TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

Communications and Connectivity Technology Newsletter

An Update on Trends and Innovations **September 2023**

Contents

Introduction

Welcome to the 13th issue of EPRI's *Communications and Connectivity Technology Newsletter*, highlighting key insights from innovation scouting and technology exploration. The focus is on technologies with a high potential for strategic impact on the electric utility industry. The target audience has information technology (IT), telecom, and communications expertise, but the content should be informative for individuals with other backgrounds. An index of previous issues and a glossary of acronyms are included to provide context.

This issue continues analysis and updates on developments in smart grid communications and mobile wireless network technologies. The information primarily comes from the Institute of Electrical and Electronics Engineers (IEEE) International Conference on Communications (ICC), the Wi-Fi Alliance, and other sources. The relevance of these topics to utility telecom professionals is twofold. First, a fundamental understanding of the evolving technologies that will be used by mobile network operators (MNOs) will allow for better decision making when choosing appropriate near-term utility applications and use cases. Second, as 5G (and coming 6G) technologies achieve economies of scale because of widespread MNO deployments, they increasingly will be adopted into private utility network implementations. Consequently, having information and understanding of these emerging technologies should facilitate long-range network planning.

Your comments on this newsletter and its content, as well as suggestions for future topics, are encouraged. Please see page 11 for links to previous issues in this series and contact us with your feedback and ideas.

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Highlights from IEEE ICC 2023: Emerging Directions for 6G Evolution

The IEEE ICC is one of the premier conferences for advanced research on communications. Compared to the last ICC in 2019, Sixth Generation (6G) is coming into a clearer focus. This newsletter highlights industry and academic researcher viewpoints about the 5G-to-6G evolution.

History and Evolution of Cellular Generations

Generations of cellular technology emerge and are standardized over roughly a 10-year cycle. Incremental improvements and milestones are given marketing names by the industry.

Analog and digital cellular systems, referred to as *First Generation (1G)* and *Second Generation (2G)*, respectively, emerged in the absence of international standards. The International Telecommunication Union (ITU) took on the standardization role for International Mobile Telecommunications (IMT) radio interfaces in the 1980s. IMT-2000 was adopted by the industry and branded as Third-Generation (3G) technology. Subsequently, ITU defined the next-gen standard as IMT-Advanced rather than Fourth Generation (4G). When long-term evolution (LTE) was standardized in 2008 with Release 8 from the 3rd Generation Partnership Project (3GPP), it was hailed as 4G technology, but it did not yet meet ITU requirements for IMT-Advanced. Release 10 fulfilled those requirements as LTE-Advanced. Further improvements in throughput via carrier aggregation (CA) were introduced in Release 13, known as LTE-Advanced Pro. Release 15 introduced 5G in 2019, and Release 18 was assigned the name of *5G Advanced* in 2023—although the specifications are still being developed.

One perspective (that can apply to many technologies) is that generations alternate between setting the stage and completion. This can be seen in cellular where 1G introduced mobile voice, which was completed with digital technology and small mobile phone form factors in 2G. The 3G generation introduced mobile data (with significant limitations), which was completed with 4G. The 5G generation introduces the expansion into adjacent markets with targeted use cases but has been incomplete to date (Figure 1). Based on that perspective, 6G may bring maturity to concepts introduced in 5G.

