COMMERCE SPECTRUM MANAGEMENT ADVISORY COMMITTEE (CSMAC)

5G SUBCOMMITTEE

FINAL REPORT

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1 NTIA Question

What are the technology and standardization challenges unique to 5G that are associated with federal/non-federal spectrum sharing, and what specific roles/actions should NTIA take to address these challenges?

2 Overview

It is widely expected that the next generation wireless technology would have to not only satisfy the increase in demand for ubiquitous broadband data, but also focus on enabling a connected society and to support critical communication all under one umbrella called “5G”.

Based on the observation of trends, it is clear that mobile devices will continue to play a critical role in every day activities. It should also be recognized clearly that 5G is not just about a larger data pipe, rather it is a technology that is being driven by various applications across multiple vertical markets. Further, it should be noted that in the future, newer use cases which have yet to be identified could emerge.

5G systems may be designed and implemented in a modular manner such that not all features are made available and implemented at once in every band. For example a certain frequency band may be found unsuitable for high density, high capacity deployments but could be suitable for others such as low bursts, ultra-low latency applications.

The ITU-R vision document for IMT-2020 has classified 5G into 3 widely accepted scenarios, and can be used as reference for sharing techniques:

- Enhanced mobile broadband
- Ultra Reliable, low latency applications
- Massive machine type communications

Industry planning for 5G has been under way for about two years. The initial focus of the work was on developing a common understanding about 5G:

- Whitepapers published – e.g., 5G Americas, NGMN white papers
- Primarily addressed use cases and the derived requirements for a “5G System”
- Included some discussion on candidate technologies

The action has now moved into the standards arena:

- Schedule and release planning
- In-depth study items
- Primarily at 3GPP and ITU, but other forums may also participate in 5G standardization

While there has been significant emphasis and investment on radio technologies research (with a focus on above 6 GHz bands & technology), these use cases and requirements point to the need for significant advances in both RAN and the core network. 5G is also so much more than speed:

- Multi-gigabit speeds and high capacity
- Connectionless massive IoT

- Ultra-low latency and high reliability
- Sub 6 GHz for wide area coverage with improved spectral efficiency
- Flexible, lean carrier design
- Multi-RAT network using sub 6 GHz, mmWave and unlicensed bands in concert
- Massive MIMO
- Densification with self-backhaul
- SDN/NFV based architecture

2.1 Timelines

The following figure shows the timelines for 5G development at both ITU-R and 3GPP.

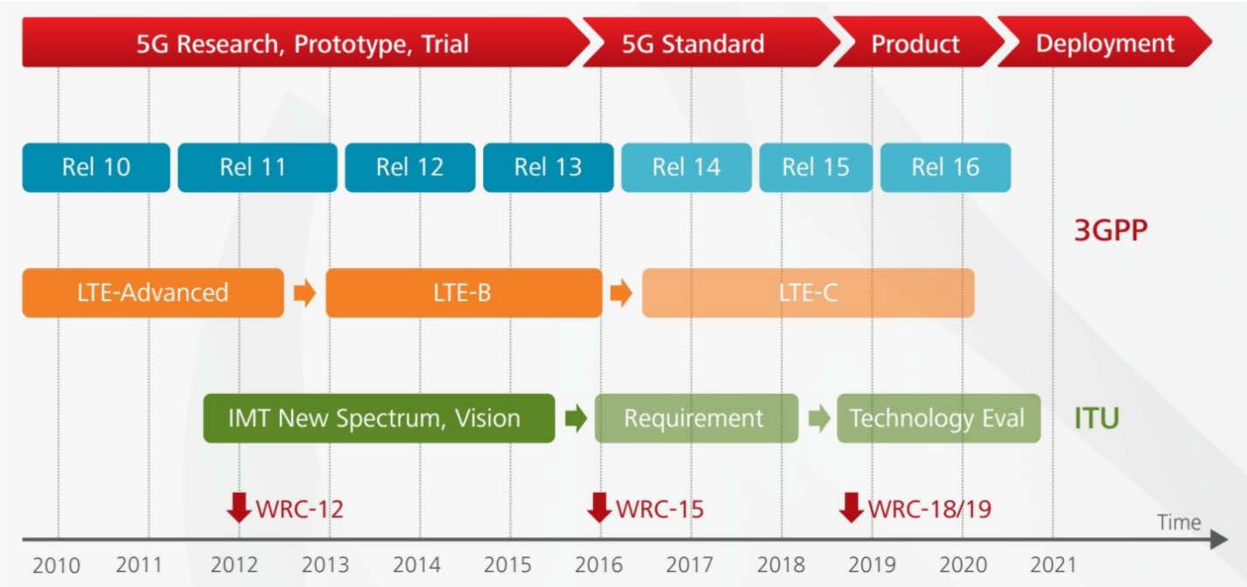

Figure 1: 5G Standards Development Timeline

2.2 Spectrum

At the WRC-15, various regional groups have presented their input on what frequency bands should be considered for 5G studies. Looking at the options presented, it is clear that administrations view different parts of spectrum as more suitable or of higher priority than others, this is based on individual administrations regulatory status and needs.

FCC's "Spectrum Frontier" NPRM has the following mmWave bands listed for comments- 27.5-28.35 GHz, 38.6 - 40.0 GHz, 37.0 – 38.6 GHz, 64 – 71 GHz, additionally during the NOI process, the commission also received input on several other bands.

The higher frequency bands should also be studied for sharing against their intended deployment model. The nature of higher frequencies do present challenges in outdoor operation and in-building penetration; certain frequencies e.g. > 40 GHz may only be suitable for indoor operations.

Finally any existing spectrum band can be used for 5G. There are several initiatives to free up spectrum in the cmWave and mmWave region and this is primarily being driven by having larger block sizes to support higher data rates. However any current or future spectrum may be used for a 5G deployment with a continuing need for lower frequency spectrum to meet coverage requirements.

3 Industry Status

3.1 International Telecommunication Union (ITU)[1]

The ITU is largely considered to be the body that will set the global standard for 5G requirements. The ITU has established the overall roadmap for the development of 5G, including a detailed timeline, and has approved the term "IMT-2020" to refer to 5G.[2] ITU's Radiocommunication Sector ("ITU-R"), through Working Party 5D (WP5D), has finalized its vision document for IMT-2020 with detailed work to begin in early 2016, including performance requirements, evaluation criteria and methodology for the assessment of the new IMT radio interface.[3]

The following figure illustrates some examples of envisioned usage scenarios for IMT- 2020 and beyond:

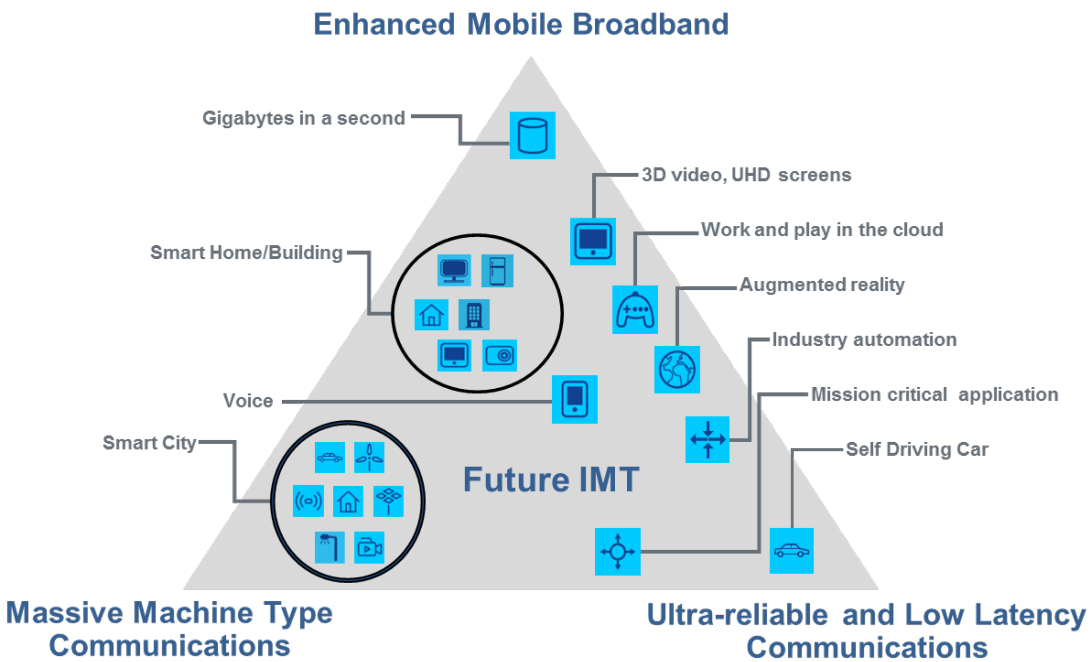

Figure 2: ITU Usage Scenarios

[1] ITU towards "IMT for 2020 and beyond", http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx.
[2] Workplan, timeline, process and deliverables for the future development of IMT, http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Documents/Antipated-Time-Schedule.pdf
[3] IMT Vision- Framework and overall objectives of the future development of IMT for 2020 and beyond, ITU-R Recommendation M.2083-0, 9/2015, http://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf.

