHz	Assigned 2017
Brazil	700 MHz, 2.3 GHz and 3.5 GHz	700 MHz Assigned, but with remaining spectrum. Expected between 2018 - 2020
Chile	3500 MHz	Band assignment under review by regulator
British Virgin Islands	700 MHz, PCS, AWS	Completed
British Virgin Islands	450, 2600 MHz to 3500 MHz	400 MHz TBD, TDD 2600 MHz to 3500 MHz expected to be awarded 2019
Colombia	700 MHz, remaining 1900 MHz	Expected 700 MHz and 1900 MHz in 2019 - 2020
Colombia	600 MHz, 90MHz, AWS-3, 2600 MHz Also 3400 to 3700 MHz	Planned for 2019 – 2021
Costa Rica	700 MHz	700 MHz TBD
El Salvador	1900 MHz, AWS	1900 MHz and AWS in consultation.
Guatemala	AWS	TBD
Mexico	700 MHz	Awarded to Wholesale Network 2016-17
Mexico	2600 MHz	2600 assigned in 2018.
Panama	700 MHz, AWS	Awarded 20 MHz in 700 Mhz. AWS expected 2019-20
Paraguay	700 MHz, 2600 MHz	700 MHz awarded. 2600 MHz TBD
Peru	700 MHz	Completed
Puerto Rico	600 MHz	Completed
Puerto Rico	24 GHz	Expected for 2018
Uruguay	2.600 MHz, E-AWS, 1.800 MHz	Announced for 2019

U.S. Virgin Islands	600 MHz	2017
Venezuela	700 MHz, 900 MHz, AWS, 2.5 GHz	TBD

Source: Regulators, 5G Americas

APPENDIX B. USE CASE REQUIREMENTS

The specific requirements for the different use cases are listed in Table B.1.

Table B.1. Use Case Requirements.

Use Case	User Data Rate	Latency	Mobility
Hotspots: Broadband Access in Dense Areas	DL: 300 Mbps UL: 50 Mbps	NA	60 km/h
Coverage Everywhere	DL: 1Mbps UL: 100 kbps	NA	0 – 120 km/h
Homes and Offices	DL: 1 Gbps UL: 100 - 500 Mbps	NA	Pedestrian
Public Transport, MBB in Cars, High Speed Trains	DL: 25 – 50 Mbps UL: 10 – 25 Mbps	NA	Up to 120 kmph
Broadband Access in Events & Large Gatherings	DL: 10 - 25 Mbps UL: 25 - 50 Mbps	NA	Pedestrian

Connected Vehicles: V2X	DL: 1 Mbps - 1 Gbps	3-100 ms	250 km/h
Moving Hotspots	DL: 10 - 50 Mbps UL: 5 - 25 Mbps	10 ms	500 km/h
Enhanced Multi-Media: Live TV	DL: 50 - 200 Mbps UL: 500 kbps	NA	0 – 8 km/h
Enhanced Multi-Media: On Demand	DL: 50 - 200 Mbps UL: 500 kbps	NA	0 – 80 km/h
Enhanced Multi-Media: Mobile TV	DL: 10 - 50 Mbps UL: 500 kbps	NA	250 – 500 km/h
Massive IoT: Sensor Networks (Connected Roads, Railways, Buildings, Smart Cities, Parking, Lighting, Environment Monitoring)	DL: 1 – 100 kbps UL: 1 – 100 kbps	50 ms - hours	0 – 500 km/h