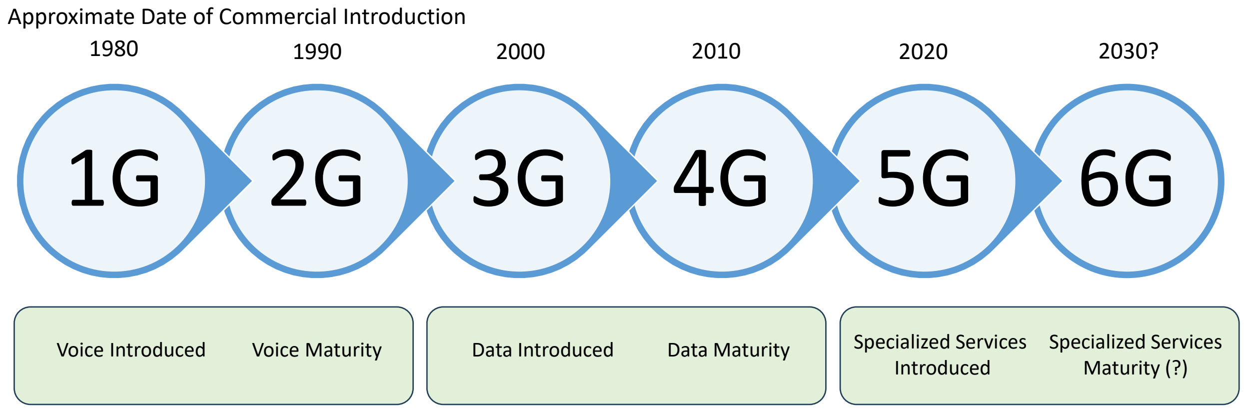

Figure 1. Evolution of cellular generations: alternate generation cadence

5G Today

In 2023, 5G networks have entered broad commercial deployment globally. As 3GPP is working on Release 18 and considering initial goals for Release 19, the research community is clarifying exactly what 6G should be, with varying opinions from academia and industry. Meanwhile, some are asking if 6G is even needed—especially given that the full promise of 5G has not yet been delivered. In the broadest view, the evolution of a new generation such as 6G has two key aspects. First, generation advances seek to push performance boundaries with an idealized goal of an order-of-magnitude improvement in key metrics for each use case profile as defined in Table 1. In reality, many of the promises of 5G have yet to be delivered to the market, even as standards are moving on toward 5G-Advanced.

The single area that 5G has delivered on its promise is the mobile broadband use case, eMBB. The 5G capability is 1 Gbps, and peak rates of 597 Mbps have been measured in the United States from commercial operators. The average throughput is, of course, lower. Some additional improvements are likely as 5G Advanced is deployed, but data rate is not the driving factor for most mobile use cases anymore. Fixed wireless access services offered by mobile operators can make high rates in high-band spectrum commercially viable for providing residential Internet service.

The picture is less clear for the Internet of Things (IoT) use case (mMTC). The 3GPP offering for mMTC has been NB-IoT to date. Although it is included as a 5G technology and has been enhanced from NB1 to NB2, NB-IoT is still fundamentally an LTE air interface. In the market, LTE-M (also known as *LTE Cat-M1*) has been the dominant choice for IoT use cases (with both commercial and private LTE networks). NB-IoT remains more of a niche, especially in North America. A scaled-down version of the 5G New Radio called *RedCap*[1] (reduced capability) promises to be the 5G version of LTE-M. It continues in standards development but is not commercially available. At the low end of performance that NB-IoT targets, deployment has been lukewarm, with effective competition from other low-power wide area network (LPWAN) technologies.

Finally, the promise of ultra-reliable low-latency communication (URLLC) has been a complete miss to date, with no availability of commercial services or devices supporting it.

Table 1. 5G Evolution and 6G Goals

Use Case Profile	Key Metrics	5G Capability of Standard	5G Actual in 2023	Goal for 6G
Enhanced Mobile Broadband (eMBB)	Data transfer rate, in gigabits or terabits per second (Gbps, Tbps)	1 Gbps	138 Mbps average; 597 Mbps peak in United States*	1 Tbps peak 10–100 Gbps "guaranteed"
Massive Machine-Type Communication (mMTC)	Service availability	238 Global 5G operators	140 Operators	IoT service from terrestrial and satellite
	Device density, per square kilometer	10^6/km^2	Limited device deployment	10^7/km^2
Ultra-Reliable Low-Latency Communication (URLLC)	Latency/jitter, in milliseconds (ms)	1 ms	Not available	0.1 ms
	Positioning accuracy[2]	3 m	Not available	0.1 m

* source: OpenSignal 5G Benchmark June 2023

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[1] EPRI, *Telecommunication Standards Guidebook V4*. 2022. https://www.epri.com/research/products/000000003002023631

[2] Mamood, A., et al. (2019). "Time Synchronization in 5G Wireless Edge: Requirements and Solutions for Critical-MTC." https://arxiv.org/pdf/1906.06380.pdf

Abstracting 6G Concepts: From Triangle to Hexagon

Since the ITU introduced the famous 5G "triangle" around 2016 as it developed the IMT-2020 specifications[3] (Figure 2), the triangle has been used as a basis to represent the differentiated use cases. The key aspect (often omitted in 5G marketing) is that the corners of the triangle represent capabilities that are typically not all available at the same time and place from a 5G network. The triangle is evolving in new directions to represent the goals of 6G, with the same caveats. The triangle accentuates the fact that 4G LTE (the central area) already supports many use cases, and 5G extends the capability and performance metrics in three areas (the tips of the triangle.)

