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5G SPECTRUM RECOMMENDATIONS

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I. INTRODUCTION

Spectrum is the lifeblood for mobile, which means it's also the lifeblood for all of the mobile applications and services upon which nearly every person and business depends. New spectrum is critical for the success of fifth-generation (5G) terrestrial mobile service. Globally, there are significant on-going activities to identify suitable spectrum, including bands that can be used in as many countries as possible to enable global roaming and economies of scale. Various efforts around the world are underway to find harmonization around spectrum to be used for 5G. The 5G services are expected to cover a wide range of applications, which are generally categorized into enhanced Mobile Broadband (eMBB), Ultra-reliable and Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC). In addition to setting different requirements on the network features, applications will drive a wide variety of deployment scenarios. The different physical characteristics of spectrum (e.g., range, penetration into structures and propagation around obstacles) leads to some applications being more suitable for, and expected to be deployed in, certain spectrum ranges.

In terms of physical characteristics, spectrum can be roughly divided into the following three ranges:

- Low-range: up to ~3 GHz
- Mid-range: ~3 to ~6 GHz
- High-range: above ~6 GHz.

Each spectrum range has specific characteristics that make it suitable for certain deployment scenarios. While the low range of spectrum has very good propagation aspects that make it feasible for large area coverage, it has limited capacity due to lack of available spectrum and component design considerations. The mid-range of spectrum provides a type of coverage more feasible for urban deployment, with 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 available at these frequencies.

As a result, with the different characteristics of high, medium and low spectrum ranges and their suitability for different use cases, no single band can meet every 5G requirement, given the diversity of future applications. Thus, in addition to proceeding with the bands in the 24-86 GHz range identified in Agenda Item 1.13 currently under study for World Radiocommunication Conference of 2019 (WRC-19), the policymakers throughout the world should initiate additional activities to consider lower frequency bands.

This paper provides an overview of the dependencies between the 5G applications spectrum requirements and spectrum ranges in the Mobile Service that may be attractive for deployment of 5G services (Section III). It also covers recent regional and global developments regarding spectrum for 5G (Section II). In North America, the government and industries have commented on the Spectrum Frontiers[1] Notice of Proposed Rulemaking / Final Notice of Proposed Rulemaking (NPRM/FNPRM) issued by Federal Communications Commission (FCC). In comments filed by 5G Americas towards the NPRM, the association promoted the 'tuning range' concept to achieve regional and global harmonization. 5G Americas also encouraged the engagement of national regulators with one another to identify solutions to co-existence issues to allow regional and global harmonization to take place.

In considering spectrum allocations, both based in the ITU-R list of WRC-19 Agenda Item 1.13 bands, and non-ITU identified spectrum, policy makers should consider not only frequencies that can be allocated domestically, but also the possibilities provided by such global 'tuning range' solutions (section IV). Thus, in examining additional bands, policy makers should consider how services can be harmonized internationally, even if identical allocations cannot be used everywhere. To that end, regulators should consider national-specific allocations within a broader globally harmonized band that accounts for the needs in various regions or countries.

[1] https://www.fcc.gov/document/fcc-promotes-higher-frequency-spectrum-future-wireless-technology-0/

II. RECENT DEVELOPMENTS (2015-2017)

Since 2015, each world region has been working to identify spectrum for 5G. This section gives an overview of those initiatives, and describes the overall activities in the regions since 2015.

A. WORLD RADIO CONFERENCE 2015 (WRC-15)

The WRC reviews and revises the Radio Regulations (RR), which comprise the global International Telecommunications Union (ITU) treaty for radio spectrum. The WRC can perform two important functions with respect to 5G: it could designate a mobile allocation for certain bands; and it can "identify" that a specific spectrum band may be used for International Mobile Telecommunications (IMT), an ITU specification. IMT-2020 (a.k.a. "5G") technologies are included in the IMT designation.

WRC-15 took significant actions on low, medium and high range spectrum, such as adopting final treaty language and proposing further action for its next meeting in 2019.[2] Some of the spectrum bands identified in 2015 are already being deployed for 4G networks in many parts of the world. As 5G standards and technologies continue to mature, bands already in use for 4G will evolve into 5G bands as operators transition their networks from 4G to 5G. Tables 1-3 summarize WRC-15's actions for the three spectrum ranges.

Table 1. WRC-15 Action on Low-Range Spectrum.

Band	Action	Future activity
470-698 MHz	14 countries allocated for mobile & identified for IMT	WRC-2023 will study this band for IMT in Region 1 [3]
698-790 MHz	Identified for IMT in Region 1, Creating near global identification	
1427-1518 MHz	Some or all the band identified for IMT	Study of IMT compatibility for 1452-1492 MHz in Regions 1&3[4]

Among the considerations that the WRC-15 cited in moving forward on low-range spectrum are the favorable economics presented when operators can deploy base stations farther apart in distance due to the propagation characteristics of this spectrum range. WRC-15 also cited the need to have solutions that work well in low population density areas.[5] As a result, this spectrum is of particular interest to developing countries.

Table 2. WRC-15 Action on Medium-Range Spectrum.

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[2] Final Acts, WRC-15, Article 5 *Frequency Allocations*, Section IV *Table of Frequency Allocations*. (For 470-698 MHz, various countries have adopted either a mobile allocation and, in many cases, have agreed to allow the band (or portions thereof) to be used for IMT) See notes 5.292, 5.293, 5.295, 5.296A, 5.297, 5.300, 5.308 and 5.308A at pages 15-17. For 698-790 MHz, see notes 5.312A and 5.313A at page 18 and note 5.317A on page 19. For 1427-1512 MHz, see notes 5.341A, 5.341B and 5.341C on page 21 (regions 1 & 3 carving out a 40 MHz duplex gap from 1452-1492 MHz not designated for IMT). For 3300-3400 MHz, see notes 5.429-5.429D on pages 27-28. See also notes 5.441A, 5.441B and 5.442 (declaring spectrum in the 4800-4990 MHz band for IMT use in a select few countries).

[3] Final Acts, WRC, Resolution 235.

[4] Final Acts, WRC-15, Resolution 761.

[5] Final Acts, WRC-15 Resolution 224.

Band	Action	Future Activity
3300-3400	Allocated for mobile and identified for IMT use in almost 50 countries	
3400-3600	Globally allocated for mobile and identified for IMT	
3600-3800 MHz	4 countries identified 3600-3700 for IMT	
5150-5925 MHz	Tabled an agenda item for WRC-19[6]	Whether to extend or revise mobile allocation to portions of the band[7]

Table 3. WRC-15 Decision on High-Band Spectrum to be Studied for Consideration at WRC-19.

Band	Action	Future activity
24.25-27.5 GHz	Existing allocation to mobile on primary basis	Sharing and compatibility studies for IMT identification
31.8-33.4 GHz		Consider a mobile allocation & IMT identification
37-40.5 GHz	Existing allocation to mobile on primary basis	Sharing and compatibility studies for IMT identification
40.5-42.5 GHz		Consider a mobile allocation & IMT identification
42.5-43.5 GHz	Existing allocation to mobile on primary basis	Sharing and compatibility studies for IMT identification
45.5-47 GHz	Existing allocation to mobile on primary basis	Sharing and compatibility studies for IMT identification
47-47.2 GHz		Consider a mobile allocation & IMT identification
47.2-50.2 GHz	Existing allocation to mobile on primary basis	Sharing and compatibility studies for IMT identification
50.4-52.6 GHz	Existing allocation to mobile on primary basis	Sharing and compatibility studies for IMT identification

[6] Final Acts, WRC-15, Resolution 239

[7] 5150-5925 MHz is partially used today for license-exempt equipment, which includes IEEE 802.11 (Wi-Fi) as well as LTE unlicensed technologies (LTE-U, LTE-LAA, and MuLTEFire). These technologies are not deemed to be IMT technologies, but they do play an important role in 5G heterogenous networks and are included in this analysis for completeness. In addition, the WRC-19 will take up issues of implementation of Intelligent Transportation Systems, which will be supported by 5G technologies. Most national ITS allocations today are housed in the 5 GHz band. Final Acts, WRC-15 Res 237.

66-76 GHz	Existing allocation to mobile on primary basis	Sharing and compatibility studies for IMT identification
81-86 GHz	Existing allocation to mobile on primary basis	Sharing and compatibility studies for IMT identification

While low- and mid-range spectrum have long been utilized by the IMT family of technologies, this is the first time that high-band spectrum is being considered for IMT. The WRC considered the following factors in its decision to support examination of these bands:

- IMT provides telecommunications services on a global scale, and demand for IMT is growing
- IMT systems help support global economic and social development
- Ultra-low latency and very high bit rate applications needed for the next generation of IMT require large contiguous blocks of spectrum available at these frequencies
- Spectrum propagation characteristics in these bands are well suited to enable advanced antenna technologies such as MIMO and beamforming

Of course, the WRC call for study also considers existing users, and the ability of future terrestrial networks to operate in a shared environment in some cases.