The following eight parameters are the key capabilities of IMT-2020:

Table 1: ITU 5G Requirements

Key Performance Indicator	**Value**
Peak Data Rate	20 Gbps
User Experienced Data Rate	100 Mbps
Latency	1 ms
Mobility	500 km/h
Connection Density	1 million/ km^2
Traffic Density	10 Mbps/ m^2
Energy Efficiency	100x IMT-ADV

WP5D plans to hold a workshop in late 2017 to discuss performance requirements and evaluation criteria and methodology for IMT-2020 candidate technologies. The entire process will be completed in 2020, when a new draft ITU-R Recommendation with detailed specifications for new radio interfaces will be submitted for approval within ITU-R.

3.2 3rd Generation Project Partnership (3GPP)[4]

The 3rd Generation Partnership Project is the specification setting body which will define the mobile wireless technical specifications for 5G for both the radio and core, similar to its predecessors- LTE, HSPA, etc. 3GPP's technical specifications are transposed by relevant standardization bodies (organizational partners) into appropriate deliverables (e.g., standards). There are seven 3GPP organizational partners from Asia (ARIB, CCSA, TSDSI, TTA, TTC), Europe (ETSI) and North America (ATIS). 3GPP is a contribution driven organization which operates by 100% consensus to design specifications, and its members include a variety of telecom vendors, operators, regulators and industrial organizations. Recently members of multiple vertical markets have started attending the sessions as well. 3GPP held a comprehensive 5G workshop in September 2015. As a result of this workshop the following work was initiated:

- 3GPP approved a Study Item on channel modelling for spectrum above 6 GHz.
    - 3GPP identified the status and expectations on high frequencies (including spectrum allocation, scenarios of interest, measurements, etc.) in Q4 2015
    - In Q1 2016, 3GPP completed the channel modeling for frequencies up to 100 GHz
- 3GPP approved a Study Item to develop 5G scenarios and requirements in December 2015
- 3GPP approved a study item in March 2016 to allow 3GPP working groups to evaluate 5G technology solutions

[4] RAN 5G Workshop – The Start of Something, September 19, 2015, http://www.3gpp.org/news-events/3gpp-news/1734-ran_5g.

- Phase 1 of specification work is currently targeted to be completed during the second half of 2018 (End of 3GPP Release 15)
- Phase 2 of specification work is currently targeted to be completed by December 2019 for the IMT-2020 submission, and will address all identified use cases and requirements.

In addition to technical specifications for the radio technology, 3GPP is also developing specifications for an end to end architecture, including the core network. 5G is inclusive of the entire ecosystem, including air interface, devices, transport, packet core and more. The initial studies include:

- TR 22.891 - Feasibility Study on New Services and Markets Technology Enablers; Stage 1 (Release 14)
- TR 22.864 - Feasibility Study on New Services and Markets Technology Enablers - Network Operation; Stage 1 (Release 14)
- TR 22.863 - Feasibility Study on New Services and Markets Technology Enablers - Enhanced Mobile Broadband; Stage 1 (Release 14)
- TR 22.862 - Feasibility Study on New Services and Markets Technology Enablers – Critical Communications; Stage 1 (Release 14)
- TR 22.861 - Feasibility Study on New Services and Markets Technology Enablers for Massive Internet of Things; Stage 1 (Release 14)

3GPP 5G system architecture work started October 2015 as part of 3GPP Release 14, and will study the next generation 3GPP system architecture (including improvements and optimizations on the existing architecture). This work will achieve a simple, flexible, scalable and extensible architecture with high overall efficiency for data services of significantly differing traffic characteristics and with high flexibility for deploying networks and network slices of different characteristics for serving various users and services' needs adequately and efficiently. Work will span over three releases:

- Release 14 currently being worked on only includes the study phase
- Release 15 expected to include a baseline system with a study in parallel on more advanced features
- Release 16 expected to include more advanced features necessary for wide scale deployments

3.3 5G Infrastructure Public Private Partnership (5G PPP)[5]

5G PPP is a joint initiative between the European Commission, the European ICT industry, and academia, with an objective of creating 5G network standards that can support ultra-high capacity, reduced energy consumption, reduced service creation time cycle, secure and ubiquitous coverage with negligible latency, dense wireless communication links and increased user security. The group is a parallel effort to 3GPP, working on waveforms, radio systems and architecture. 5G PPP plans to invest more than 4 billion Euros to rethink the infrastructure and to create the next generation of communications networks and services. 5G PPP is currently in

[5] https://5g-ppp.eu/

the research stage, but plans to move to the optimization stage in 2016-2017 and to conduct large scale trials in 2019-2020. In July 2015, 5G PPP launched its first wave of research and innovation projects, including 19 separate research projects to address a wide variety of 5G challenges.[6]

Horizon 2020 is a European Union research and innovation program providing 80 billion Euros in public funding for projects spanning 2014-2020, with the goal of ensuring Europe produces world-class science, removes barriers to innovation, and facilitates public and private sector collaboration.[7] 5G PPP is a Horizon 2020 project, and 700 million Euros from the Horizon 2020 public funding has been earmarked for 5G PPP projects.

3.4 Institute of Electrical and Electronics Engineers (IEEE)[8]

In 2015, IEEE held a series of 5G summits to provide a platform for industry leaders and researchers to collaborate with the aim of driving the development of standards and rapid deployment. The October 2016 issue of the IEEE communications magazine will focus on the 5G radio access network architecture and technologies. Additionally, IEEE is working on the new 802.11ax Wi-Fi standard, which could deliver gigabit speeds and fit into the 5G puzzle.[9]

3.5 Next Generation Mobile Networks (NGMN) Alliance[10]

NGMN is a global mobile operator alliance with a focus to expand mobile broadband across various business models, with a particular focus on 5G while accelerating the development of the LTE-Advanced ecosystem. In March 2015, NGMN published a white paper on 5G that explores multiple deployment and sharing models in addition to key performance requirements.[11] The white paper also sets a 5G timeline goal, including finalization of 5G standards by the end of 2018 and commercial 5G deployments in mid-2020.

NGMN has developed twenty-five representative use cases for 5G, which are grouped into the following eight use case families:

[6] The 5G Infrastructure Public Private Partnership (5G PPP), First Wave on Research & Innovation Projects, https://5g-ppp.eu/wp-content/uploads/2015/10/5GPPP-brochure-final-web.pdf.
[7] What is Horizon 2020? http://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020
[8] http://www.comsoc.org/
[9] Add citation
[10] https://www.ngmn.org/about-us/vision-mission.html.
[11] A Deliverable by the NGMN Alliance, NGMN 5G White Paper, 17 February 2015, https://www.ngmn.org/fileadmin/ngmn/content/downloads/Technical/2015/NGMN_5G_White_Paper_V1_0.pdf