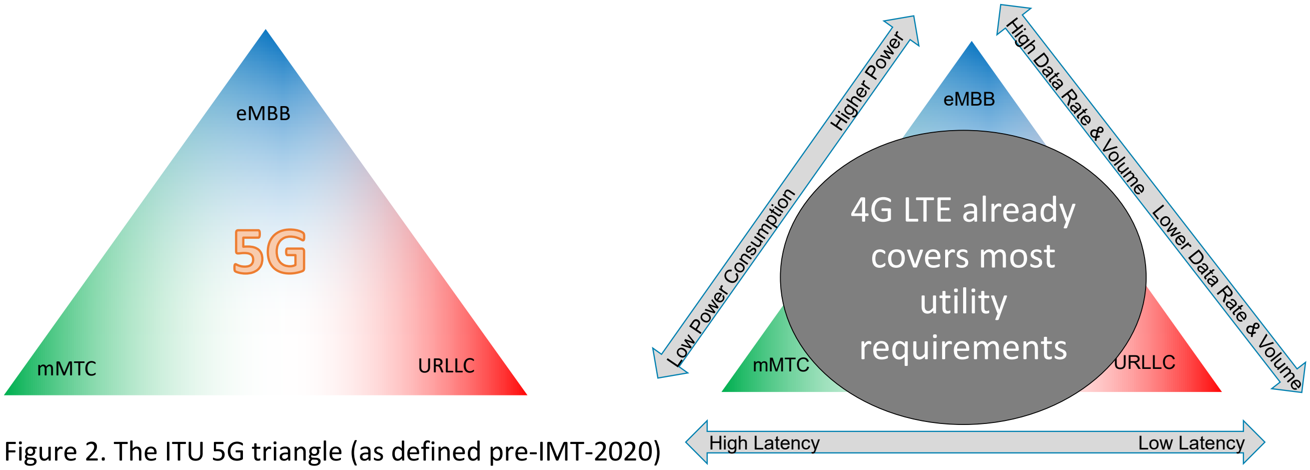

Figure 2. The ITU 5G triangle (as defined pre-IMT-2020)

One perspective presented at ICC by a company from China adds two new vertices to the 5G triangle to make it a tetrahedron. The three existing use cases from the triangle are enhanced to their "plus" versions to indicate performance enhancements (Figure 3).

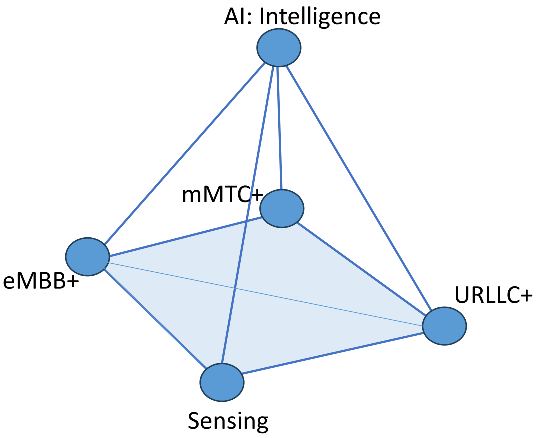

Figure 3. Tetrahedron 6G conceptual model

The base is extended to add the sensing use case. Sensing is an emerging capability that uses the radio-frequency (RF) channel measurements required for multi-input-multi-output (MIMO) radios to infer the presence and locations of passive objects in the vicinity. This builds on existing capabilities for active devices

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[3] ITU, "Emerging Trends in 5G/IMT2020." https://www.itu.int/en/membership/documents/missions/gva-mission-briefing-5g-28sept2016.pdf

to locate themselves and peer devices. Sensing expands on location to detect and localize humans, walls, and other nonelectronic objects. This capability is being standardized for Wi-Fi (IEEE 802.11) in the TGbf (WLAN Sensing) Task Group. 3GPP has identified the capability in the planned features for Release 19 as "Integrated Sensing and Communication."

The vertical dimension is extended to represent the application of artificial intelligence. This has two aspects: AI for the Network (where AI is used internally to manage and optimize the wireless network) and Network for AI, where exchange of AI models and other communication from external applications becomes a class of network traffic and a differentiated use case itself that the network handles. Some refer to the 6G evolution as *native AI/ML*, where AI and ML (machine learning) operate autonomously between devices and the network, optimizing all protocol layers. ML is trained by performance data gathered from the varying operating conditions and environments.