At present, ITU-R Working Party 5D is conducting and completing portions of the studies called for in Resolution 238, including spectrum needs, and technical and operational characteristics (including protection criteria and deployment scenarios). By March 31, 2017, Working Party 5D is scheduled to report its results to ITU-R Task Group 5/1 (TG5/1). This task was completed at the February 2017 WP5D meeting. TG 5/1 will then commence sharing and compatibility studies in accordance with Resolution 238. When the WRC-19 convenes in November 2019, it will decide on possible mobile allocations and identification of spectrum for IMT under WRC-19 agenda item 1.13.

B. AMERICAS

1. North America

United States of America

The U.S. has achieved significant progress toward making spectrum above 24 GHz available for 5G. These bands have traditionally been used for fixed and satellite services. The FCC, realizing the significance of availability of spectrum for 5G, looked into the centimeter (cmWave) and millimeter wave (mmWave) bands. The FCC has been driving this process in three steps:

- Notice of Inquiry (NOI) issued in end of 2014
- Notice of Proposed Rulemaking (NPRM) issued at the end of 2015
- Report and Order (R&O) and including a Final NPRM (FNPRM) issued in mid-2016

Below is an overview of the outcomes of these activities.

Notice of Inquiry (NOI

Major developments started with the October 17, 2014, FCC NOI, in which the FCC wanted to examine the potential for the provision of mobile radio services in bands above 24 GHz. With this action, the FCC became the world's first regulatory body to formally initiate proceedings for 5G spectrum.

The NOI poised numerous questions regarding viability of the spectrum above 24 GHz for 5G. It also included questions related to spectrum sharing and licensing option in the following bands:

- 24 GHz bands: 24.25-24.45 GHz and 25.05-25.25 GHz
- Local Multipoint Distribution Service (LMDS) band: 27.5-28.35 GHz, 29.1-29.25 GHz, and 31-31.3 GHz
- 39 GHz band: 38.6-40 GHz
- 37/42 GHz bands: 37.0-38.6 GHz and 42.0-42.5 GHz
- 60 GHz bands: 57-64 GHz and 64-71 GHz (extension)
- 70/80 GHz bands: 71-76 GHz, 81-86 GHz, 92-95 GHz[8]

The mobile industry generally praised the FCC for taking this important step and provided numerous ways the mobile systems could put these bands into practical use.

Notice of Proposed Rulemaking (NPRM)

The FCC followed the NOI with an NPRM for the use of spectrum above 24 GHz, released on October 23, 2015. Here, the Commission proposed rules for the following four bands above 24 GHz for mobile service, and sought comments on proposed service rules authorizing mobile and other operations in those bands.

- 27.5-28.35 GHz
- 38.6-40 GHz
- 37-38.6 GHz
- 64-71 GHz

NPRM proposed the following licensing regimes for these bands:

- **Licensed**
    - 27.5-28.35 GHz
    - 38.6-40 GHz
- **Hybrid Licensing**
    - 37-38.6 GHz
    - Outdoor: licensed
    - Indoor: free for property owners
- **Unlicensed**
    - 64-71 GHz
- **License Area Size for 28 GHz, 39 GHz and Outdoor 37 GHz Bands**
    - County
    - There are 3,143 counties in the U.S.
- **License Term:** 10 years

The NPRM also set forth a proposal for licensing rules for the 28 GHz, 39 GHz and 37 GHz bands and proposed to create a new service for the 28 GHz and 39 GHz bands: The Upper Microwave Flexible Use Service (UMFUS) under a new Part 30 of FCC Rules. The NPRM proposed to establish rules to allow an UMFUS licensee to provide any form of fixed or mobile service (including aeronautical mobile, where consistent with the allocation).

Most of the responders applauded the FCC for taking the first step in the important process of ensuring that additional spectrum resources are available to meet the deployment of fifth generation ("5G") mobile

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[8] On October 16, 2003, the Commission adopted a Report and Order FCC 03-248 (modified by Memorandum Opinion and Order on reconsideration) establishing service rules to promote non-Federal Government development and use of the "millimeter wave" spectrum in the 71-76 GHz, 81-86 GHz and 92-95 GHz bands on a shared basis with Federal Government operations. These bands are essentially undeveloped and available for use in a broad range of new products and services, including high-speed, point-to-point wireless local area networks and broadband Internet access. Highly directional, "pencil-beam" signal characteristics permit systems in these bands to be engineered in close proximity to one another without causing interference. http://wireless.fcc.gov/services/index.htm?job=service_releases&id=millimeter_wave&page=O.

wireless technologies. In addition to providing responses to the service rules and spectrum sharing, some of the commenters requested the following:

- Consider additional bands above and below 24 GHz as part of this proceeding, particularly the bands originally mentioned in the NOI, those designated by the Inter-American Telecommunications Commission (CITEL) for consideration at WRC-15 and those designated at WRC-15 for additional study
- Refrain from adopting the hybrid indoor/outdoor approach to the 37 GHz band. Instead, fully license the 37 GHz band and harmonize the rules for this band with those for the 39 GHz band
- Designate a portion of the 64-71 GHz band for licensed use

Report and Order (R&O) and FNPRM

On July 14, 2016, the Commission adopted and released an R&O and FNPRM making spectrum in certain bands above 24 GHz available for fifth generation wireless technologies ("5G"), asking additional questions regarding implementation of the rules governing those bands and proposing to make additional spectrum available for 5G use.

The FCC created a new Part 30 of its rules governing the 28 GHz, 39 GHz and 37 GHz bands (i.e., the UMFUS). UMFUS licensees in these bands will be able to choose their regulatory status (common carrier, non-common carrier or both).

Table 4 summarizes how the R&O addressed the bands:

Table 4. Bands Addressed by the FCC Spectrum Frontiers R&O.

28 GHz Band (27.5-28.35 GHz)	Currently licensed for Local Multipoint Distribution Service (LMDS) operations. Existing licensees will receive two 425 MHz authorizations on a county basis in exchange for their current 850 MHz licenses issued on a Basic Trading Area (BTA) basis. Remaining spectrum will be auctioned
39 GHz Band (38.6-40 GHz)	Currently licensed for fixed microwave (point-to-point and point-to-multipoint operations). Existing licensees will be permitted to repack the band to create 200 MHz-wide channels (rather than the current 50 x 50 MHz channels). Licenses will be re-issued on a Partial Economic Area (PEA) basis. Remaining spectrum will be auctioned
37 GHz Band (37-38.6 GHz)	There are no current, non-federal terrestrial operations in the band. The lower segment (37-37.6 GHz) is to be made available on a shared basis between federal and non-federal users. The upper segment (37.6-38.6 GHz) will be auctioned in 200 MHz blocks on a PEA basis
64-71 GHz Band	The band will be available for unlicensed use using the same rules (Part 15) applicable to the unlicensed 57-64 GHz band

Satellite operations are secondary in 28 GHz and co-primary in the 37/39 GHz bands. Existing satellite operations are grandfathered, and additional limited use will be permitted in non-populous areas. The FCC imposed a hard cap of 1250 MHz in auctions and the same level as a screen in transactions. End-of-license-term performance metrics for different applications were established. The technical rules adopted were generally endorsed by the wireless industry.

The FCC created a new Part 30 of its rules governing the 28 GHz, 39 GHz and 37 GHz bands (i.e., the UMFUS). There were several petitions for reconsideration filed with the FCC to revisit some of the proposed rules under Part 30.

Further Notice of Proposed Rulemaking (FNPRM)

In the FNPRM issued at the same time as the R&O, the FCC sought comment on the following:

- Use of additional millimeter wave bands, and under what conditions
- How the lower segment of the 37 GHz band should be shared between federal and non-federal users (as well as other questions regarding operations in that band)
- Proposed shared use of the upper segment of the 37 GHz band, either by federal users, or under a use-it-or-share-it approach
- Whether there should be additional performance metrics to qualify for renewal (including the possibility of imposing use-it-or-share-it throughout the millimeter wave bands)
- Implementation of the spectrum aggregation limits at auction, how to apply them to new millimeter wave bands and holding periods for auctioned licenses
- Potential increase in power flux density (PFD) limits for satellite operations in the 39 GHz band and permitting satellite user equipment in the band
- Digital station identification
- Technical issues such as permitted antenna heights, smaller authorized bandwidths for certain devices, coordination criteria at market borders for fixed operations and appropriate sharing analysis and modeling

Table 5 provides an overview of these proposals.

Table 5. Summary of Proposals in FCC's FNPRM on Spectrum Frontiers.