Massive IoT: Smart Grid/Utilities	DL: 1– 100 kbps UL: 1 – 100 kbps	50 ms - hours	Pedestrian
Massive IoT: Wearables	DL: 100 kbps - 5 Mbps UL: 100 kbps – 5 Mbps	1 - 10 ms	0 – 120 km/h
Massive IoT: Agriculture	DL: 1 – 100 kbps UL: 1 – 100 kbps	1 - 10 ms	Pedestrian
Industry Process Automation	DL: 100 kbps - 10 Mbps UL: 100 kbps – 10 Mbps	0.5 – 1 ms	Pedestrian
Automated Factories	DL: 100 kbps – 10 Mbps UL: 100 kbps – 10 Mbps	0.5 – 1 ms	Pedestrian
Tactile Interaction	DL: 100 kbps UL: 100 kbps	0.5 – 1 ms	Pedestrian
Emergency Services, Public Safety	DL: 100 kbps – 10 Mbps UL: 100 kbps – 10 Mbps	1 - 10 ms	0 – 120 km/h
Urgent Healthcare	DL: 100 kbps – 10 Mbps UL: 100 kbps – 10 Mbps	1 - 10 ms	0 – 120 km/h
Fixed Wireless	DL: 100 kbps - 5 Mbps UL: 100 kbps – 1 Mbps	10 ms	Pedestrian

3GPP TS 22.261[46] specifies the service and operational level requirements for the 5G system. A summary is included in Appendix A. The different Key Performance Indicators (KPIs) are:

[46] 3GPP TS 22.261, *Service requirements for the 5G system*; Stage 1 (Release 15).

- User-experienced data rate requirements vary from 1 Gbps downlink and 500 Mbps uplink for indoor hotspot environments to 50 Mbps downlink and 25 Mbps uplink for rural macro environments
- Latency targets are as low as 0.5 ms for tactile interaction
- Capacity targets can be as high as 15 Tbps/km2 with 250 000 users/km2 for indoor hotspots such as office environments

These service level requirements, in turn, generate operational level requirements for the 5G systems. For example, the 5G network not only needs to be scalable to support a very large number of devices, but also customizable in order to allow for tailoring the network to the different KPIs.

APPENDIX C. SUITABLE SPECTRUM FOR 5G APPLICATIONS

To date the most suitable spectrum has been licensed bands because they are the only spectrum capable of meeting goals such as coverage, quality of service, security and congestion/load balancing. The ITU-R WP 5D reviews spectrum needs for mobile services and makes recommendations to regulatory authorities. The ITU-R's spectrum needs estimate, shown in Table C.1, considers frequency ranges below 6 GHz and above 24 GHz for 5G applications. The propagation characteristics of spectrum in the 24-86 GHz range are suitable for certain applications, mainly outdoor hotspot and indoor micro and pico-deployment environments. Most of the frequency ranges below 6 GHz are suitable for all deployment scenarios.

To support all 5G applications in different deployment environments, spectrum both below and above 6 GHz is necessary. Table C.1 considers this notion and specifies the suitable spectrum ranges below 6 GHz and above 24 GHz for a variety of 5G applications. The spectrum in the 6-24 GHz range is suitable for 5G applications. The lower part of 6-24 GHz spectrum can be used in similar scenarios as the spectrum below 6 GHz, and its upper part has similar characteristics as the spectrum above 24 GHz.

Table C.1. Spectrum Ranges Considered Suitable for 5G Applications.

Usage Scenario	High-level Requirement	Potential Spectrum-Related Implications	Spectrum Ranges Considered Suitable
Enhanced Mobile Broadband	Ultra-high-speed radio links	Ultra-wide carrier bandwidths, for example 500 MHz Multi-gigabit front haul/backhaul, indoor	> 24 GHz
	High speed radio links	Wide carrier bandwidths, for example 100 MHz Gigabit fronthaul/backhaul	3-6 GHz