Another perspective that was widely embraced at ICC expands the triangle into a hexagon (Figure 4). This representation is based on a figure presented by ITU in the draft *Framework and overall objectives of the future development of IMT for 2030 and beyond*.[4]

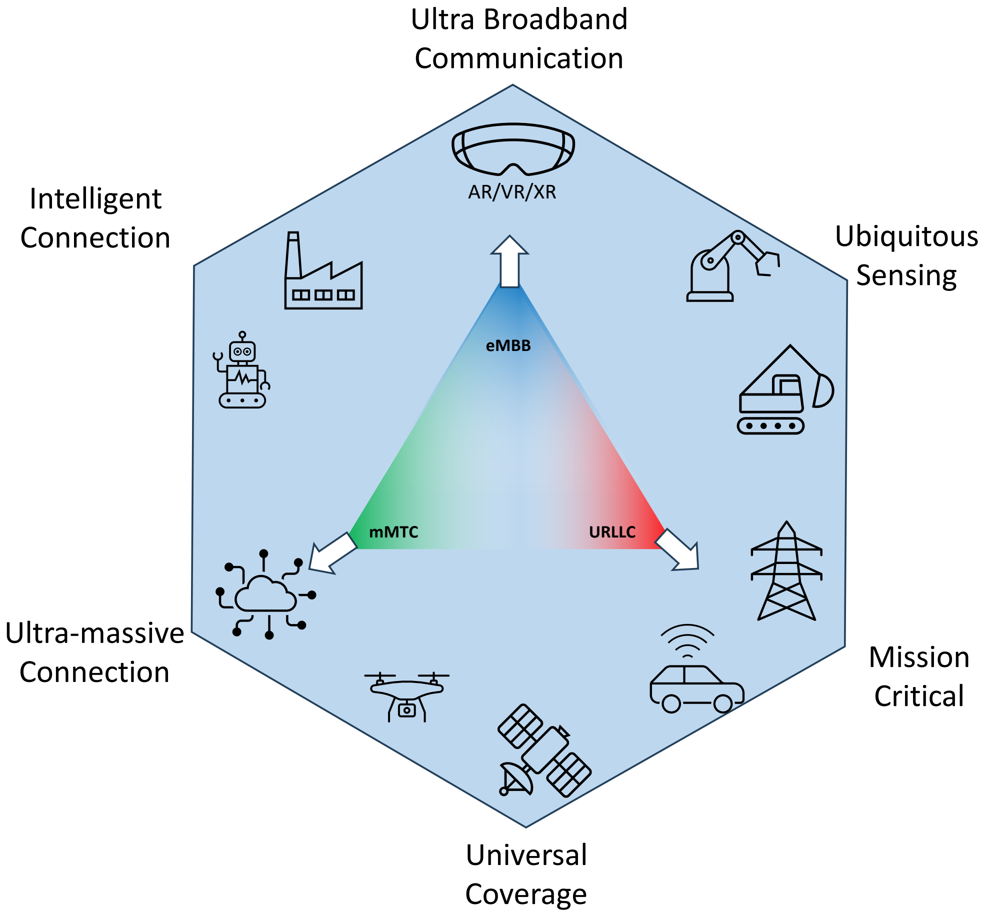

Figure 4. 6G hexagon use case visualization

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[4] Not available to the public from ITU but can be found in embedded attachment in this IEEE document.

The hexagon visualization extends the 5G enhanced mobile broadband to ultra broadband communications. Others call this *immersive communications*. Few mobile use cases can effectively use hundreds of Gbps or even Tbps data rates. The notable use case presented is the evolution of virtual reality/augmented reality (VR/AR) use cases toward lightweight glasses-style AR devices, with eventual fully immersive "all-day XR" providing virtual telepresence. This evolution still ignores the fact that today's uses of extended reality (XR) outdoors are in the minority, although many compelling utility-centric AR use cases are outdoors. Today, commercially available AR devices are typically integrated with Wi-Fi rather than a 5G cellular connection.

URLLC and Mission Critical Communication

The URLLC corner is extended to mission critical or critical services. The commonly cited use cases (focused on broad markets) continue to be self-driving vehicles and industrial automation. This capability will be a clear fit that is well aligned with utility protection and control use cases. It will be tested extensively by EPRI when it becomes available.

Ultra-Massive Connection for Omnipresent IoT

The massive machine-type communication (mMTC) corner is extended to ultra-massive connection or omnipresent IoT. Although the 5G message was "support for billions of devices," the 6G goal is "trillions of embeddable devices." A related goal is extremely low power. The 5G goal was multi-decade battery life. The 6G goal includes zero-energy devices operating with ambient or scavenged power.

Non-Terrestrial Networks for Universal Coverage

The first new vertex for 6G is universal coverage or global broadband. This is based on the non-terrestrial networks (NTN) standardization activity in 3GPP, which has a goal of enabling direct communication between mobile devices and standard modems with satellite services. NTN also supports high-altitude balloon platforms and communications through and with unmanned aerial vehicles (UAVs; that is, drones).