24 GHz Bands (24.25-24.45 GHz and 24.75-25.25 GHz)	• Adding a mobile allocation to the 24.25-24.45 and 24.75-25.25 GHz segments of the 24 GHz band and a fixed allocation to 24.75-25.05 GHz • Authorizing both mobile and fixed operations in those segments on a co-primary basis under the Part 30 UMFUS rules • Licensing the 24.25-24.45 GHz band segment as a single, unpaired block of 200 megahertz, and the 24.75-25.25 GHz band segment as two unpaired blocks of 250 MHz each • Promoting effective sharing between satellite and mobile uses
32 GHz Band (31.8-33.4 GHz)	• Adding primary non-federal fixed and mobile service allocations to the 32 GHz band, and authorizing fixed and mobile allocations there under the Part 30 UMFUS rules • Licensing the band using either 200- or 400-MHz wide channels • Protecting radio navigation operations in the 32 GHz band and protecting radio astronomy observations in the adjacent 31.3-31.8 GHz band
42 GHz Band (42-42.5 GHz)	• Authorizing fixed and mobile service to operate in the 42 GHz band under the Part 30 UMFUS rules, as long as adjacent-channel RAS services are protected • Geographic area licensing using PEAs as the geographic area • Denying the Fixed Wireless Communications Coalition's (FWCC) request for establishing point-to-point-only rules for fixed service in the band, but keeping FWCC's request pending for the 42.5-43.5 GHz band • Establishing protections for RAS observations (e.g., special OOBE limits or a guard band) in the 42.5-43.5 GHz band • Appropriate band plan for the 42 GHz band • Adding federal fixed and mobile allocations into the band • Establishing a framework under which federal and non-federal users could share the band (potentially on a co-primary basis)

47 GHz Band (47.2-50.2 GHz)	• Authorizing fixed and mobile operations in the 47 GHz band under the Part 30 UMFUS rules • Adopting the sharing framework adopted for the 28 GHz band • The best approach for sharing between FSS user equipment and terrestrial operations • Sharing with co-primary federal services in the 48.2-50.2 GHz band • Protection of passive services in the adjacent 50.2-50.4 GHz band • Appropriate band plan for the 47 GHz band and notes, as a possibility, dividing the band into six channels of 500 MHz each
50 GHz Band (50.4-52.6 GHz)	• Authorizing fixed and mobile operations in the 50 GHz band under the Part 30 UMFUS rules • Using geographic area licensing on a PEA basis • Non-federal satellite allocations in the 50.4-51.4 GHz band • Sharing between terrestrial and satellite operations • Sharing with co-primary federal services in the 50.4-52.6 GHz band • Protecting passive services in the adjacent 50.2-50.4 GHz and 52.6-54.25 GHz bands • Appropriate band plan for the 50 GHz band and notes, as a possibility, establishing 10 channels of 200 MHz each, consistent with the 39 GHz band
70/80 GHz Bands (71-76 GHz and 81-86 GHz)	• Establishing a Spectrum Access System (SAS)-based regulatory framework under either the Part 96 CBRS rules or the new Part 30 UMFUS rules • Protecting mechanism for existing 70/80 GHz licensees • Appropriate means for protection of federal incumbents • Feasibility of authorizing Part 15 unlicensed, indoor-only operations • Establishing a separate regulatory framework for the 16 counties already heavily registered with incumbent users
Bands above 95 GHz	• Most attractive parts of the spectrum from the standpoint of technology development and successful coexistence with existing services • Licensed or unlicensed use • Appropriate technical rules • Permitting mobile and fixed service

Commenters generally applauded the Commission for considering more bands in addition to the R&O bands for 5G services. Some commenters, including 5G Americas, asked the FCC to also consider bands that WRC-15 agreed to study over the current cycle and are not among the FNPRM bands.

5G Americas also urged the FCC to adopt the following:

- Repurposing all of the FNPRM bands for flexible use, and doing so on a solely licensed basis
- Denying an SAS approach because it is not appropriate for the millimeter wave bands under consideration
- Rejecting ‘Use it or Share it’ (UoS) in the Upper Band Segment (UBS) of 37.6-38.6 GHz
- Considering the 70/80 GHz bands for flexible licensed use, including mobile
- Meeting the same technical requirements and using a common coordination framework for co-equal federal and non-federal users
- Providing sufficient incentives for efficient use of spectrum through the FCC’s early adoption of secondary market rules

With respect to the question of potential increase in power flux density ("PFD") limits for satellite operations in the 39 GHz band and permitting satellite user equipment, the mobile industry generally rejected such considerations.

Other bands of interest

From the point of view of global harmonization in the 3 to 5 GHz range as the main mid-range spectrum target for 5G, interests have been expressed in use of this range for 5G in the United States. This could potentially include current CBRS band (3.55-3.7 GHz) and beyond (e.g. up to 4.2 GHz).

Canada

In Canada, the Innovation, Science and Economic Development (ISED) ministry has opened a proceeding to repurpose TV spectrum in the 600 MHz band for mobile wireless use.[9] Per that decision, ISED will repurpose 84 MHz of spectrum, the same amount as the U.S. will repurpose via its voluntary incentive auction. Currently, ISED is engaged in extensive planning with its broadcaster licensees to transition the band to mobile.

At present, there is no specific consultation open to assign high-band spectrum for mobile services.[10] However, there are a number of co-primary allocations to mobile in the millimeter wave bands that are similar to mobile allocations currently being adopted and/or assigned in other jurisdictions: 27-29.5 GHz, 31-40.5 GHz, 42.5-47 GHz, 47.2-50.2 GHz, 50.4-52.6 GHz, 55.78-76 GHz, 81-86 GHz, 92-94 GHz and 94.1-100 GHz.

2. Latin America

5G Americas recently published a comprehensive review of spectrum allocations and utilization in Latin America.[11] That analysis focused almost exclusively on low-band spectrum and the region's progress in both allocating and assigning licenses in a range of bands commonly used globally for mobile services. Among the key findings:

- There is growing demand for mobile services, with mobile service penetration in the region at 120% and data demand rising
- The need for spectrum to be allocated and assigned is strong, and there remains a need for internationally harmonized mobile spectrum in the low bands
- As of April 2017, the region had allocated on average less than 27 percent of the 2015 ITU-recommended amount of spectrum to support mobile networks
- Individual countries in the region are continuing to auction spectrum, particularly in the 700 MHz, AWS and 2600 MHz bands
- While adverse economic conditions and the prospect for lower auction revenues may make governments reluctant to put spectrum on the block, the resulting benefits to GDP growth and social benefits outweigh the immediate benefit of auction proceeds

Table 6, taken from the report, summarized activity on upcoming auctions in the region as of April 2016. Since that time, there has been both progress and delays in the previously announced schedules.

[9] *Consultation on Repurposing the 600 MHz Band*, Decision, SLPB-004-15 (August 14, 2015).
[10] With respect to high range spectrum, Canada recently reviewed license requirements for 24, 28 and 38 GHz bands. New Licensing Framework for the 14, 28, and 38 GHz Bands and Decision on a License Renewal Process for the 24 and 38 GHz bands, Decision, SLPB-006-14 (Dec 18, 2014). This decision, however, focused on the use of these bands for fixed point-to-point for fixed point-to-multipoint microwave, and did not flexibly licensed the band for terrestrial mobile use.
[11] *Analysis of ITU Spectrum Recommendations in Latin America*, 5G Americas. April 2016.

Table 6. Upcoming and Recent Auctions in the Americas Region.

Country	Type of Auction/Award	Status
Argentina	Direct allocation	Regional 2.5 GHz licenses
British Virgin Islands	700 MHz, PCS, AWS	Completed
British Virgin Islands	450, 2600 MHz	TBD
Colombia	700 MHz, 900 MHz, remaining 1900 MHz and 2600 MHz	MinTIC committed to 2017
Colombia	AWS-3, 2300 MHz	MinTIC committed to 2017-2019
Costa Rica	1800 MHz and 1900/2100 MHz; 900 MHz	May-17
El Salvador	806-894 MHz and AWS	TBD
Guatemala	AWS	2017
Mexico	700 MHz	Wholesale Network Awarded 2016-17
Mexico	2600 MHz / AWS-3	Expected in Third Quarter of 2017
Panama	AWS	TBD
Paraguay	700 MHz and 2600 MHz	Planned for early 2017
Peru	700 MHz	Completed
Puerto Rico	600 MHz	Completed
Uruguay	700 MHz / AWS	2017
US Virgin Islands	600 MHz	2017
Venezuela	700 MHz, 900 MHz, AWS, 2.5 GHz	TBD

Source: Regulators, 5G Americas

With the addition of 700 MHz in Mexico, Peru and the BVI, a total of 18 regional jurisdictions have assigned 700 MHz spectrum to carriers. In addition to these updates, Argentina committed in May 2016 that it will clear spectrum at 512-698 MHz by the end of 2018 to permit the band to be used by mobile services going forward. The band is now used by pay TV operators.

Although the WRC-15 identified the 1427-1518 MHz band for IMT in Region 2, Latin American countries have not yet moved to implement the WRC-15 decisions. 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.