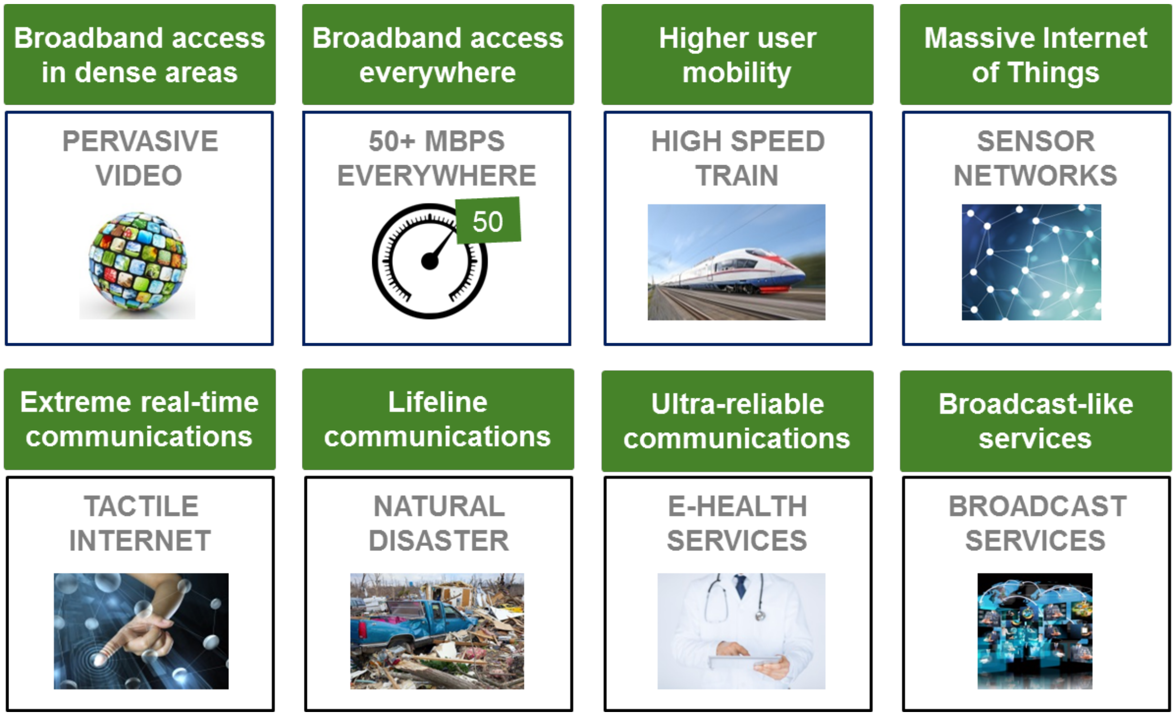

Figure 3: NGMN Use Case Families

The 5G use cases demand very diverse, and in some instances, extreme requirements. In order to reflect use case dependency, the NGMN requirements are specified according to "Use Case Categories." For each use case category, one set of requirement values is given, which is representative of the extreme use cases(s) in the category. Further, the key performance indicators are classified in six types, such as user experience, system performance, device, etc.

The requirements table is extensive and can be found in the NGMN white paper. Some key requirements are summarized for reference in Table 2 below.

Table 2: NGMN 5G Requirements

	User Experience			System Performance	
Use Case Category	User Experienced Data Rate	E2E Latency	Mobility	Connection Density	Traffic Density
Broadband access in dense areas	DL: 300 Mbps UL: 50 Mbps	10 ms	0-100 km/h	200-2500 /km^2	DL: 750 Gbps / km^2
Indoor ultra-high broadband access	DL: 1 Gbps, UL: 500 Mbps	10 ms	Pedestrian	75,000 / km^2 (75/1000 m^2 office)	UL: 125 Gbps / km^2

	User Experience			System Performance	
Broadband access in a crowd	DL: 25 Mbps, UL: 50 Mbps	10 ms	Pedestrian	150,000 / km^2 (30.000 / stadium)	DL: 3.75 Tbps / km^2 (DL: 0.75 Tbps / stadium) UL: 7.5 Tbps / km^2 (1.5 Tbps / stadium)
50+ Mbps everywhere	DL: 50 Mbps UL: 25 Mbps	10 ms	0 -120 km/h	400 / km^2 in suburban 100 / km^2 in rural	DL: 20 Gbps / km^2 in suburban UL: 10 Gbps / km^2 in suburban DL: 5 Gbps / km^2 in rural UL: 2.5 Gbps / km^2 in rural
Ultra-low cost broadband access for low ARPU areas	DL: 10 Mbps UL: 10 Mbps	10 ms	0-50 km/h	16 / km^2	16 Mbps / km^2
Mobile broadband in vehicles (cars, trains)	DL: 50 Mbps UL: 25 Mbps	10 ms	up to 500 km/h	2000 / km^2 (500 active users per train x 4 trains, or 1 active user per car x 2000 cars)	DL: 100 Gbps / km^2 (25 Gbps per train, 50 Mbps per car) UL: 50 Gbps / km^2 (12.5 Gbps per train, 25 Mbps per car)
Airplanes connectivity	DL: 15 Mbps per user UL: 7.5 Mbps per user	10 ms	up to 1000 km/h	80 per plane 60 airplanes per 18,000 km^2	DL: 1.2 Gbps / plane UL: 600 Mbps / plane
Massive low-cost/long-range/low-power MTC	Low (typically 1-100 kbps)	Seconds to hours	up to 500 km/h	Up to 200,000 / km^2	Not Critical
Ultra-low latency	DL: 50 Mbps UL: 25 Mbps	< 1 ms	Pedestrian	Not Critical	Potentially High

	User Experience			System Performance	
Ultra-high reliability & Ultra-low latency	DL: 50 kbps to 10 Mbps; UL: From a few bps to 10 Mbps	1 ms	up to 500 km/h	Not Critical	Potentially High
Ultra-high availability & reliability	DL: 10 Mbps UL: 10 Mbps	10 ms	up to 500 km/h	Not Critical	Potentially High
Broadcast like services	DL: Up to 200 Mbps UL: Modest (e.g. 500 kbps)	< 100 ms	up to 500 km/h	Not Applicable	Not Applicable

3.6 5G Americas[12]

5G Americas is an industry trade organization composed of telecommunications service providers and manufacturers, with a mission to advocate for and foster the advancement of the LTE and its evolution beyond to 5G. The organization aims to lead 5G development for the Americas and maintain the current global innovation lead in North America with LTE technology. The group has published several white papers related to 5G requirements, solutions, spectrum and 4G evolution.[13] 5G Americas' October 2015 "5G Technology Evolution Recommendations" white paper sets forth the following 5G performance requirements[14]:

Table 3: 4G Americas 5G Requirements

Scenario	Download Data Rate	Upload Data Rate	E2E Latency	Mobility	Battery Life	Reliability
Dense Urban	> 200 Mbps	25-200 Mbps	10-100 ms	~1 m/s	Days	99.99%
Urban	> 200 Mbps	25-200 Mbps	10-100 ms	~1 m/s	Days	99.99%
Suburban	25-200 Mbps	< 25 Mbps	10-100 ms	~> 10 m/s	Days	99.99%
Rural	25-200 Mbps	< 25 Mbps	10-100 ms	~> 10 m/s	Days	99.99%
Remote	> 200 Mbps	25-200 Mbps	< 10 ms	~1 m/s	Days	99.99%

12 http://www.4gamericas.org/en/5g/
13 http://www.4gamericas.org/en/5g/white-papers/ 5G
14 Technology Evolution Recommendations, October 2015, http://www.4gamericas.org/files/2414/4431/9312/4G_Americas_5G_Technology_Evolution_Recommendations_-_10.5.15_2.pdf

Scenario	Download Data Rate	Upload Data Rate	E2E Latency	Mobility	Battery Life	Reliability
Automotive	25-200 Mbps	25-200 Mbps	< 10 ms	~> 10 m/s	Weeks	> 99.999%
Extreme Video, VR, and Gaming	> 200 Mbps	25-200 Mbps	< 10 ms	~1 m/s	Days	99.99%
Public Safety	> 200 Mbps	25-200 Mbps	10-100 ms	~> 10 m/s	Weeks	> 99.999%
PSTN Sunset	< 25 Mbps	< 25 Mbps	10-100 ms	~1 m/s	Weeks	99.99%
M-Health and Telemedicine	> 200 Mbps	25-200 Mbps	10-100 ms	~1 m/s	Weeks	> 99.999%
Smart Cities	25-200 Mbps	25-200 Mbps	10-100 ms	~1 m/s	Long	99.99%
Sports and Fitness	< 25 Mbps	< 25 Mbps	10-100 ms	~1 m/s	Days	< 99.99%
Increased Density of Data Usage	> 200 Mbps	25-200 Mbps	10-100 ms	No	N/A	99.99%

3.7 5GNOW[15]

5GNOW was a joint European project to investigate non-orthogonal waveforms suitable for both large data (such as video), and very short bursts of data transmission (for IoT). The project produced four deliverables covering 5G scenarios and system requirements, a transceiver and frame structure concept, MAC/networking concepts, and an assessment of demonstrator concept and implementation.[16] The project was funded by the European Union's 7th Framework Program ("FP7"), which was the predecessor to Horizon 2020.