Joint Communication and Sensing

The next new vertex for 6G is ubiquitous sensing, also referred to as *joint communication and sensing (JCAS)* in 3GPP. As networks evolve to use higher frequencies and higher order MIMO, the radio system must create an increasingly precise channel propagation map (channel state information [CSI]) for the area of coverage. In a pure communications network, this map enables the radio to maximize throughput by taking advantage of the differences in the CSI for the multiple paths between multiple antennas in a MIMO system to perform beam steering and optimally selecting modulation and coding for various resource blocks across frequency and time. The opportunity for sensing has come about through the realization that the CSI data can be used to deduce the physical configuration of the environment—including objects in the environment—purely by passive measurements. With millimeter wave 5G spectrum, the resolution for detecting a person or object can be approximately 1 cm. Widespread adoption of this capability in public networks has privacy implications because the use of wireless sensing cannot be easily detected and operates even in the dark. On the other hand, it presents opportunities for enhancing surveillance use cases in privately owned areas such as substations and other utility-owned sites.

Integration of Computing and AI

The final new vertex for 6G is intelligent connection or integration of computing and artificial intelligence (AI), which is discussed above as subdividing into AI for the network and the network for AI.

New Considerations for 6G Technologies

Several 6G concepts were introduced that were more abstract and not related to services or typical network performance metrics. These overarching considerations look at the evolving network as a whole and the global implications on business, individuals, and the environment.

Energy Efficiency

Energy consumption and the technology changes needed to enable more sustainable networks globally are gaining more attention with 6G. Sustainability objectives are primarily related to energy consumption of the network infrastructure but increasingly includes a wider scope, such as reduced e-waste, more autonomous and efficient supply chains, and use of network sensing capabilities for environmental sensing. The area is also considering digital inclusion, which falls more in the policy realm. In addition to energy efficiency and sustainability objectives, plans for 6G also consider the use of resources—for example, by optimizing equipment longevity, repair, reuse, and recycling.

The deployment of 5G (mostly as an overlay to 4G) increased the total energy requirements of the network. Although silicon technology advances have reduced the energy required for complex computing, the physics of wireless communications are unyielding. Achieving power efficiency in wireless systems is challenged by the increasing use of higher frequency bands and wider channel bandwidths, which each require more power to establish a link over comparable distances. The broader use of small cells increases the total number of network base stations and adds to the amount of fixed (copper/fiber) network backbone required to support them. Finally, the increasing use of massive MIMO for increasing the number of simultaneous users in limited spectrum comes at the cost of requiring dozens or even hundreds of radios where there were previously a handful—each radio requiring energy to operate.

The industry realizes that these trends are incompatible with energy efficiency and sustainability goals and is making green networks a focus for 6G technology. This is a systemwide optimization problem that can leverage the trend toward broader use of software-defined networking and AI/ML (Figure 5).