Similarly, with respect to mid-range spectrum, the Latin American region has significant work to do to pave the way for the fullest possible use of 5G technologies. Among the major economies in the region, only Colombia has a co-primary allocation for mobile in the 3500-4200 MHz band, while Argentina has a secondary allocation to mobile in the 3300-3400 MHz band. Colombia is also the only country that has discussed an auction schedule for the 3500 MHz band, anticipating an auction in the 2017-2019 timeframe. This relatively low level of regional activity stands in sharp contrast to the status of these bands in the U.S., Canada and Europe.

With respect to high-range spectrum, some of the larger jurisdictions in the region are already well-positioned to move forward on high-range spectrum needs for 5G. As Table 7 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 to the work on-going in preparation for WRC-19 with respect to these bands.

Table 7. 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 *Source: CITEL Spectrum Allocation Database*	81-86 GHz	81-86 GHz		81-86 GHz

To date, no country has initiated proceedings to utilize these bands for mobile services, such as initiating proceedings to assign licenses. At a minimum, all nations in the region should now be focused on whether additional allocations to mobile will be needed for spectrum 25 GHz or higher, taking into account harmonization with the larger markets in the region, as well as WRC-19 Agenda item 1.1. Nations should also consider taking steps to assign licenses, and in particular seek to align spectrum regulations to U.S. decisions in the band, because equipment will be made available in the bands identified by the U.S. as early as 2017-2018.

One of the important ways countries can begin to align their 5G spectrum planning is to consider collateral policies that place an emphasis on the importance of 5G to meet economic and social goals. For example, Brazil's Communications Ministry has entered into a Memorandum of Understanding (MOU) with the European Commission (DG Connect) for the development of 5G technologies.[12] Among the MOU's goals:

[12] https://ec.europa.eu/digital-single-market/en/news/eu-and-brazil-work-together-5g-mobile-technology

- To strive to reach a common understanding on the broad definition, the key application priorities and functionalities and overall timetable for 5G
- To align strategies to facilitate the emergence of global standards for 5G, in view of supporting harmonized standardization approaches in relevant fora, such as 3GPP and ITU
- To cooperate to facilitate the identification of globally harmonized radio frequency bands to meet the additional spectrum requirements for 5G, and in this context, to reinforce cooperation in the preparatory framework of ITU and WRC
- To work together to explore further possibilities for cooperating on, and implementing, joint R&D actions and projects in the field of 5G, as well as encouraging companies, academia and researchers to seek partnerships on both sides and proceed with exchanges of experts
- To join forces to support and facilitate the development of new applications and ecosystems that offer high potential societal value (the so-called "verticals") in such domains as smart cities, agri-food, health, education, industrial productivity, transport, energy, utilities management and possibly future forms of high-quality video content distribution

To be clear, not every country requires a 5G MOU with a different global region. But the principles called out in the MOU are important policies for regulators around the region to consider and adopt when thinking about how to advance 5G implementation in their countries for the benefit of citizens.

C. ASIA

In 2016, the regional organization Asia-Pacific Tele-Community (APT) approved a recommendation on frequency arrangements for implementation of IMT in the band 698-806 MHz. This recommendation is based on a harmonized frequency arrangement and study included in the APT Report APT/AWF/REP-14 that was approved in late 2010. This is now being globally considered and adopted as APT700, and REP-14 was used in 3GPP as basis for development of radio interface specifications with a band plan for FDD (Band 28), 703-748/758-803 MHz (UL/DL) and TDD (Band 44), 698-806 MHz. During the WRC-15, additional countries from the APT regions joined the footnote for this frequency range. As a result, there are now 26 Region 3 countries that have identified this band, or portions of it, for IMT. Several countries in the region have implemented it.

There were also several new bands identified by WRC-15. As a result, APT Wireless Group (AWG) has started working on harmonized frequency arrangements for these bands: 470-698 MHz, 1427-1518 MHz, 3300-3400 MHz and 4800-4990 MHz.

In addition, AWG has started on a new APT Report about sharing and compatibility studies for selected frequency bands below 6 GHz.

For WRC-19 related studies 1452 – 1492 MHz (WRC-19 Agenda Item 9.1 CPM Report Issue 9.1.2), and 1980 – 2010 / 2170 – 2200 MHz (WRC-19 Agenda Item 9.1 CPM Report Issue 9.1.1). Also, for studies to facilitate IMT implementation and not related to WRC-19 for some interested APT Members; 470-698 MHz, 1427-1452 MHz, IMT in 1492-1518 MHz and MSS in 1518-1525 MHz, 3300 – 3400 MHz, 4400 – 4500 MHz, and 4800 – 4990 MHz (Note that these frequency ranges are an initial list and it may be updated in future AWG meetings). These studies in AWG are planned to be concluded in Q3 2018.

Additionally, for spectrum related to WRC-19 and Agenda Item 1.13, there is work initiated on a new APT Report on sharing and compatibility studies for IMT above 24 GHz with the scope; to survey existing services or applications operating on a primary basis in the frequency ranges listed in Resolution 238 (WRC-15), to provide RF characteristics and relevant propagation models as required to support sharing and compatibility studies for IMT above 24 GHz and existing services, to conduct sharing and compatibility studies between IMT and other services within APT region taking into account mitigation techniques for co-existence between IMT and other systems, and to deliver study results to relevant ITU-R groups and APG. A survey was sent to APT Member States on usage and future plans of frequency bands in relation to studies on WRC-19 Agenda Item 1.13 in Asia-Pacific that is planned to finalize in the next AWG meeting in

April 2017. The studies in AWG for IMT in spectrum above 24 GHz are planned to be concluded in Q3 2018. In addition to work on Agenda Item 1.13, there are some other agenda Items for WRC-19 that technical work in AWG will be performed to support the activity in the APT Preparatory Group (APG) towards WRC-19.

In addition to activities related to WRC-19 agenda item 1.13, several countries in the region have started planning on making additional spectrum available for 5G in mid- and high-range bands. Notably, China, Korea and Japan could likely release additional mid-range spectrum between 3 and 5 GHz in anticipation of the standardization work in 3GPP to define a 5G radio interface for this range. In the high range, Korea and Japan have expressed intent to use all or parts of the 26.5-29.5 GHz range for delivery of enhanced mobile broadband applications as part of trials for the 2018 winter Olympics and 2020 summer Olympics, respectively. These trials are expected to be followed by commercial services in all or parts of the said range. Other regulatory planning is also underway in some other Asian countries to identify and make available additional new spectrum for 5G services and applications in low-, mid- and high-range bands.

D. EUROPE

In Europe, studies are ongoing around the spectrum allocations for the next generation IMT system (5G). Studies of certain 5G bands are stemming from decisions made in ITU WRC-15, possibly leading to decisions in WRC-19. Some of the bands under study are more suitable for implementation of mobile service in Europe, as described in the following:

24.25-27.5 GHz (3250 MHz bandwidth)

This range has more favorable propagation characteristics, compared to other listed bands under study, while providing enough bandwidth to provide coverage while being able to accommodate several national service providers. The range 24.25 – 27.5 GHz (“26 GHz”) carries the potential to become a preferred range of spectrum in Europe, and is being studied in ITU toward WRC-19.

- All European Union countries will most likely select at least part of the range 24.25 – 27.5 GHz as a pioneer band for early implementation of 5G above 24.25 GHz in Europe to facilitate launch of 5G on a large scale by year 2020
- Additionally, the Conference for European Postal and Telecommunications Administration (CEPT) is likely to start a work stream on studies for this band and is expected to actively support this band
- If the 26 GHz range is subsequently combined with band 27.5-29.5 GHz (“28 GHz”) or parts thereof in the U.S., Korea, Japan and elsewhere, the combined bandwidth would be even larger, up to 5250 MHz

While individual countries may not allocate the entire 26 GHz band, a tuning range approach including both 26 GHz and 28 GHz would enable terminals to select a sub-band for the region/country it is used in.

31.8-33.4 GHz (1600 MHz bandwidth)

This range has challenges due to the allocation to Radio Astronomy and passive Space Service use in adjacent bands. This may require the introduction of an in-band guard band and makes it less feasible to combine with lower bands in 26 GHz and 28 GHz. It can be noted that this band is not allocated to the Mobile Service in the table of allocations of the ITU Radio Regulations.

37-43.5 GHz (6500 MHz bandwidth)

This range is currently distributed over several services. The uses are different between countries based on information from proposals to the WRC-15. Such fragmentation could possibly be worked out by a tuning range approach, enabling terminals to select a sub-band for the region/country it us used in.

Table 8 provides an overview of the services in the band.

Table 8. Services Allocated to 37-43.5 GHz in Europe.