3.8 Giga KOREA Project[17]

This "pan-governmental project" led by the Korean Ministry of Science, ICT, and Future Planning (MSIP) was launched in 2012 with the ultimate goal of commercializing 5G technology by 2020, collaborating internationally to create a 5G standard, supporting 5G research and development, and creating a technological ecosystem for developing 5G technology. In February 2015, MSIP announced it would embark on a joint research project for 5G standards with China's Ministry of Industry and Information Technology covering several areas of 5G technology. In October 2015, South Korea's MSIP and the EU initiated a joint research study that will investigate: (1) the development of 5G wireless architecture and core algorithms; (2) a synchronization technology for IoT platforms; and (3) a platform technology for relaying cloud resources.

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[15] http://www.5gnow.eu/
[16] http://www.5gnow.eu/?page_id=418
[17] http://gigakorea.wgk24.kr/

3.9 5G Forum[18]

5G Forum, a collaborative development environment for 5G wireless communications, was founded by Korea's MSIP in 2012 to promote 5G technology research and development as well as international collaboration on 5G technology. 5G Forum's goal is to become the leading force in the development of next-generation communications technology. The Forum has identified four strategies to promote 5G technology in Korea: (1) support active 5G research and development; (2) implement of universal infrastructure; (3) create 5G mobile service; and (4) establish national policy to facilitate 5G technology development. 5G Forum members consist of mobile telecommunication carriers, manufacturers, academic professional and start-ups in content and other telecommunications-related industries.

3.10 NYU WIRELESS[19]

NYU WIRELESS is an interdisciplinary academic research center located in Brooklyn, NY and is funded by the National Science Foundation and an Industrial Affiliates program that involves sponsorships from 16 major telecommunications companies. NYU WIRELESS has been an industry leader for mmWave propagation research, and is currently working on nine research projects that focus on various aspects of mmWave technology.[20]

NYU WIRELESS published its most-recent research paper on mmWave technology in October 2015.[21] The paper provides an overview of NYU WIRELESS's extensive indoor mmWave wireless channel modeling campaign, which may be used for wireless system simulations and designs for pending mmWave indoor communications. In April 2016, NYU WIRELESS and Nokia Networks jointly held the third Brooklyn 5G Summit,[22] which will focus on overall 5G system design across the entire spectrum range, progress in 5G propagation channel modeling, and regulatory aspects of 5G.

3.11 5G Innovation Centre (5GIC)[23]

Funded by the Higher Education Funding Council for England and industry and regional partners, including EM3 Local Enterprise Partnership, 5GIC at the University of Surrey is the largest UK academic research center dedicated to the development of next generation mobile and wireless communications. 5GIC's goal is to help to define and develop the 5G infrastructure that will underpin future communications. 5GIC's research will address challenges in the development of 5G infrastructure in seven key work areas, each of which will be led by a dedicated research team working in partnership with industry.[24] 5GIC's live outdoor and indoor testbed will enable its researchers and industry partners to test technologies in real-world situations.

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[18] http://www.5gforum.org/
[19] http://nyuwireless.com/
[20] http://nyuwireless.com/research/
[21] Indoor Office Wideband Millimeter-Wave Propagation Measurements and Channel Models at 28 and 73 GHz for Ultra-Dense 5G Wireless Networks, Maccartney, G.R. et al, http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=7289335
[22] http://brooklyn5gsummit.com/Home.aspx
[23] http://www.surrey.ac.uk/5gic
[24] http://www.surrey.ac.uk/5gic/research

5GIC published a white paper proposing a disruptive change to cellular networking by offering a more connected experience over a dynamic cloud-based architecture that separates the user plane and control plane, integrating the Internet of Things and adding new SCADA-like control system capabilities to the cellular framework.[25] 5GIC will also soon be publishing its vision for 5G.[26]

3.12 Ministry of Science & Technology (MOST) 863-5G Project[27]

The 863-5G Project, a Chinese government-sponsored research project under the larger 863 Program managed by MOST, collaborates with both academia and industry professionals to conduct 5G research. In 2013, the first stage of the 863-5G Project, which will run from 2014 through 2016, was launched.[28] The first stage involves: (1) exploring the radio-access-network architecture needed 5G targets of 10 Gbps per node, 10x spectral/energy efficiency gains, and 25x throughput gain per node; (2) developing radio-transmission technologies such as Massive Multiple Input Multiple Output (MIMO) and distributed cooperation; (3) establishing 5G requirements and identifying spectrum bands for 5G use; and (4) instituting 5G evaluation and testing methodology.

As of July 2014, China's 863-5G Project consisted of 55 members, including domestic companies such as Huawei, ZTE, and China Mobile; local universities; and international telecommunications companies, such as Ericsson and Nokia. China's 863-5G Project has worked on a range of studies that will enable 5G technologies, including investigating use of mmWave bands and developing large-scale MIMO.

3.13 Fifth Generation Mobile Communications Promotion Forum (5GMF)[29]

5GMF is a Japanese non-profit association inaugurated in September 2014 to conduct research and development on 5G mobile communications systems and 5G standardization, as well as to coordinate with related organizations to both collect and disseminate information. According to a presentation by the acting chair of 5GMF's Technical Committee at the Indonesia and Japan Forum on 5G & Connectivity in September 2015[30], the technical committee has been initially focused on the following four areas: (1) developing the basic concept defining the radio technology evolution scenario; (2) contributing to the development of the specification of "IMT-2020" by ITU-R; (3) collecting and analyzing information on potential spectrum bands for future 5G use; and (4) developing a relevant radio technology "road map." 5GMF's white paper reporting on these activities was expected to be released in the fall of 2015. 5GMF expects to begin performing verification tests of the mobile network, wired network, and mobile applications in FY 2017.

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[25] The Flat Distributed Cloud (FDC) 5G Architecture Revolution, January 2016, https://www.surrey.ac.uk/5gic/flat-distributed-cloud

[26] http://www.surrey.ac.uk/5gic/white-papers#academic

[27] National High-tech R&D Program (863 Program), http://www.most.gov.cn/eng/programmes1/200610/t20061009_36225.htm

[28] 4G Americas' Summary of Global 5G Initiatives, June 2014, Page 7, http://www.4gamericas.org/files/2114/0622/1680/2014_4GA_Summary_of_Global_5G_Initiatives__FINAL.pdf

[29] http://5gmf.jp/en/

[30] 5GMF Activities for 202 and Beyond in Japan, Nakamura, Takaharu, September 21, 2015, http://www.codebali.net/media/01_150921_CodeBali_5GWS_sub.pdf.

3.14 2020 and Beyond Ad Hoc Group (20B AH)[31]

20B AH was established in September 2013 by Japan's Association of Radio Industries and Businesses' (ARIB)[32] to study terrestrial mobile communications systems in 2020 and beyond. Its tasks include studying the technologies used for future communications systems, the system concepts and fundamental architecture of future systems, and the services and applications offered by future communications systems, as well as cooperating and coordinating with other international and domestic organizations.

20B AH published a white paper in October 2014 that summarized its studies on system concepts and technical trends of mobile communications systems in 2020 and beyond.[33] The white paper discussed results from 20B AH's studies on technical trends, such as radio access technologies and network technologies. The white paper also described 20B AH's research on system concepts such as market and user trends, traffic trends, cost and spectrum implications, usage scenarios, and the requirements and capabilities of future mobile communications systems.

4 Technology

5G requirements call for technology developments in all areas to meet the performance requirements set forth by ITU-R and other industry organizations. Furthermore, 5G may not be limited to a single radio access technology, but rather a collection of heterogeneous networks that are jointly managed to meet performance requirements. To achieve the performance requirements requires a healthy R&D investment in key enabling technologies.

These technology developments can be classified into six broad categories and are listed below. This list is not intended to be a comprehensive list, rather it represents a subset of key technologies that are representative of what is needed for 5G[34].

4.1 Hardware Advances in Circuits, Devices, and Antennas

Hardware advances, especially in circuit design, are needed to support the increased bandwidth needs, to achieve high throughput. In some instances, bandwidths as high as several GHz in mmWave spectrum will be needed to meet throughput numbers. In addition, spectrum flexibility has become essential as easy reallocations of spectrum from legacy users to more advanced communication services have already happened.

Components are another important area where technology innovation is needed, especially to support mmWave communications. Such innovations include power efficient mmWave components such as efficient power amplifiers and low-cost and low-power analog beamforming. Dynamic operations of these technologies will require component innovations

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[31] Advanced Wireless Communications Study Committee (ADWICS), 2020 and Beyond AdHoc, http://www.arib.or.jp/ADWICS/2020bah-E.pdf.