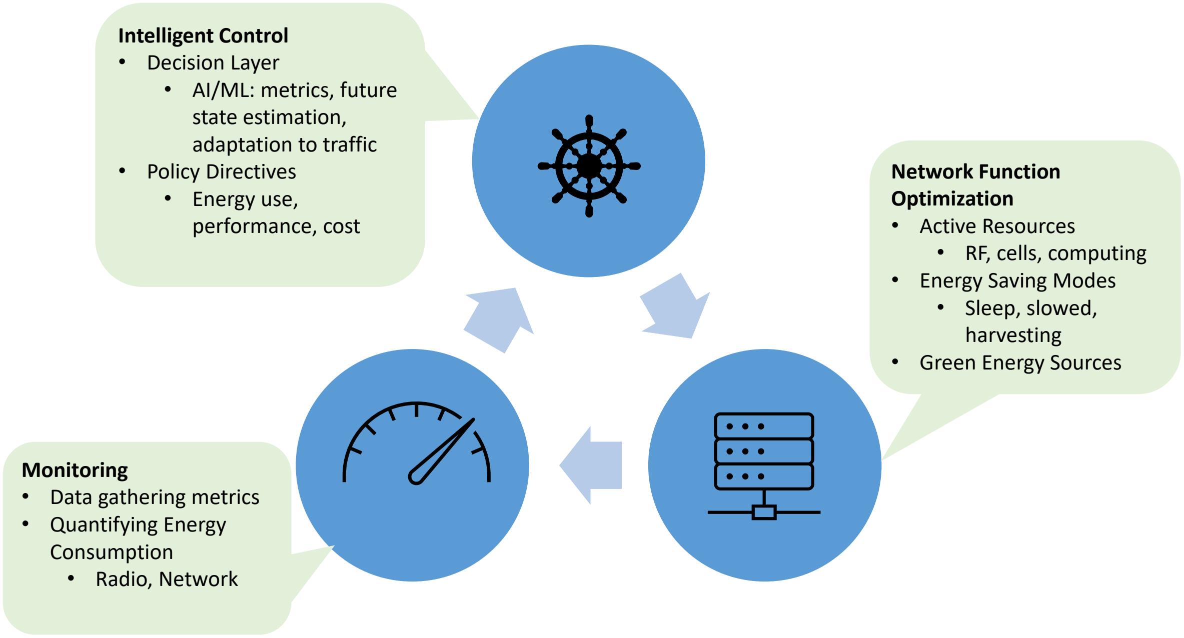

Figure 5. Green networks for 6G: optimizing energy consumption

Diversification of Services and Customers

There is an ever-present desire in the ecosystem to expand 3GPP networks into adjacent markets and evolve the network into a “platform” to expand revenue opportunities. This expansion includes vertical networks, non-terrestrial networks, residential networks, and even personal area (wearable) networks. These are already served by existing technologies, so they are not dependent on 6G before they can exist. Some benefits could result from standardization in the cases in which standards do not already exist. This diversification focus was introduced with 5G but not fully realized. It also includes the desire to enable distributed computing, edge computing, AI as a service, and additional service-focused application programming interfaces (APIs) as additional offerings for network providers.

Spectrum for 6G Networks

The “elephant in the room” topic is spectrum for 6G. The global reality is that there is no new spectrum. Every band that is usable from kHz to THz has been allocated to some type of service. At ICC, several presentations called out the “new upper mid-band” in the 7–15 GHz range as the target for new capacity needed for 6G. Of course, that spectrum is not “new” and is already occupied by incumbents using it for many services, including utilities using part of that range for microwave links. Some have already given this band the designation *FR3*[5] to complement the existing FR1 (410–7125 MHz) and FR2 (24–71 GHz). The assumption is that spectrum sharing will be technically feasible and supported by regulation to allow concurrent operation of 6G systems across this entire spectrum.[6]

With all prior generations of cellular technology, regulators reallocated and reassigned spectrum to mobile networks designating it for exclusive use for international mobile telephone (IMT). These allocation changes always included the requirement that the mobile network operators pay for the relocation of any licensed incumbents in the bands they were taking over. Over the past 10 years, the concept of spectrum sharing has been adopted as the new regulatory framework, with the assumption that sharing eliminates the need for relocation of incumbents. The first two spectrum-sharing systems—TV White Space[7] and CBRS[8]—were implemented with exceedingly careful and thorough mechanisms and policies to ensure the protection of incumbents. These have generally been quite successful. The third spectrum-sharing framework for unlicensed operation in the 6–7 GHz band[9] (AFC) has been less considerate to incumbents. Now, the spectrum from 7GHz to 15 GHz has been identified as a target for 6G. Based on experiences in the 6 GHz band, if similar spectrum-sharing models are adopted for 7–15 GHz, there may be a potential for interference between new 6G services and incumbent systems.

The Standards Timeline for 6G

The goal of the industries behind 3GPP standards is to see all wireless systems using future 6G technologies. How that will be accomplished technically is just starting to be considered. As with prior generations, 6G will follow the requirements set forth by the ITU in IMT specifications. ITU-R Recommendation M.2150 (previously known as *IMT 2020*) was approved in 2020[10] but did not incorporate all planned 5G aspects. ITU-

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[5] Rohde and Schwarz. https://youtu.be/XKT6HNHMxhM?t=40

[6] https://pixl8-cloud-techuk.s3.eu-west-2.amazonaws.com/prod/public/afc9633a-982e-443d-a20cf2c52618453d/UKSPF6G-in-7-to-24-GHzfinal-report.pdf

[7] https://www.fcc.gov/general/white-space

[8] https://www.fcc.gov/wireless/bureau-divisions/mobility-division/35-ghz-band/35-ghz-band-overview

[9] https://www.fcc.gov/document/fcc-opens-6-ghz-band-wi-fi-and-other-unlicensed-uses

[10] https://techblog.comsoc.org/2020/11/26/imt-2020-specs-approved-by-itu-r-but-may-not-meet-5g-performance-requirements-no-frequencies-specified/

R M.2150-1 is an amendment that incorporates 3GPP 5G standards through Release 17. The M.2150-1 revision[11] was published in February 2022.

In June 2023, Working Party 5D released a draft recommendation[12] *Framework and overall objectives of the future development of IMT for 2030 and beyond*, which provides direction toward the future IMT-2030.