37.0 – 38.0 GHz	**Space Research Service**
37.0 – 39.5 GHz	Fixed and Mobile Service
37.5 – 39.5 GHz	Fixed Satellite Service
37.5 – 39.5 GHz	Earth Exploration Satellite Service, secondary basis
37.0 – 40.5 GHz	Earth Exploration Satellite Service, downlink operations, secondary basis
37.5 – 42.5	Fixed Satellite Service, downlink operations
39.5 – 40.5 GHz	Mobile Satellite Service, downlink operations
40.0 – 40.5 GHz	Earth Exploration Satellite Service, uplink operations Space Research Service, uplink operations
40.5 – 42.5 GHz	Broadcasting and Broadcasting Satellite Services
42.5 – 43.5 GHz	Fixed Satellite Service, uplink operations Radio Astronomy Service

In some European countries, the upper sub-range 40.5 – 43.5 GHz has been designated to terrestrial fixed service point-to-multipoint systems, which have their origin in telecommunication, and possibly broadcasting, which provide fixed wireless access directly to the end user, such as for multimedia services. Therefore, this band is considered suitable for 5G, both access systems and backhaul.

The lower sub-range 37-39.5 GHz is already allocated partly to mobile, while the mid-band 39.5-40.5 GHz, currently not allocated for mobile terrestrial service, would be attractive to include to achieve a contiguous 6500 MHz.

45.5-47 GHz, 47-50.2 GHz and 50.4-52.6 GHz (4700 plus 2200 MHz bandwidth)

For the three sub-ranges 45.5-47 GHz, 47-47.2 GHz and 47.2-50.2 GHz, the lower range provides 4700 MHz as combined, and 2200 MHz in the upper sub-range. The middle band 47-47.2 GHz, representing a bandwidth of 200 kHz, is currently allocated to the amateur and amateur satellite services, and markedly, not allocated to the Mobile Service. Speculating around the use of four sub-ranges combined, including the band 50.2 – 50.4 GHz, would provide about 7000 MHz. However, the band 50.2-50.4 GHz, which is allocated to passive services, the Earth Exploration Satellite Service and the Spacer Research Services, is not within the scope of WRC-19 studies.

Notably, the sub-ranges 47.2-50.2 GHz and 50.4-51.4 GHz are subject to studies for non-geostationary satellite orbit (NGSO) network uses under the WRC-19 AI 1.6. The 51.4 – 52.4 GHz band is studied under WRC-19 Issue 9.1.9 for the fixed satellite service for uplink operations.

Therefore, from a sharing point of view, this range may offer some significant challenges.

66-71 GHz (5000 MHz bandwidth)

The band 66-71 GHz, or parts thereof, is currently in use in some countries for mobile backhaul. The band is being considered for possible unlicensed use. For example, in the U.S. the FCC has already decided on unlicensed use.

The bands currently have several allocations covering inter-satellite, mobile, mobile satellite, radio navigation and radio navigation satellite services.

Due to the global allocation status and the very limited usage over Europe, there is a high potential for global harmonization of this band with other regions. Coexistence studies in other bands have typically shown that sharing between terrestrial services and inter-satellite service is feasible without significant limitations.

71-76 GHz and 81-86 GHz (10000 MHz bandwidth)

This range, termed the E-band, 71.0 – 76.0 GHz paired with 81.0 – 86.0 GHz, is currently in use for mobile backhaul. It is also being considered as a possible band for unlicensed services.

3.5 GHz (400 MHz bandwidth)

In addition to the bands studied for potential WRC-19 decision, the range 3400-3800 MHz is regarded as suitable for the introduction of 5G services in Europe before 2020. This band is already harmonized for 5G and consists of up to 400 MHz of continuous spectrum, enabling wide channel bandwidth. This band has the possibility to put Europe at the forefront of 5G deployment.

A challenge is that the band is unfortunately fragmented in terms of arrangements, usage and license expiry dates. The C-band normally provides paired assignments but is used for the fixed and FWA services, and some few fixed satellite service incumbents earth stations still remain in the band. The mobile industry is pursuing the initial objectives to acquire an amount of the order of hundred megahertz per service provider within the range 3400-3800 MHz for enhanced 4G and later 5G services.

On November 9, 2016, the Radio Spectrum Policy Group (RSPG) of the European Commission (EC) released its Strategic Roadmap toward 5G for Europe to facilitate the launch of 5G on a large scale by 2020.[13] The goal is that the benefits of 5G-based services are available to all European citizens in a timely manner, driving industrial and societal transformation and economic growth in Europe from 2020 and beyond. Key points of this roadmap include:

1. The RSPG considers the **3400-3800 MHz** band to be the primary band suitable for the introduction of 5G-based services in Europe, even before 2020. This band is already harmonized for mobile networks, and consists of up to 400 MHz of continuous spectrum enabling wide channel bandwidth. This band has the possibility to put Europe at the forefront of the 5G deployment
2. The RSPG believes that 5G also will need to be deployed in bands already harmonized below 1 GHz, including particularly the **700 MHz** band, in order to enable nationwide and indoor 5G coverage
3. The RSPG stresses that there are many frequency bands above 24 GHz that are of potential interest for 5G in Europe. The RSPG will define the timeline for availability of bands taking into account sharing and transition challenges, such as for mobile access and fixed services (including backhaul)
4. The RSPG notes the mobile industry support for the **24.25-27.5 GHz** band as a **pioneer band** for earlier implementation in Europe of 5G above 24 GHz. The RSPG recommends the 24.25-27.5 GHz as a pioneer band for 5G above 24 GHz and that:
   - Europe should develop harmonization measures on the basis of the radio spectrum decision in this band before 2020

[13] Radio Spectrum Policy Group, "Strategic Roadmap Towards 5G for Europe" RSPG16-032 FINAL, 09 November 2016.

- Member states should make available a portion of this frequency band for 5G in response to market demand, taking into account that 5G deployment in this frequency range is likely to remain geographically limited by 2020

5. RSPG recognizes that the band **31.8-33.4 GHz** looks promising for 5G and could be made available relatively easily by many European administrations, taking into account the existing fixed service deployment in this band. This frequency band will need further studies in order to assess the future availability, the demand from industry, the potential for global harmonization and the required technical conditions to protect existing services, including passive services in the adjacent bands. RSPG recommends that, in the meantime, shift of use from other bands to this 31.8-33.4 GHz band should be avoided as far as possible in order to keep the option open to make it available for 5G in the future
6. RSPG considers the band **40.5-43.5 GHz** a viable option for 5G in the longer term, taking into account the support from the mobile industry and the need to take into account the general balance between mobile and satellite sector to access the 40/50 GHz range. Shift of use from other bands to this 40.5-43.5GHz band should be avoided as far as possible in order to keep the option open to make it available for 5G in the future
7. The RSPG will prepare a supplementary opinion elaborating on the implementation of this opinion, taking also into account the work of the RSPG working groups on IoT and ITS, as well as existing licenses in the pioneer bands

III. SPECTRUM RANGES CONSIDERED SUITABLE FOR 5G APPLICATIONS

Recommendation ITU-R M.2083, IMT Vision – "Framework and overall objectives of the future development of IMT for 2020 and beyond" – identified three major usage scenarios for 5G:

- **Enhanced Mobile Broadband**: Mobile broadband addresses the human-centric use cases for access to multi-media content, services and data. The demand for mobile broadband will continue to increase, leading to enhanced mobile broadband. The enhanced mobile broadband usage scenario will come with new application areas and requirements in addition to existing mobile broadband applications for improved performance and an increasingly seamless user experience. This usage scenario covers a range of cases, including wide-area coverage and hotspot, which have different requirements. For the hotspot case (i.e., for an area with high user density), very high traffic capacity is needed, while the requirement for mobility is low and user data rate is higher than that of wide area coverage. For the wide-area coverage case, seamless coverage and medium to high mobility are desired, with much improved user data rate compared to existing data rates. However, the data rate requirement may be relaxed compared to hotspot
- **Ultra-Reliable and Low-Latency Communications**: This use case has stringent requirements for capabilities such as throughput, latency and availability. Some examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid and transportation safety
- **Massive Machine-Type Communications**: This use case is characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. Devices are required to be low cost, and have a very long battery life[14]

[14] Recommendation ITU-R M.2083, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond," 09/2015.

Figure 1 illustrates some usage scenarios and example applications.