[32] http://www.arib.or.jp/english/html/arib/establishment.html

[33] Mobile Communications Systems for 2020 and beyond, Version 1.0.0, October 8, 2014, http://www.arib.or.jp/english/20bah-wp-100.pdf

[34] A good reference for needed technology developments can be found in the recent NSF Workshop Report on Enhancing the Available of Spectrum (EARS) (http://www.nsf.gov/mps/ast/2015_ears_workshop_final_report.pdf)

that can simultaneously work across multiple bands without cross-interference, and provide better selectivity due to the more ad-hoc nature of 5G system operation and the dynamic range challenges this creates.

Dynamic operation will also require antennas that can work efficiently over large swaths of spectrum. Smart antennas will be needed at user terminals, across large ranges of frequencies, and will have to contend with the impact of having a body in near proximity.

4.2 Core Network Innovations

Core network innovations will be driven by the need for the core to be more access agnostic and softwarization. At the same time, latency reductions will be critical for 5G to support new applications such as autonomous vehicles or tactical internet applications.

Based on the NGMN whitepaper and 5G Americas, 5G use cases are very diverse and varied:

- A wide range of speed demands
- High broadband speeds as well as very low speeds for IoT
- A wide range of latency requirements
- A wide range of device types
- Very smart devices with short shelf life
- Very inexpensive devices with long lives in the field
- A wide range of mobility needs
- Fast moving trains to stationary IoT devices

Not all requirements are needed to be supported simultaneously, which necessitates the concept of “network slicing”. Softwarization (SDN, NFV and cloud technologies) is a key enabler for 5G networks. Network Slicing and the need for operational flexibility make these technologies indispensable.

Softwarization will play an important role in providing the flexibility to support heterogeneous networks. Virtualization is already happening, therefor 5G systems are expected to support deployments in virtualized environments SDN based policy frameworks will be used for operator policies. 5G will employ NFV and cloud concepts to define more granular functions with reusable interfaces that are easy to virtualize, minimize access specific nodes, and support the concept of service specific core and Network Slicing.

The varied use cases and requirements point to the need for the 5G core to support multiple access technologies simultaneously:

- LTE and its evolution
- New RAT(s) (possibly mmWave)
- Wireless LAN and unlicensed spectrum
- Fixed broadband access

Therefore 5G needs an access agnostic core. Two key benefits of an access agnostic core are it allows independent evolution of radio and the core network, and enables architecture convergence between the 3GPP accesses and other access technologies e.g. WLAN, fixed broadband access. 5G will also require the need for a new control plane – separated from the user plane, to have tight integration between LTE Advanced with 5G while avoiding core network complexity. LTE Advanced should support a new control plane to connect natively to 5G core. CP-UP separation benefits include:

- Independent scaling of control and user plane entities.
- Optimal placement of control and user plane entities.

SDN principles should be considered for the interaction between these two planes. This would allow integration of 3GPP control plane with SDN based transport network's control plane.

Standardize architectures, interfaces, and operations are needed to facilitate rapid interactions and mediate between the application layer (switches, routers, firewalls and load balancers) and the physical network layer to enable dynamic networking in real time. This includes joint optimization with software defined radio for joint optimization with the physical layer, both its data and control planes. To glue together these heterogeneous networks require advance networking principles for service negotiation, discovery, and interconnection while considering the global consequences and interaction of the selection of heterogeneous network parameters.

> SDN will go hand and hand with NFV which allows general computing services to replace proprietary and dedicated networking devices. Its biggest payoff for NFV will come when general cloud services can be deployed to reliably support network functions for carriers.

4.3 Diverse waveform sets and MAC protocols

Several advanced waveforms and access technologies are under evaluations by various technical groups as an alternative to LTE (OFDMA). The following are a subset of those under consideration: non orthogonal multiple access (NOMA), filtered OFDM (FOFDM), filter bank multi-carrier modulation (FBMC), pattern division multiple access (PDMA), sparse code multiple access (SCMA), interleave division multiple access (IDMA) and low density spreading (LDS) etc. All these methods are aimed to improve the spectral efficiency of the future 5G systems. The selection of a waveforms and the media access protocol (MAC) depends of the objectives of the wireless link with some waveforms having better property trade-offs of low power, high data rate, very-low latency, and reliability than others for specific applications. Selection of the proper waveform or combinations of waveforms can help with location determination of a device, especially in an indoor environment to support the Location of Everything (LOE) capability of next generation wireless systems.

Furthermore, new waveforms will likely be more robust in adjacent channel interference or co-channel interference environments, either as a direct property of the waveform or the suitability of the waveform to support interference rejection/avoidance processing techniques. Advanced antenna technologies such as 3D-beamforming (3D-BF), active antenna system (AAS), massive MIMO and network MIMO can help reduce interference to increase spectrum efficiency. These MIMO approaches provided antenna gain to overcome power amplifier inefficiency had high channel losses.

It may be noted that the FCC hasn't specified any duplexing requirements for its proposed 5G bands. It is entirely possible that 5G may not be limited to simple choice of FDD, TDD alone, but rather would involve complex schemes such as TDD-FDD joint operation, dynamic uplink/downlink resource allocation, multi-connectivity, simultaneous transmission and reception on the same frequency etc. to increase spectrum efficiency. Flexibility in the duplexing architecture has important ramifications in being able to flexibly use available spectrum.

4.4 Spectrum sharing methodologies

Spectrum sharing will play a major role for 5G systems. In some cases it will not be possible to move legacy users to make way for new technologies and services, and therefore it may not be possible to allocate spectrum or develop service rules for exclusive use in future reallocations, including in mmWave spectrum. This is not only true in the US, but around the world.

Early generations of spectrum sharing systems exist today, but 5G will probably require new spectrum sharing schemes. What makes 5G spectrum sharing difficult technically is that sharing mechanisms will differ from band to band and country to country because of the differences in legacy users of the spectrum and the regulatory environment in each country. Hence, there will be variations in RF and signal processing requirements for these different situations that will require 5G systems to have maximum flexibility.

Clearly, radar spectrum is a prime candidate for sharing since it consumes much of the spectrum and it is often used sparsely geographically. Radar systems are mostly fixed and its coverage can be predicted with much certainty. In addition to radar spectrum as a source of 5G spectrum, movement is underway to support cellular standards in unlicensed bands. Such a movement is already underway with the near term deployment of technologies as LTE-U. It is reasonable to assume that 5G cellular may also strive to use the unlicensed bands and insuring compatibility with existing users within the unlicensed band will be an important technical challenge.

Database techniques for spectrum sharing have been underway for many years for unlicensed devices in TV white space band[35] and more recently in the 3.5 GHz band for licensed devices[36]. It is unclear what the best architecture might be for spectrum sharing with 5G, certainly it will be more involved given the focus of 5G to provide lower latency and heterogeneous network integration and new capabilities such as beam forming. Ideally the architecture should be flexible enough to account for differences in legacy users in different bands while sharing some commonality to facilitate large-market commercial viability. These issues will likely motivate fresh thinking in the overall spectrum sharing architecture for 5G.

4.5 Security and Information Assurance

Security has become an ever increasing concern and now that commercial cellular technologies are being embraced by military and public safety entities security and information assurance (ability to communicate with network or jamming attacks) and to keep the information private. Each generation of cellular technologies has brought new security concerns and security flaws. For example, first generation systems had to deal with cloned phones. Second generation systems were susceptible to rogue base stations and today’s 4G systems are vulnerable to control channel spoofing. Denial of service is now becoming more important given the criticality of new

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[35] Second Report and Order and Memorandum Opinion and Order, “Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz band”, November 14, 2008, FCC 08-260.

[36] Report and Order and Second Further Notice of Propose Rulemaking, “Amendment of the Commission’s Rules with Regard to Commercial Operations in the 3550-3650 MHz band”, April 17, 2015, FCC 15-47.

5G applications such as e-health, autonomous vehicles and other cyber physical systems become life-critical systems. Yet, due to the plethora of protocols; heterogeneous system interoperability; spectrum sharing management; and SDN, SDR, and NFV functions the attack surface for 5G systems will be much wider than for past cellular systems. The technological solutions to the security and information assurance are unclear, but in any event a complicated security framework would likely impact and could potentially undermine 5G goals for low-latency and interoperability with heterogeneous networks.