The IMT requirements set forth by ITU inform the 3GPP, which will develop standards to meet the requirements. The desires of the ITU are tempered with business realities as well as regulatory considerations as they enter the standardization process. The 3GPP organization operates on a time-based cadence of releases; the objective is to issue successive releases on a 12- to 18-month cycle. The scope and content for each release are selected by 3GPP while keeping the release schedule in mind. Therefore, six or more releases will occur during the nominal 10-year life cycle of a technology generation. A new generation such as 6G is introduced in parallel with the final phases of maturity and evolution of 5G. In 2024 to 2025, 3GPP will perform feasibility studies on the various aspects of 6G. Based on the findings of the studies, the specification will be subsequently conducted in three stages. Stage 1 is the service-level description of the capabilities. Stage 2 defines an abstract architecture of the functional elements. Finally, Stage 3 defines the details of the protocols and implementation of the elements. A possible timeline and roadmap based on several viewpoints is presented in Figure 6.

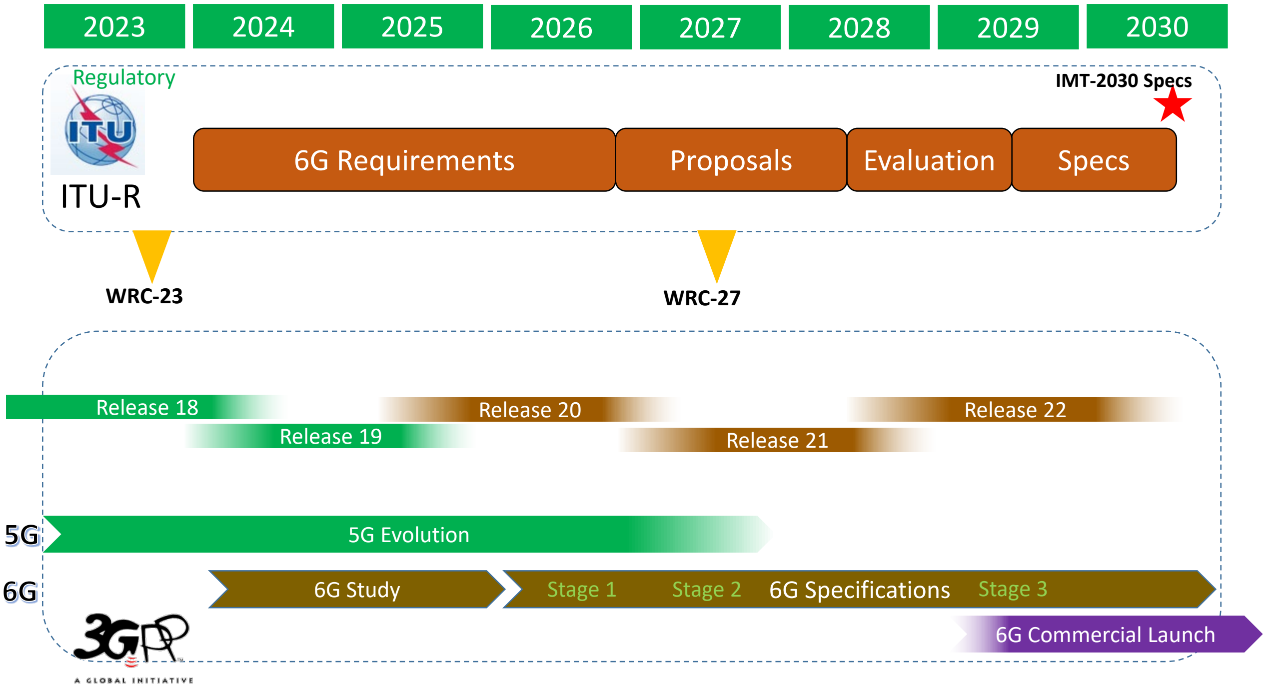

Figure 6. High-level roadmap for 5G evolution toward 6G

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[11] https://www.itu.int/rec/R-REC-M.2150-1-202202-I/en

[12] Not available to the public from ITU but can be found in embedded attachment in this IEEE document.

Summary and Conclusions

As 5G becomes the mainstream technology for global cellular networks, the requirements for 6G are beginning to be addressed. Given that many of the promises of 5G (such as URLLC) remain unfulfilled, some aspects of 5G may be relabeled as part of 6G.

The evolution to 6G may fill in the currently differentiated use cases for 5G, offering combinations such as the low power and range of mMTC with the higher data rates of eMBB. A different evolution could provide the low latency of URLLC combined with the large number of devices of mMTC. Most applicable and valuable for utility use cases is providing low-latency URLLC and high-rate eMBB concurrently. Those attributes tend to go hand in hand because technology that delivers higher data rates also delivers those data faster. Providing both is technically feasible but becomes more of a business or governance issue because providing high reliability and low latency comes at the cost of lower spectrum efficiency. This is a manageable trade-off for private networks but will have significant cost implications on public networks. The most difficult combination to provide is low latency and low-power operation. Low power is typically achieved by carefully scheduling radio operation so that the device can stay in a sleep state most of the time. Unless the communications are periodic with short messages on a highly predictable schedule, the goals of low latency and extended sleep intervals are mutually incompatible.