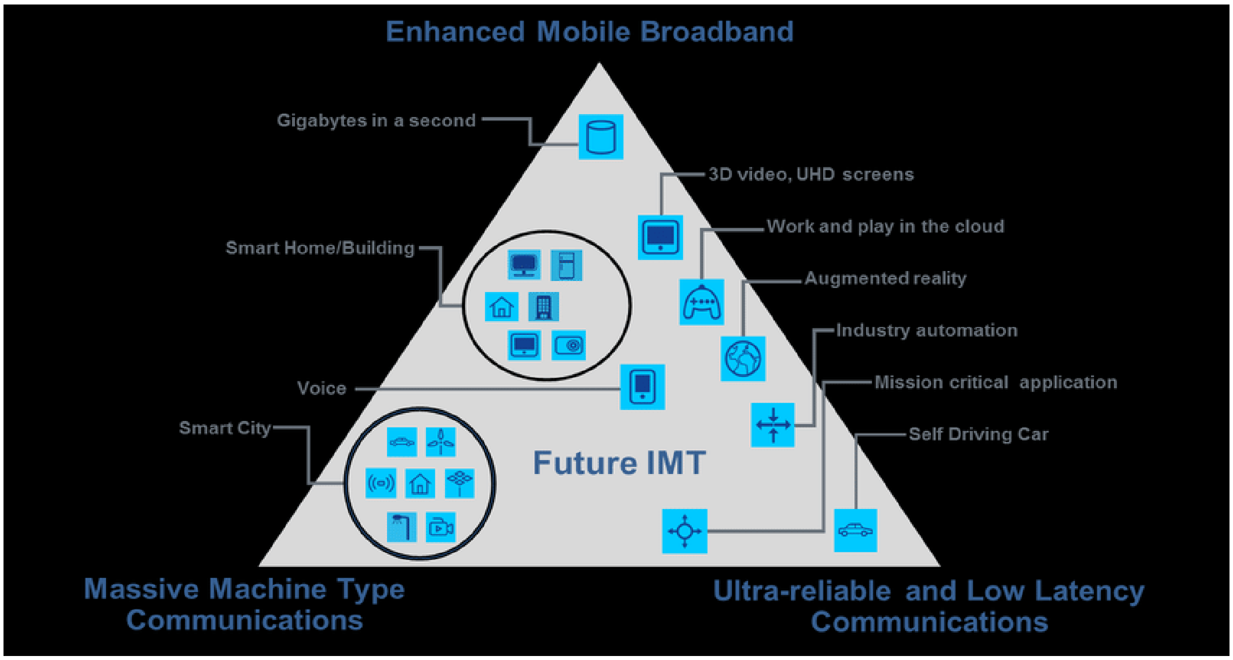

Figure 1. Usage Scenarios of IMT for 2020 and Beyond.

To be enabled, these applications each have specific technical requirements that need to be addressed through adequate design of the 5G radio interface(s) and access to appropriate frequency ranges. In its *5G Spectrum Recommendations*[15] white paper, 5G Americas summarized the important implications of various applications on radio interface design and spectrum and further considered the potential impact on spectrum, as shown in Tables 9 and 10.

Table 9. Potential Requirements of Various 5G Applications Impacting Radio Link Design.

(not a comprehensive list)[16]

Usage Scenario	Application	High-level Requirement
Enhanced Mobile Broadband	UHD video (4K, 8K), 3D video (including broadcast services)	Ultra-high speed radio links Low latency (real-time video)
	Virtual Reality	Ultra-high speed radio links ultra-low latency
	Augmented Reality	Ultra-high speed radio links low latency
	Tactile Internet	Ultra-low latency
	Cloud gaming	Ultra-high speed radio links low latency

[15] 5G Spectrum Recommendations, 4G Americas. August 2015.
[16] Ibid.

	Broadband kiosks	Ultra-high speed radio links Short range
	Vehicular (cars, buses, trains, aerial stations, etc.)	Ultra-high speed radio links Short to long range Support for low to high-Doppler environments
Ultra-Reliable Communications	Industrial Automation	Ultra-high reliability radio links High speed radio links Low to ultra-low latency Short to long range Operation in cluttered environments
	Mission-critical applications e.g. e-health, hazardous environments, rescue missions, etc.	Ultra-high reliability radio links High speed radio links Low to ultra-low latency Short to long range Operation in cluttered environments Ground/obstacle penetration
	Self-driving vehicles	Ultra-high reliability radio links High speed radio links Low to ultra-low latency Short to long range Operation in cluttered environments Operation near fast moving obstacles
Massive Machine-Type Communications	Smart home	Operation in cluttered environment Obstacle penetration
	Smart office	Operation in cluttered environment Obstacle penetration High reliability radio links
	Smart city	Short to long range Operation in cluttered environment Operation near fast moving obstacles High reliability radio links Ground/obstacle penetration
	Sensor networks (industrial, commercial, etc.)	Short to long range Operation in cluttered environment Operation near fast moving obstacles Ground/obstacle penetration Mesh networking

Table 10. Potential Spectrum-Related Implications of Various 5G Requirements.[17]

High-Level Requirement	Potential Spectrum-Related Implications
Ultra-High-Speed Radio Links	Ultra-wide carrier bandwidths, e.g., 500 MHz Multi-gigabit fronthaul/backhaul
High-Speed Radio Links	Wide carrier bandwidths, e.g., 100 MHz Gigabit fronthaul/backhaul
Support for Low to High-Doppler Environment	Depends on the throughput requirement
Ultra-Low latency	Short-range implications
Low Latency	Mid-short range implications

[17] *5G Spectrum Recommendations*, 4G Americas. August 2015.

Ultra-High-Reliability Radio Links	Severe impact of rain and other atmospheric effects on link availability in higher frequencies, e.g., mm-wave, for outdoor operations
High-Reliability Radio Links	Impact of rain and other atmospheric effects on link availability in higher frequencies, e.g., mm-wave, for outdoor operations
Short Range	Higher frequencies, e.g., mm-wave
Long Range	Lower frequencies, e.g., sub-3 GHz
Ground/Obstacle Penetration	Lower frequencies, e.g., sub-1 GHz
Operation in Cluttered Environment	Diffraction dominated environment in lower frequencies Reflection dominated environment in higher frequencies
Operation near Fast-Moving Obstacles	Frequency-selective fading channels
Mesh Networking	High-speed distributed wireless back haul operating in-band or out-of-band

A. FACTORS AFFECTING SPECTRUM NEEDS OF 5G APPLICATIONS

Factors such as, peak data rate to be supported by a radio system, spectral efficiency, user experienced data rate, and expected device density, all impact spectrum needs. In addition, usage scenarios, including expected coverage area, deployment environments and target applications introduce technical requirements and conditions on a radio system that directly or indirectly impact spectrum needs. For instance, all other aspects held constant, a system targeting an application requiring 100 Mbit/s user rate would require 10 times more spectrum than a system targeting another application requiring only 10 Mbit/s user rate.

Whether one does very simple, rough estimates of spectrum needs based on key performance indicators (KPIs) such as peak or user experienced data rate, or detailed calculations involving aspects such as link budget and system-level simulations, it should be recognized that for the system to support these KPIs, certain capabilities need to exist in the radio interface irrespective of geography or user demand/device projections.

As a simple example, starting with user experience data rate, if:

- D: Maximum data rate supported by a user/device
- N: Number of simultaneously supported users/devices in a cell
- S: Spectral efficiency (bits/s/Hz)

the amount of spectrum, B, required to support such rate could be calculated as:

$$B = (D \times N)/S \qquad \text{Eq. (1)}$$

In order to understand the spectrum requirements various applications could impose on 5G radio interface and network design, characteristics of a few prominent applications are described in the sections following.

Very High Data Rate video, e.g., VR/AR Applications

There are several high data rate eMBB applications envisaged today for 5G. These include ultra-fast content transfer, such downloading an entire movie in a fraction of a second from a kiosk, virtual reality (AR) and augmented reality (AR), especially those that integrate the physical surroundings into the VR/AR.[18]

Based on equation (1), and considering a user experienced data rate of 1 Gbit/sec that might be required for data intensive video applications, and a 3x spectral efficiency increase over IMT-Advanced for cell-edge users/devices (as per Recommendation ITU-R M.2083), B (in GHz) could be calculated as follows:

[18] *" Intel's CES 2017 Press Conference Put the Audience Inside VR"*

Table 11. eMBB Spectrum Needs Based on Some of M.2083 Performance Targets.

	N=1	N=2	N=4
B (GHz)	3.33	6.67	13.33

The number of simultaneous users served by a base station, N, depends on the radio interface design, including scheduling algorithms and distribution of resources throughout the network.

It should be noted that the above results are per RF carrier and do not consider use of multiple carriers for frequency reuse and/or spectrum needs of multiple network operators in a given area, which increases the total amount of needed spectrum. Network and operational factors play a determining role in the amount of spectrum needed to be made available by regulators. For instance, one country may wish to make sufficient 5G spectrum available for three network operators, while another country may desire to accommodate four operators. These factors need to be taken into account if a full picture of spectrum requirements is to be obtained.

It should also be noted that the above example uses the highest cell-edge spectral efficiency among various environments described in IMT-Advanced.[19] Other environments with lower spectral efficiency targets would result in higher spectrum needs.

The Fully Autonomous Vehicle

The fully autonomous vehicle is the amalgamation of a variety of diverse, and sometimes opposing, needs. The complexity of functions, combined with safety requirements, turn these future platforms into a culmination of everything 5G could, or is being envisaged to, deliver. These functions span a wide range from high-speed connectivity, ultra-low latency connectivity, environment sensing and mapping, both local and long-range connectivity to infrastructure, on-board edge computing and analytics supported by deep learning/machine learning, and a multitude of sensors to collect information needed to make the vehicle work autonomously.