4.6 Regulatory and enforcement

Technology improvements for the regulatory and enforcement communities will need to keep pace with the technology innovations of 5G. 5G devices and networks may have a high degree of dynamic operation to meet communications needs in challenging environments. This operation that may come with 5G could drive new innovations for automated measurement and enforcement technologies. Regulators will be faced with certification of very complex and dynamic systems and as the technology develops so too there will be a need to develop technologies in parallel that can aid in the certification and enforcement of such devices.

4.7 Deployment Scenarios

Significantly more spectrum and much wider bandwidths than what is available today will be needed to realize the performance targets of the 5G systems. It is estimated that the next generation technology would carry more than 1000 times the current capacity and the majority of growth to be driven by ultra-high resolution video streaming, cloud-based applications, IoT etc. It is also expected that the new technology will offer at least a ten-fold improvement in the user experience compared to 4G in terms of peak data rates and latency.

Mobile broadband as we know today is simply a mobile internet access but 5G is expected to go far beyond that. The growth in mobile data traffic will also be accompanied by an increase in the number of communication devices, ranging from phone, tablet and laptop to smart wearables.

5G deployments needs to accommodate both -- growth in data and the number of connections. The current methods of network design and deployment and as a consequence the sharing methodology needs to evolve considering the attributes of the next generation of wireless standard.

The ITU-R and NGMN have identified three broad usage scenarios for 5G which provide a broad classification for most of the use cases:

- Enhanced mobile broadband (eMBB)
- Massive machine-type communications (mMTC)
- Ultra-reliable and low-latency communications (URLLC)

A range of 5G deployment scenarios fall within the above usage scenarios, network densification is the key to 5G, but some of the main features such as Massive MIMO and 3D-BF are instrumental in improving spectral efficiency and interference reduction. Other aspects such as the waveform, and different duplexing schemes under study are also important considerations for the underlying service support. E.g. FDD is advantageous for wide area coverage and high mobility while TDD is preferable for ultra-dense deployments, wider bandwidths.

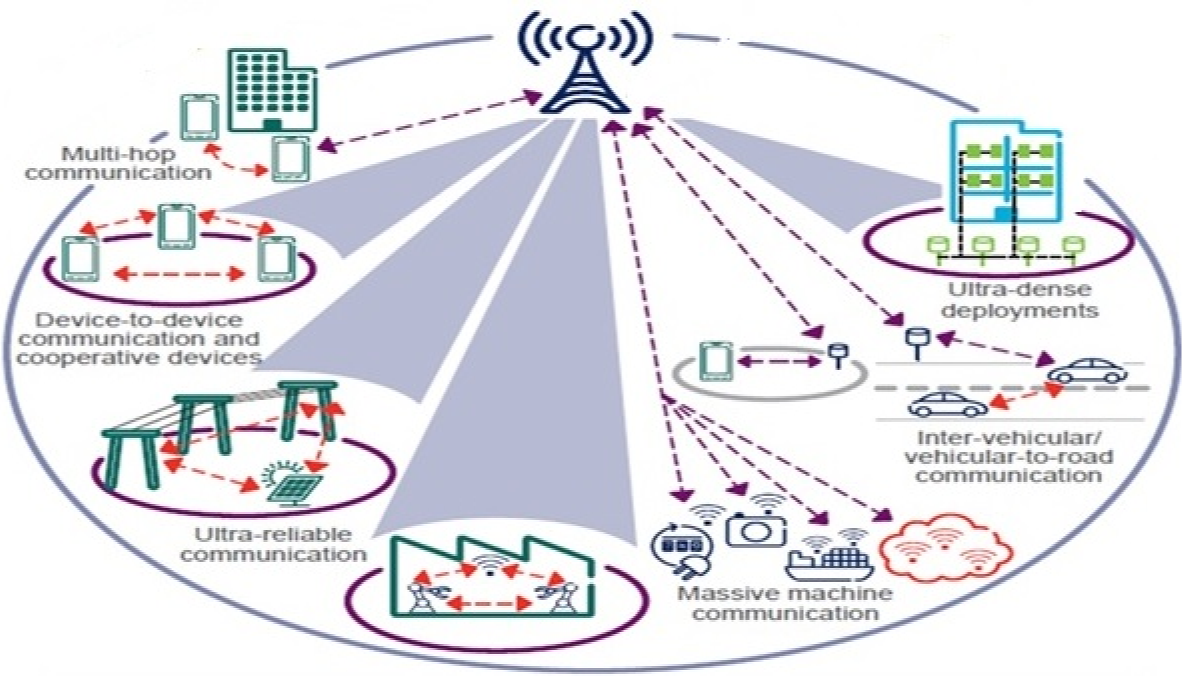

Figure 4: 5G Deployment Scenario Courtesy: Ericsson

For eMBB, following deployment scenarios are envisioned by NGMN, and each of these scenarios has a different set of attributes and sharing considerations.

Table 4: eMBB Deployment Scenarios

Scenario	Examples	Attributes	Sharing Considerations[1]	Frequency Range[1]
Indoor hotspot	Indoor deployment for indoor hotspots, e.g., office, residential and shopping mall	Indoor base stations and users, very high data rate, low mobility, high user density	High bandwidth requirements, Limited coverage, signal strength and high penetration loss	High bands – cm and mm wave frequencies
Dense Urban	Heterogeneous network with combination of macros and small cells such as Downtown area	Macro coverage but traffic is carried predominantly on small cells, users could be indoor (high-rise/mid-rise buildings) and outdoors, low mobility, high user density	Very short coverage distance by small cells, high bandwidth required, deployment below clutter, heavy signal attenuation	Low band for Macro, High bands – cm and mm wave frequencies for small cells

Scenario	Examples	Attributes	Sharing Considerations[1]	Frequency Range[1]
Urban/ Sub-urban Macro	Standard deployment with Macro cells such as current 3G/4G networks	High power outdoor base stations, indoor and outdoor users, medium user density , medium data rates, medium mobility	Similar to previous CSMAC studies	Low bands (< 6 GHz)
Rural Macro	Standard deployment with Macro cells such as current 3G/4G networks	High power outdoor base stations, indoor and outdoor users (predominantly vehicular), low user density, medium data rates, high mobility	Similar to previous CSMAC studies	Low bands (< 6 GHz)
High speed	TBD	TBD	TBD	TBD
High density	Special outdoor events such as concerts, inauguration etc.	Low power outdoor base stations, user location depends on the event, very high user density, medium data rates, low mobility	Location of the event and the network/user density. Large bandwidths	High bands – cm and mm wave frequencies

[1] The last two columns of this report are not part of NGMN. The first three columns are part of the NGMN deployment scenarios, while the last two columns are added to elaborate on the impact of sharing.

5G is expected to provide wireless connectivity to a wide range of new applications and use cases which are mainly driven by the vertical industries. It is anticipated that most of those non-eMBB use cases can be supported by the above eMBB deployment scenarios. As the technical characteristics of 5G is unknown at this time, it is not possible to identify the use case types that cannot be supported by eMBB deployments. It should also be noted that if in the future, there is such a scenario that requires a standalone deployment for a single or a set of use cases, then the traffic characteristics of the underlying use case(s) and the device density will drive the type of deployment and consequently any spectrum requirements as well.

Some of the well-known use cases are listed below for reference

1) Critical MTC, requiring high availability, reliable communication
    a. V2X- including V2V, V2I, V2P
        i. V2V involving communication with the surrounding vehicles at low power and low data rate. Sharing studies should consider that the most of the signal is at ground level, aperiodic, bursty, high mobility and heavily attenuated by surrounding clutter in most cases

    ii. V2I involves standard communication with infrastructure (i.e. nearest base station), Sharing studies should consider this similar to outdoor user scenario.
    iii. V2P involves communication between vehicles and pedestrian mainly applicable to dense urban, urban environment. Sharing studies should consider characteristics similar to V2V but with low mobility and lower power for "P"

  b. m-Health
  c. Smart Grids
  d. Industrial automation and monitoring

2) Massive MTC
  a. Ultra low power devices: these small form factor devices are supposed to have a battery life of ~10+ years, supporting bursty traffic at low transmit power. Sharing studies should consider that these devices occupy very narrow band and have large sleep cycles
    i. Asset tagging
    ii. Sensor nodes
    iii. Smart meters
  b. Personal area networking: 5G is also envisioned to support connectivity between devices within short range such as
    i. Augmented reality and VR
    ii. Wearable devices
    iii. High definition video delivery
    iv. Gaming
  c. Tactile Internet

4.8 Conclusion

Even as the need for spectrum sharing increases, dedicated licensed spectrum access is expected to remain the baseline for mobile broadband both in terms of reliability and certainty. The shared spectrum is expected to play a complementary role to address the new vertical market needs and IoT.