With every new technology generation, there are opportunities and risks. The primary opportunity from the utility perspective is seeing the promises of 5G fully realized. Standardization for non-terrestrial networks presents an opportunity for an interoperable ecosystem, including satellite. The primary risk is the ongoing pressure to reassign wireless spectrum already in use by incumbents to expand the holdings of commercial cellular networks.

Index of Previous Issues

Issue	Publication Date	EPRI Product ID and Link	Topics
12	January 2020	3002017359	2019 IEEE International Communications Conference (ICC) updates, 5G dynamic spectrum sharing, Resilience Week 2019, 3GPP 5G standardization roadmap, Cellular Vehicle-to-X
11	October 2019	3002014754	2018 IEEE SmartGridComm, 2019 Mobile World Congress, 3GPP 5G standardization roadmap
10	December 2018	3002014753	2018 IEEE ICC updates, Cellular Vehicle-to-X, 5G updates
9	December 2017	3002011576	2017 ICC updates, 5G critical MTC, 5G NR
8	July 2017	3002011575	2017 Mobile World Congress (MWC) updates, NB-IoT and 5G massive MTC technologies
7	November 2016	3002009348	5G definitions, architecture, roadmap, and enabling technologies (next-generation radio, LTE, softwarization, and Wi-Fi)
6	March 2016	3002008549	Utility-relevant observations from the IEEE SmartGridComm conference and International Consumer Electronics Show
5	November 2015	3002007165	Utility-relevant observations from the 2015 IEEE ICC, emphasizing emerging 5G technologies
4	June 2015	3002006502	Leveraging of consumer-focused communications technologies for utility applications
3	February 2015	3002004408	IoT developments and standards for connectivity at very high speeds—above 1 Gbps
2	October 2014	3002004407	FAN infrastructure, LTE technologies and standards, and radio and network virtualization in utility applications
1	May 2014	3002004089	State of the industry, key trends, and utility IoT applications

Acronyms

1G - 6G	1st, 2nd, 3rd, 4th, 5th, 6th Generation
3GPP	3rd Generation Partnership Project
AI	Artificial Intelligence
AR	Augmented Reality
CA	Carrier Aggregation
CIP	Critical Infrastructure Protection
CSP	Commercial Service Provider
C-V2X	Cellular Vehicle to X (anything)
D2D	Device to Device
dB	Decibels
DL	Downlink
DOE	U.S. Department of Energy
DSRC	Dedicated Short-Range Communications
DSS	Dynamic Spectrum Sharing
eMBB	Enhanced Mobile Broadband
eNB	3GPP term for the enhanced Node B (eNodeB) or base station
FAN	Field Area Network
FCC	U.S. Federal Communications Commission
FDD	Frequency Division Duplexing
Gbps	Gigabits per second
GHz	Gigahertz
GPS	Global Positioning System
ICC	International Conference on Communications (sponsored by IEEE)
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
ITU	International Telecommunication Union
kbps	Kilobits per second
km	Kilometers
LTE	Long-Term Evolution

m	Meter
M2I	Metamaterial-Enhanced Magnetic Induction
MEC	Mobile Edge Computing (original name)
MEC	Multi-Access Edge Computing (ETSI rebranding for beyond mobile)
MHz	Megahertz
MIMO	Multiple Input Multiple Output
ML	Machine Learning
mMTC	Massive Machine Type Communication
mmWave	Millimeter Wave
MNO	Mobile Network Operator
ms	Milliseconds
MTC	Machine-Type Communication
MWC	Mobile World Congress
NB-IoT	Narrow Band IoT
NOPR	Notice of Proposed Rule Making
NR	New Radio
NTIA	U.S. National Telecommunications and Information Administration
NTN	Non-Terrestrial Networks
OFDMA	Orthogonal Frequency Division Multiple Access
OSI	Open Systems Interconnection
OTT	Over-the-Top
PC5	3GPP D2D or SideLink protocol
PHY	Physical Layer
ProSe	Proximity Services
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
RF	Radio-Frequency
s	Seconds
SA	Standalone
Tbps	Terabits per second
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UL	Uplink
URLLC	Ultra-Reliable and Low-Latency Communications

V2X	Vehicle to Anything
VLEO	Very Low Earth Orbit
VR	Virtual Reality

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