While some operational aspects of the fully autonomous vehicle might require modest peak throughput, other operational aspects such as safety-related features could require very low latencies, in the order of a few milliseconds. For any given spectral efficiency, the lower the latency, the higher the throughput required to transfer a certain amount of data.

As a simple example for demonstrative purposes, assuming 1 Mbytes of data (e.g., a low-res photograph) is to be transferred over the 5G radio link with a spectral efficiency of 1 bit/s/Hz, a required air interface latency of 1 millisecond would require 8 GHz of spectrum (i.e., 1000x more spectrum than the case of an acceptable latency of 1 second).

The previous example demonstrates that all operational requirements of 5G applications need to be considered and not only peak throughput.

eHealth

Similar to automotive case, eHealth applications also present a variety of characteristics due to the diversity of use cases and environments in which these applications operate. While some eHealth applications require long range in order to reach over long distances (e.g. in rural areas), other applications such as monitoring vital signals inside hospitals and clinics face a totally different set of challenges including operation in cluttered multi-path environment.

[19] Report ITU-R M.2135-1, "Guidelines for evaluation of radio interface technologies for IMT-Advanced," 12/2009.

An eHealth application, currently under significant research and development efforts, is remote surgery. Remote surgery requires very short latencies in the order of sub-milliseconds in performing life-saving operations incorporating haptic technology and tactile Internet connectivity.

Smart Cities

The urbanization of societies has been growing at an enormous rate. In 2016, the United Nations projected that by the year 2030, 5 billion people will live in urban areas around the world. That's 60 percent of the world population. Today, cities consume 75 percent of the world's energy while being responsible for 80 percent of the carbon impact. The problem of energy consumption will only grow over time and needs solutions for sustainable growth if the 5G vision of connected societies in a connected world is to happen.

Around the world, meeting the demands of urban living in an environmentally-friendly manner is increasingly an important objective among the citizenry, corporations and the government. Smart public services and smart infrastructure solutions that help to reduce carbon footprint (e.g., smart mobility, energy efficient buildings) and reduce resource use (e.g., recycling, sharing) and improve citizen wellbeing (e.g., reduced air and water pollution) are high on the agenda of many municipalities.

At the same time, we are at a point in the world where the convergence of mobile, social, cloud and information is occurring. This convergence could be taken advantage of in creating smart city solutions. The systems that are going to make smart city solutions so impactful are going to require an unprecedented integration of wireless connectivity, computing intelligence and distributed cloud resources.

All-Knowing and Energy-Efficient Outdoor Lighting

This example integrates extensive sensor capabilities into the existing LED lighting fixtures. The sensing capability, combined with processing power embedded into light fixtures, collects multiple data streams (e.g., pollution, sound, seismic, visual) and enables multiple applications. These light fixtures could deliver edge analytics for real-time data intelligence, which would be critical for low-latency applications and reducing the load on the core network. The ability to run local analytics at the edge for real-time needs also allows for more robust analytics and data fusion.

Video capabilities of such light fixtures can be used for smart parking, pedestrian detection and license plate recognition (law enforcement). It should be noted that the offered real-time high-definition video transmission density requirements (bit/m^2) of this application operating in a variety of environments from dense urban to suburban areas are determined by the surveillance area for meaningful observation, and not by the RF environment. As a result, these type of applications, might require as much capacity in less dense areas as they do in densely populated areas.

Cutting Drive Time, Reducing Pollution and Creating Revenue Opportunities with Smart Parking

Smart parking allows drivers to efficiently locate and pay for their parking, increases safety and the use of available resources, reduces congestion and related air pollution, lowers the cost of parking enforcement, and enables third-party organizations to create innovative, revenue-producing applications using smart parking data. A modular, infrastructure-based sensor system could gather data on the parking situation, which results in residents spending considerably less time looking for parking and reduces traffic volume where parking availability increases.

B. ITU-R SPECTRUM NEEDS FOR IMT-2020 IN BANDS ABOVE 24 GHZ

In preparation for WRC-19 agenda item 1.13, and as requested by Resolution 238 (WRC-15), ITU-R Working Party 5D (WP5D) performed studies to determine spectrum needs of IMT-2020. The outcome of these studies[20] will be used by another ITU-R group, Task Group 5/1 (TG5/1), as part of a larger study on

[20] See document 5-1/36, "spectrum needs and characteristics for the terrestrial component of IMT in the frequency range between 24.25 GHz and 86 GHz," Liaison statement to Task Group 5/1, WP5D, 28 February 2017.

bands between 24.25 GHz and 86 GHz, to prepare input material for consideration of administration at WRC-15.

The analysis done by WP5D considers several approaches to the problem, including spectrum requirements of various applications envisaged for 5G, as well as technical performance requirements targets included in Recommendation ITU-R M.2083, or IMT-2020 Vision. WP5D also included a set of inputs it received from certain administrations on how they address spectrum needs of 5G in their own domestic processes.

Application-Based Approach

Considering several existing and future applications, such as video streaming, and their throughput requirements, combined with consideration of different tele-density environments and spectral efficiency capabilities of 5G systems, two separate examples were considered. Table 12 summarizes these results.

Table 12. Estimated Spectrum Needs Based on the Application-Based Approach (Source: 5-1/36).

Example	Tele-densities	24.25-33.4 GHz	37-52.6 GHz	66-86 GHz	Total
Example 1	Overcrowded, Dense urban and Urban areas	3.3 GHz	6.1 GHz	9.3 GHz	18.7 GHz
	Dense urban and Urban areas	2.0 GHz	3.7 GHz	5.7 GHz	11.4 GHz
Example 2	Highly crowded area	666 MHz	1.2 GHz	1.9 GHz	3.7 GHz
	Crowded area	333 MHz	608 MHz	933 MHz	1.8 GHz

The differences in the amount of spectrum needed between the two examples are due to differing assumptions about target applications and their throughput requirements, as well as connection/user/device density assumptions. For instance, it is expected that applications requiring higher peak throughput and lower latencies (e.g., UHD video and VR/AR) require more spectrum than applications such as certain MTC applications (e.g. sensor networks).

However, in order to cover the most demanding of the 5G applications, WP5D studies show that up to 18.7 GHz of spectrum is needed in the 24-86 GHz range.

Technical Performance-Based Approach

In this approach, target values in M.2083, including peak throughput, cell-edge throughput and latency, were considered as target capabilities of the radio interface of 5G and thus determine the amount of spectrum needed in order to achieve these targets. Several examples where considered based on different technical performance requirements. Table 13 contains spectrum needs based on cell-edge and latency targets in M.2083 (IMT Vision).

Table 13. Estimated Spectrum Needs Based on Cell-Edge and Latency Targets.

Examples	Spectrum Needs
#1 – Based on cell-edge user throughput and spectral efficiency targets in Recommendation ITU-R M.2083 with *N* simultaneously served users/devices at the cell-edge	User experienced data rate of 1 Gbit/s: 3.33 GHz (*N*=1), 6.67 GHz (*N*=2), 13.33 GHz (*N*=4), e.g., Indoor User experienced data rate of 100 Mbits/s:

	0.67 GHz (*N*=1), 1.32 GHz (*N*=2), 2.64 GHz (*N*=4), for wide area coverage
#2 – Based on cell-edge user spectral efficiency (obtained from 3GPP technical specifications) and data rate targets (from Recommendation ITU-R M.2083) in two given test environments	0.83-4.17 GHz (for eMBB Dense Urban) 3-15 GHz (for eMBB Indoor Hotspot)
#3 – Impact of latency and spectral efficiency targets and a typical user throughput value on spectrum needs	With a file transfer of 10 Mbits by a single user at cell-edge in 1 msec: 33.33 GHz (one direction) With a file transfer of 1 Mbit by a single user at cell-edge in 1 msec: 3.33 GHz (one direction) With a file transfer of 0.1 Mbits by a single user at cell-edge in 1 msec: 333 MHz (one direction)

The difference in the amount of spectrum needed between examples #1 and #2 is due to consideration of different cell edge throughput requirements in different environments and associated spectral efficiency. It is evident that lower throughput targets over a wide area would require less spectrum. However, such environments are more likely to be covered with spectrum below 6 GHz, which characterize farther reach more suitable for less dense environments.

In addition, in example #3, the amount of data to be transferred over a low-latency link has a determining impact on the amount of spectrum needed. However, it becomes clear that even a modest file size of 1 Mbit would require more than 3 GHz of spectrum. To put things in contrast, a picture captured on most smartphone cameras is in the order of 3-5 Mbytes (24-40 Mbits).

Information from Certain Countries

Several countries[21] provided information on their existing or planned 5G spectrum allocations for bands above 24 GHz. Table 14 summarizes the results.