Sharing scenarios should be considered on a case-by-case bases. Each deployment use cases should be evaluated independently for spectrum sharing, because one use case may be un-suitable while other may be favorable. For example if a particular spectrum band is primarily being used for indoor applications, then the sharing regime would be different compared to a macro outdoor type deployment. Or if a particular spectrum or a portion of it is being used for IoT applications, then that portion is subject to a different type of assumptions for sharing. Spectrum sharing should also be evaluated under both horizontal and vertical sharing regimes. It is possible that a given scenario can benefit from one technical solution but the same solution may not be beneficial for another scenario.

The spectrum sharing capacity of the next generation technology may be improved by incorporating advanced techniques such as learning, sensing RF environment and adapting accordingly. These techniques may be unique to certain deployments in some cases, and in others they could generally be applied.

Although, it is still very unclear at this point which mix of technologies can and will be used to achieve these characteristics.

Below are a few of the desirable characteristics of 5G:

- Varied set of uses and deployment environments are envisioned as part of 5G
- Multiple RATs to support a variety of use cases ranging from extreme speeds to extreme connectivity (for IoT) to reduced latency for extreme real-time applications like tactile communications
- Larger channel bandwidths and higher frequency ranges
- Use of advanced techniques for improving spectrum efficiency and enhancing sharing such as massive MIMO, cognitive radio, and dynamically allocated, self-organized high density networks.
- Increase energy efficiency via reduced continuous signaling (e.g. pilots, etc.)
- One area that is still unclear is the duplexing scheme – whether both TDD and FDD will be specified and widely deployed across low and high frequency bands; FDD could be deployed on low paired frequency bands while TDD could be deployed over higher frequency bands

Field trials and testbeds that are underway will further assist in identifying the right technological mix and several 5G technology trials have been announced. For some technical areas there are a number of potential good technology paths based on solid a R&D record and in some areas there may not be a clear technology path. Much like LTE (LTE to LTE-A to LTE-A Pro), the complexity of 5G technologies is only manageable through an evolutionary approach. Hence, one may expect that not all the performance characteristics will be present in the early releases of 5G, particularly those performance characteristics that will depend on large leaps in technology. Even if future R&D does provide new and quantifiable leaps in technology, assuming that this technology will go into 5G may be naïve. Technology selections are often influenced by intellectual property and marketing positioning when it comes to creating a standard.

5 Regulatory Status and Matrix of Potential Bands

Besides the existing spectrum which could be used for 5G, the following is a list of future potential bands:

	U.S.	ITU	Other
Under 6 GHz	600 MHz band to be repurposed through the Incentive Auction	WRC-15 finalized 700 MHZ in Region 1 (EMEA) plus 16 additional countries in Region 3 (APAC). Now global allocation. 470-960 MHz to be reviewed in WRC-23 for Region 1. Resolution COM4/6 (WRC-15)[37]	EU: 12 of 28 member states have released 800 MHz band spectrum to operators for 4G LTE; spectrum is in the pipeline for the remaining states. 700 MHz released in Germany and France in 2015. Cooperation agreements reached between the EU, South Korea, Japan, and China for 5G research and harmonization; no specific bands identified China: In 2014, the IMT-2020 Working Group identified 450-470 MHz, 698-806 MHz, and 3.4-3.6 GHz as bands for short-term consideration, and 1.427-1.518, 3.3-3.4, 4.4-4.5, and 4.8-4.99 GHz as bands for mid-term consideration
6 GHz – 20 GHz		ITU-R to study satellite sharing within existing FSS allocations in 17.7-19.7 GHz for WRC-19 Resolution COM6/17 (WRC-15)[38]	

[37] Provisional Final Acts, World Radio Conference (WRC-15), 2-27 November 2015, http://www.itu.int/dms_pub/itu-r/opb/act/R-ACT-WRC.11-2015-PDF-E.pdf
[38] Id.

	U.S.	ITU	Other
20 GHz – 30 GHz	27.5-28.35 (“28”) GHz band proposed for mobile and other uses in Spectrum Frontiers NPRM[39] FCC seeking additional comment on 24.25-24.45 GHz and 25.05-25.25 GHz bands	ITU-R to study satellite sharing within existing FSS allocations in 27.5-29.5 GHz for WRC-19 Resolution COM6/17 (WRC-15)[40] ITU-R to conduct IMT sharing and compatibility studies in the 24.25-27.5 GHz band for WRC-19 Resolution COM6/20 (WRC-15)[41]	Korea announced at WRC-15 trials of 5G in the 28GHz band for 2018 Winter Olympics. Japan announced deployment of 5G for the 2020 Summer Olympics
30 GHz – 60 GHz	37-38.6 (“37”), 38.6-40 (“39”) GHz bands proposed for mobile and other uses in Spectrum Frontiers NPRM[42] FCC seeking additional comment on 31.8-33 GHz and 42-42.5 GHz bands.	ITU-R to conduct IMT sharing and compatibility studies in the 37-40.5, 42.5-43.5, 45.5-47, 47.2-50.2, and 50.4-52.6 GHz bands(existing primary mobile allocation), and 31.8- 33.4, 40.5-42.5, 47-47.2 GHz bands (may require additional allocations to mobile service on a primary basis) Resolution COM6/20 (WRC-15)[43]	
Over 60 GHz	64-71 (“64”) GHz proposed for Part 15 use in Spectrum Frontiers NPRM[44] FCC seeking comment on specific proposals for bands above 86 GHz	ITU-R to conduct IMT sharing and compatibility studies in the 66-76 GHz and 81-86 GHz bands Resolution COM6/20 (WRC-15)[45]	

[39] Use of Spectrum Bands Above 24 GHz for Mobile Radio Services, FCC GN Docket No. 14-177, October 23, 2015, https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-138A1.pdf
[40] See FN 37.
[41] Id.
[42] See FN 39.
[43] See FN 37.
[44] See FN 39.
[45] See FN 37.

6 Actionable Recommendations for the NTIA

6.1 Deployment specific evaluation

If one were to look at the varied range of envisioned use cases and potential RATs to support them, 5G networks could use different portions of the spectrum for different types of deployments. The deployment characteristics could vary widely with the supported use case and application. The different deployment scenarios will impact sharing in multiple ways:

- Initial 5G technologies are likely to be deployed first in urban, high-density environments where building penetration and clutter may greatly impact propagation, and so should be considered in determining coordination zones and other sharing parameters;
- A band that is sparsely used by incumbents for critical communications may be shared to support non-critical, delay insensitive IoT type applications such as smart meters and atmospheric sensors.
- In addition, the main difference in design philosophy between LTE and 5G is that LTE was focused on mobile broadband for its main use case but 5G is being considered to support various vertical services in addition to mobile broadband in a single technical framework. One of the design objectives of 5G is the capability to provide flexibility in multiplexing multiple vertical services within a carrier bandwidth. Depending on the outcome of 3GPP discussions, it is possible that a 5G base station would transmit physical channels with different numerologies, meaning that depending on supported use cases, a base station can divide entire carrier bandwidth into smaller sub-bands and transmit physical channels on each sub-band with different numerologies. Further, these sub-bands could have different waveforms, access schemes, channel coding and even large power deltas between them.

Recommendation: NTIA should facilitate coexistence evaluation for three broad categories of 5G use cases, as opposed to previous technologies where there was only one case for evaluation (broadband). The three broad categories are broadband, machine-type communications (IoT), and critical communications (e.g. low-latency). As a first step, include lessons learned from the AWS-3 and 3.5 GHz coordination process.

6.2 Large frequency range and bandwidths

Based on the wide range of frequencies and bandwidths being considered for 5G, it is essential to conduct sharing and co-existence studies for each band independently, especially because the technical and operational characteristics including protection criteria and deployment scenarios would vary widely. 3GPP is considering utilizing different waveforms depending on the frequency bands, i.e. a waveform X can be supported between Frequencies A and B, a waveform Y between frequency B and C and henceforth. Further, in many cases due to the large envisioned channel bandwidths, it is possible that the spectrum overlap is only partial either within the channel or at the edges only, and as consequence the impact and mitigation techniques could vary significantly. Likewise the large bandwidths will also impact OOBE and adjacent bands.