	Support for low to high-Doppler environment	Depends on the throughput requirement	All ranges
	Ultra-low latency	Short range implications	3-6 GHz, > 24 GHz
	Low latency	Mid-short-range implications	3-6 GHz
	Ultra-high reliability radio links	Severe impact of rain and other atmospheric effects on link availability in higher frequencies, for example mm-wave, for outdoor operations	< 6 GHz
	High reliability radio links	Impact of rain and other atmospheric effects on link availability in higher frequencies, for example mm-wave, for outdoor operations	< 6 GHz
Ultra-reliable Communications	Short range	Higher frequencies, for example mm-wave	> 24 GHz
	Medium-Long range	Lower frequencies, for example sub-6 GHz	< 6 GHz
	Ground/obstacle penetration	Lower frequencies, for example sub-1 GHz	< 1.5 GHz
Massive Machine-Type Communications	Operation in cluttered environment	Diffraction dominated environment in lower frequencies Reflection dominated environment in higher frequencies	All ranges
	Operation near fast-moving obstacles	Frequency-selective fading channels	All ranges, especially below 6 GHz
	Mesh networking	High-speed distributed wireless backhauls operating in-band or out-of-band	> 24 GHz

APPENDIX D. ADDITIONAL RESOURCES

2.1. UNITED STATES

NOI 2014: https://docs.fcc.gov/public/attachments/FCC-14-154A1.pdf

NPRM 2015: https://docs.fcc.gov/public/attachments/FCC-15-138A1.pdf

R&O and FNPRM 2016: https://docs.fcc.gov/public/attachments/FCC-16-89A1.pdf

2nd R&O and 2nd FNPRM 2017: https://docs.fcc.gov/public/attachments/FCC-17-152A1.pdf

3rd FNPRM 2018: https://docs.fcc.gov/public/attachments/FCC-18-73A1.pdf

4th FNPRM 2018: https://docs.fcc.gov/public/attachments/FCC-18-110A1.pdf

Spectrum Horizons NPRM 2018: https://docs.fcc.gov/public/attachments/FCC-18-17A1.pdf

APPENDIX E. ACRONYMS

ACMA	Australian Communications & Media Authority
AFC	Automated Frequency Control
ATC	Air Traffic Control
BSS	Broadcasting Satellite Service
CA	Communications Authority (Hong Kong)
CBRS	Citizens Broadband Radio Service
CBSD	Citizens Broadband radio Service Device
CEPT	European Conference of Postal and Telecoms Administrations
dB	decibel
DBS	Direct Broadcast Satellite
EA	Economic Area
ESC	Environmental Sensing Capability
ECC	Electronic Communications Committee
EESS	Earth Exploration Satellite Service
eMBB	enhanced Mobile Broadband
ETSI	European Telecommunications Standards Institute

FAA	Federal Aviation Administration
FDD	Frequency Division Duplex
FNPRM	Further Notice of Proposed Rulemaking
FS	Fixed Service
FSS	Fixed Satellite Service
GAA	General Authorized Access
GOES	Geostationary Operational Environmental Satellites
ISED	Innovation, Science and Economic Development Canada
ISS	Inter-Satellite Service
ITU-R	International Telecommunication Union- Radio Telecommunication Group
Km	kilometer
MIIT	Ministry of Industry and Information (China)
mMTC	massive Machine-Type Communication
mmWave	millimeter wave
MSS	Mobile Satellite Service
MVDDS	Multi-Channel Video Distribution and Data Service
NOI	Notice of Inquiry
NOMA	Non-Orthogonal Multiple Access
NPRM	Notice of Proposed Rulemaking
NTIA	National Telecom and Information Administration
OOBE	Out-of-Band Emission
PAL	Priority Access License
PEA	Partial Economic Area
RLAN	Radio Local Area Network

RAS	Radio Astronomy Service
RSA	Rectangular Service Area
RSPG	Radio Spectrum Policy Group
SAL	Shared Access License
SAS	Spectrum Access System
SE	Spectrum Engineering
SRS	Space Research Systems
TDD	Time Division Duplex
UMFUS	Upper Microwave Flexible Use System
U-NII	Unlicensed National Information Infrastructure
WAS	Wireless Access Systems
WG-FM	Working Group - Frequency Management
WRC	World Radio Conference

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The contents of this document reflect the research, analysis, and conclusions of 5G Americas and may not necessarily represent the comprehensive opinions and individual viewpoints of each particular 5G Americas member company.