Table 14. Spectrum Needs Based on the Information from Some Countries.

Frequency ranges	**24.25-43.5 GHz**	**43.5-86 GHz**
Spectrum needs	2-6 GHz	5-10 GHz

C. SUMMARY

Derivation of spectrum needs of 5G, expectedly, is dependent on the methodology and the target numbers used in each methodology. It is evident from the discussions in this section that various applications require different amount of spectrum to be delivered to users/devices. In addition, target technical performance requirements have a direct impact on the total amount of spectrum needed.

General spectrum implications described above can be further assessed to identify specific frequency ranges that offer the necessary characteristics, including bandwidth and propagation, to enable these applications. Table 15 provides that assessment.

Table 15. Spectrum Ranges Considered Suitable for 5G Applications.

[21] The United Sates, The Republic of Korea, Sweden, Brazil, Arab Republic of Egypt, Kingdom of Bahrain, and the Russian Federation.

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, e.g. 500 MHz Multi-gigabit front haul/backhaul, indoor	> 24 GHz
	High speed radio links	Wide carrier bandwidths, e.g. 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, e.g. mm-wave, for outdoor operations	< 6 GHz
	High reliability radio links	Impact of rain and other atmospheric effects on link availability in higher frequencies, e.g. mm-wave, for outdoor operations	< 6 GHz
Ultra-reliable Communications	Short range	Higher frequencies, e.g. mm-wave	> 24 GHz
	Medium-Long range	Lower frequencies, e.g. sub-6 GHz	< 6 GHz
	Ground/obstacle penetration	Lower frequencies, e.g. 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

It should be noted that ranges, reflecting a variety in assumptions, are inevitable when developing spectrum needs based on technical performance criteria of 5G systems. However, in order to support envisaged applications and/or KPIs and to provide the benefits to users as envisaged in Recommendation ITU-R M.2083, spectrum availability should not be the bottleneck. Therefore, among various results derived based on different KPIs in different environments, the largest amount of spectrum should be chosen to ensure that every usage scenario and associated applications could be fully supported in line with the envisaged target KPIs.

Lastly, it should be recognized that for the radio interfaces of 5G systems to provide support for a variety of applications with differing spectrum needs, it becomes mandatory for the radio interface to be able to support the highest amount of spectrum needed in order to become universally inclusive of all envisaged applications, usage scenarios and deployment conditions.

IV. HARMONIZATION OF 5G SPECTRUM

A. 5G SPECTRUM IN LEADING MARKETS

For regulators in the Americas region, the framework for a regional roadmap for spectrum policy decisions to support 5G networks already exists, as discussed in Section II of this paper. Not only is there a growing global consensus about 5G spectrum, but industry has carefully analysed use cases and propagation characteristics needed to support the wide variety of 5G services that can be made available. For spectrum policy, additional low-range spectrum (<3 GHz) is needed, with a particular focus on the 600 and 700 MHz bands. Mid-range spectrum (3-6 GHz), particularly in the 3-4 GHz range, is also proving to be an important 5 GHz ingredient, as demonstrated by the activities of both European and U.S. regulators. Finally, broad swaths of millimeter wave spectrum above 6 GHz are necessary to support a growing range of services that 5G networks will offer.

5G Americas believes that regulators throughout the region should immediately take stock of how ready their policies are to support 5G networks, both with respect to bands identified at WRC-15, as well as millimeter wave bands identified for action at WRC-19. For bands previously identified, jurisdictions should re-double their efforts to assign the spectrum to service providers that can put the spectrum to work. For bands under consideration, jurisdictions should at a minimum begin proceedings that would enable the relevant bands to be allocated to mobile, or allocated to mobile on a co-primary basis. Jurisdictions should also consider whether to begin the rulemaking process to define how spectrum should be assigned in the future.

Key Bands for Regulatory Decision-Making

- *700 MHz (low-range) -* In reviewing the global activity for low-range spectrum, the 700 MHz band stands out as a band that is well on its way to being implemented with a global footprint. Regulators in the Latin American region, while initiating proceedings in many major jurisdictions, have not yet assigned spectrum to operators. Regulators should re-double their efforts to complete the assignment process as quickly as possible
- *24 GHz and above (high-range) -* From the WRC-19 agenda item, as well as decisions in Europe and the United States, it is now clear that millimeter wave spectrum above 24 GHz will become a key part of 5G networks. Several major Latin American jurisdictions already have a co-primary allocation in the bands that are under study for WRC-19. For jurisdictions that are lacking a co-primary allocation, consideration should be given to creating one, and planning should begin to identify which of the bands can be offered for cleared, exclusively licensed use, and which might need to be shared. Jurisdictions should strongly consider whether it is possible to open 28 GHz for mobile services, as the U.S. has done. Other priority ranges for deployment include 24-27.5 GHz, 27.5-29.5 GHz and 37-43.5 GHz
- *3 GHz bands (mid-range) -* Spectrum from 3.4-3.6 GHz is globally allocated for mobile and identified for IMT, with another 50 countries also identifying 3.3-3.4 GHz for IMT. Europe has announced its intent to open 3.4-3.8 GHz as 5G spectrum region-wide.[22] However, in the Americas, significant mid-range spectrum shortage represents a gap for operators that will need to have mid-range spectrum to deploy certain 5G use cases that benefit from the inherent coverage-capacity trade-off, which is the main characteristic of the mid-range spectrum for cellular services. Countries throughout the region need to evaluate their readiness for mobile operations in these bands in

[22] *Strategic Roadmap Towards 5G for Europe,* RSPG16-032 FINAL, Radio Spectrum Policy Group. 9 November 2016.

support of 5G use cases, and begin to take steps to migrate the bands so that they can be used for 5G mobile networks

In addition to the above identified bands, regulators should facilitate the use of existing IMT bands for 5G usage. 3GPP identified several existing IMT bands in the early 5G New Radio release. It is important that regulators allow 5G in existing bands. 3GPP Release 15 includes an objective to develop co-channel coexistence between LTE and New Radio. A good example of an existing IMT band that is available for New Radio deployment today is the 2.5 GHz band.

B. FACTORS LEADING TO ECONOMIES OF SCALE

Spectrum harmonization is a crucial factor in enabling mobile broadband by facilitating economies of scale and global roaming. However, harmonization is not limited to a situation where all regions have identical spectrum allocations. The benefits of harmonization can also be derived from "tuning range" solutions covering adjacent or nearly-adjacent bands in which equipment can be reconfigured to operate over multiple bands (i.e., they are within the same tuning range).

Tuning ranges are critical to delivering the benefits of harmonization as the radio units in user devices developed for one band can also be utilized in some nearby bands without requiring entirely new development efforts. Cost, performance and complexity trade-offs impact the feasibility of covering harmonized frequency ranges with a single radio unit. As technology and volume manufacturing capabilities advance over time, further widening of radio tuning ranges may become feasible.

The concept of radio tuning ranges is also an important consideration with respect to WRC-19 Agenda item 1.13 on IMT as differences in uses and priorities among various countries and regions may make it difficult to reach consensus on the global identification to IMT for individual bands. Fortunately, radio tuning ranges can be created that potentially cover more than one region. For example, the U.S. has already decided to move forward with enabling mobile broadband in 27.5-28.35 GHz, and other countries plan to use 26.5-29.5 GHz, or parts thereof. Meanwhile, Europe has identified 24.5-27.5 GHz as a priority band for 5G. The combination of the 28 GHz band in some countries and 26 GHz band in other countries could create an opportunity for a band plan where all or significant part of the 24.25-29.5 GHz range has meaningful chances for being supported by a single radio, thus driving the economies of scale and facilitating global roaming.

The use of existing IMT bands has the advantage of being able to reuse existing front end modules for 5G NR usage.

C. FLEXIBLE LICENSING

Understanding tuning ranges, and their contribution to harmonization of spectrum and radio equipment, raises a corollary issue that should not be ignored: flexible licensing for mobile services. Flexible licenses are those that are not tied to a particular technology, a generation of a mobile technology, or a particular use case. With 5G mobile networks expected to support much broader ranges of radio spectrum than ever before and address a much wider range of use cases, licenses should not contain limitations that act as artificial barriers to an operator's ability to utilize its radio spectrum. Operators can continue to be expected to coordinate with each other to the extent different generations of technology will operate in geographic proximity.

V. CONCLUSIONS

This paper analyzes recent developments around the globe in the area of finding and allocating the right amount and appropriate spectrum that could address the challenges of upcoming 5G systems. A review of relevant recent activities in various regions, followed by a detailed analysis of spectrum needs of various 5G usage scenarios, points the reader to suitable ranges and associated factors that need to be considered by regulators around the globe for adequate and timely allocation of spectrum for 5G. This report also presents specific calls to action and recommends practical means for achieving global harmonization on 5G spectrum that would create economies of scale and help create a healthy 5G ecosystem.

VI. ACKNOWLEGEMENTS

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