Recommendation: As the channel bandwidth size in 5G can be large (100 MHz and above), the chance of overlaps with different types of federal systems will increase. NTIA should facilitate a collaborative government-industry study of large bandwidth sharing scenarios that potentially involve multiple incumbents, waveforms and applications for future higher frequency bands

6.3 New duplexing schemes

Currently 2G, 3G, and 4G technologies either operate on an FDD, TDD or downlink only mode. For 5G it is envisioned that new duplexing schemes will be introduced, such as dynamic duplexing, simultaneous transmission and reception on same frequency. This may provide more flexibility in coexistence with adjacent or co-channel networks.

Recommendation: 5G will introduce new duplexing schemes besides FDD and TDD, such as dynamic duplexing and simultaneous transmission and reception on the same frequency. NTIA should facilitate a collaborative government-industry study of the impact of these new duplexing schemes.

6.4 Baseline assumptions

Traffic characteristics are going to vary widely depending on what kind of services the spectrum is utilized for. For example, spectrum utilized for low powered IoT type use cases with sparse but delay tolerant traffic may require a different coordination approach than mobile broadband use cases. The sharing studies in general should consider the traffic characteristics of the services deployed in a spectrum band and the probability of interference, specifically when one calculates cumulative interference, and the impact of that interference from the perspective of what harm it could cause. This becomes more relevant to 5G due to advanced techniques such as MU-BF and 3D-MIMO that steer signal only in the wanted region instead of wide area coverage. Also in practice many system deployments are over-designed to support high reliability metrics and should be able to able to handle both short term and long term interference at different thresholds.

In the past, the sharing analysis was mostly based on a “worst-case” scenario. A more probabilistic approach that can still provide a strong level of protection to incumbent systems should be investigated (e.g., exceeding an interference level of X for less than Y% of the time at Z locations where X, Y and Z could vary from system to system).

Recommendations: NTIA should facilitate a multi-stakeholder collaboration to agree on future baseline criteria (such as probability aspects), detection and mitigation techniques that can empower technology innovation for ensuring effective sharing of the spectrum between federal and non-federal 5G systems

6.5 Phased approach with upgrades

As has been the case with 4G (LTE) and how it progressed from LTE to LTE-A to LTE-A Pro, it is expected that 5G will also be developed and be deployed in phases. Newer technologies will be incorporated into the initial 5G standards over several evolutions of the specifications and some of the technologies that may not be currently available for effective sharing could become available during the latter part of the evolutionary cycle of 5G. Similarly it may be reasonable to assume that the other incumbent technologies would also migrate to advanced versions. With each upgrade cycle, it would be very helpful if it is encouraged to incorporate sharing technologies within new versions. Another consideration could be to use similar physical layer characteristics to improve compatibility and sharing.

Recommendations: The NTIA working with the FCC and through the existing Department of Commerce 3GPP membership, should facilitate the introduction of a work item that requests 3GPP to evaluate sharing technologies. The CSMAC can help with the drafting of the documents necessary.

6.6 Propagation Modeling for sharing/co-existence studies

Historically, models like ITM and TIREM have been the main stay during the coordination analysis and determination of protection zones. However, these models may not have the same level of predictability at higher frequencies (20 GHz and above) to estimate the interference from 5G systems. In absence of such models very conservative assumptions may be used which may lead to unnecessary constraints when evaluating capability between systems.

Recommendation: NTIA should allocate the resources necessary to investigate revision of propagation models, and if needed undertake measurements, for the higher frequencies so that accurate/appropriate models can be utilized for estimating interference from 5G systems in a varied set of environments and distances. New models should be promoted in ITU-R Study Group 3 for global harmonization at WRC-19.

7 CSMAC future work

CSMAC recommends future work build on the above recommendations in the below areas:

1. The final recommendations include to some extent future work that could be considered as next steps.

2. CSMAC should develop specific recommendations for next steps in Federal / Non-Federal access to 37-40 GHz bands, the work should take note of both FCC rulemakings as well as information on Federal use.[46, 47]
    a. Passive services allocations below 37 GHz included Earth Exploration Satellite Services and Space Research Service.
    b. In the 37-38.6 GHz band considered by the FCC Spectrum Frontiers rulemaking there are Federal allocations for space research, fixed and mobile service operations in the 37-38 GHz band. There are also Federal fixed, mobile and FSS (space-to-Earth) allocations in 38.6-39.5 GHz.
    c. In 39.5-40 GHz there are Federal allocation for FSS (space-to-Earth) and MSS (space-to-Earth).

[46] Amendment of the Commission's Rules Regarding the 37.0-38.6 GHz and 38.6-40.0 GHz Bands, ET Docket No. 95-183, Report and Order and Second Notice of Proposed Rule Making, 12 FCC Rcd 18600, 18637 ¶ 79 (1997).
[47] Federal Spectrum Use Summary, 30 MHz-3000 GHz, National Telecommunications and Information Administration Office of Spectrum Management, June 21, 2010 (https://www.ntia.doc.gov/files/ntia/publications/spectrum_use_summary_master-07142014.pdf)

3. Legislation is considering additional bands for future networks, CSMAC should evaluate those bands to understand the level of Federal/non-Federal sharing applicable for 5G networks.[48]

[48] S.2555: Making Opportunities for Broadband Investment and Limiting Excessive and Needless Obstacles to Wireless Act or the MOBILE NOW Act, Introduced 2/11/2016, https://www.congress.gov/bill/114th-congress/senate-bill/2555?q=%7B%22search%22%3A%5B%22%5C%22s2644%5C%22%22%5D%7D

8 Table of Acronyms

20B AH	2020 and Beyond Ad Hoc Group
3D-BF	3 Dimensional Beamforming
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5G PPP	5G Infrastructure Public Private Partnership
5GIC	5G Innovation Centre
5GMF	Fifth Generation Mobile Communications Promotion Forum
AAS	Active Antenna System
APAC	Asia Pacific
ARIB	Association of Radio Industries and Businesses
cm	Centimeter
CSMAC	Commerce Spectrum Management Advisory Committee
DL	Downlink
E2E	End to End
eMBB	Enhanced mobile broadband
EMEA	Europe, the Middle East and Africa
EU	European Union
FBMC	Filter Bank Multi-Carrier Modulation
FCC	Federal Communications Commission
FD-MIMO	Full Dimension MIMO
FDD	Frequency Duplex Division
FOFDM	Filtered OFDM
FP7	European Union's 7th Framework Program
FSS	Fixed Satellite Service
FY	Fiscal Year
Gbps	Gigabits per second
HSPA	High Speed Packet Access
ICT	Information and Communications Technology
IDMA	Interleave Division Multiple Access
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IMT-2020	International Mobile Telecommunications for 2020 and beyond
IoT	Internet of Things
ITU	International Telecommunications Union
ITU-R	International Telecommunications Union Radiocommunication Sector
km	Kilometer
LDS	Low Density Spreading
LOE	Location of Everything
LTE	Long Term Evolution
LTE-A	LTE Advanced
LTE-A Pro	
LTE-B	LTE Advanced (2nd Phase)
LTE-C	LTE Advanced (3rd Phase)

LTE-U	Long Term Evolution – Unlicensed
M	Meter
m	Meters
MAC	Media access control address
Mbps	Megabits per second
MIMO	Multiple-Input Multiple-Output
mm	Millimeter
mMTC	Massive machine-type communications
mmWave	Millimeter Wave
MOST	Ministry of Science & Technology 863-5G Project
ms	Millisecond
MSIP	Ministry of Science, ICT, and Future Planning
MTC	Machine Type Communications
NFV	Network Function Virtualization
NGMN	Next Generation Mobile Networks Alliance
NOI	Notice of Inquiry
NOMA	Non Orthogonal Multiple Access
NPRM	Notice of Proposed Rulemaking
NTIA	National Telecommunications & Information Administration
NYU	New York University
OFDMA	Orthogonal Frequency-Division Multiple Access
PDMA	Pattern Division Multiple Access
R13	
R14	
R&D	Research and Development
RAT	Radio Access Technologies
RF	Radio Frequency
SCADA	Supervisory Control And Data Acquisition
SCMA	Sparse Code Multiple Access
SDN	Software Defined Networks
SDR	Software Defined Radio
Tbps	Terabits per second
TDD	Time Duplex Division
TV	Television
UK	United Kingdom
UL	Uplink
URLLC	Ultra-reliable and low-latency communications
US	United States
V2I	Vehicle to Infrastructure
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to thing
VR	Virtual Reality
WP5D	ITU-R Working Party 5D
WRC-12	World Radiocommunication Conference 2012
WRC-15	World Radiocommunication Conference 2015

WRC-18/19 World Radiocommunication Conference 2018/2019