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TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

Communications & Connectivity Technology Newsletter

An Update on Trends & Innovations **January 2020**

Contents

Introduction

Welcome to the 12th issue of EPRI's *Communications & 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 Fifth Generation (5G) 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, Resilience Week 2019, and other sources. The relevance of these topics to utility telecom professionals is two-fold. 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 technologies achieve economies of scale due to 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 pp. 17-18 for links to earlier issues in this series, and contact us with your feedback and ideas.

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The IEEE ICC is one of the premier conferences for advanced research on communications. It is a leading source of information on 5G, and hints of Sixth Generation (6G) directions are starting to emerge. ICC 2019, held in Shanghai, China, featured a strong emphasis on the application of machine learning and artificial intelligence (AI) more broadly. This article introduces the 5G-to-6G evolution, as well as several prominent technical areas and research directions.

History and Evolution of 5G Toward 6G

Generations of cellular technology emerge and are standardized over roughly a 10-year cycle. Incremental improvements and milestones periodically 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.[1] Subsequently, ITU defined the next-gen standard as IMT-Advanced rather than Fourth Generation (4G). When Long-Term Evolution (LTE) was introduced in 2008 in Release 8 from the Third Generation Partnership Project (3GPP), it was hailed as 4G technology, but it did not meet ITU requirements for IMT-Advanced.[2] In 2011, 3GPP 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.

Now that 5G networks are entering broad commercial deployment, the research community is starting to define the path to the next generation. In the broadest view, the evolution has two key aspects. First, technology advances seek to push performance boundaries with a proposed goal of an order-of-magnitude improvement in key metrics for each 5G network "slice," as defined in Table 1 and illustrated in Figure 1.

Table 1 - 5G Evolution: Improvements Per Network Slice

Network Slice	Key Metrics	5G Capability	5G+, 5G++ Evolution Toward 6G
Enhanced Mobile Broadband (eMBB)	Data Transfer Rate, in gigagbits or terabits per second (Gbps, Tbps)	1 Gbps	1 Tbps
	Coverage	Spotty	99%
Massive Machine-Type Communication (mMTC)	Range, as measured by link budget in decibels (dB)	164dB	+40dB (to 204dB)
	Device Density, per square meter (m)	$1/m^2$	$10/m^2$
Ultra-Reliable Low Latency Communication (URLLC)	Latency/Jitter, in milliseconds (ms)	1 ms	0.1 ms
	Positioning Accuracy[3]	3 m	0.1 m

[1] ITU, "About mobile technology and IMT-2000," http://www.itu.int/osg/spu/imt-2000/technology.html
[2] ITU, "IMT-Advanced," http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-adv/Pages/default.aspx
[3] Mamood, A., *et al*. (2019). "Time Synchronization in 5G Wireless Edge: Requirements and Solutions for Critical-MTC," https://arxiv.org/pdf/1906.06380.pdf

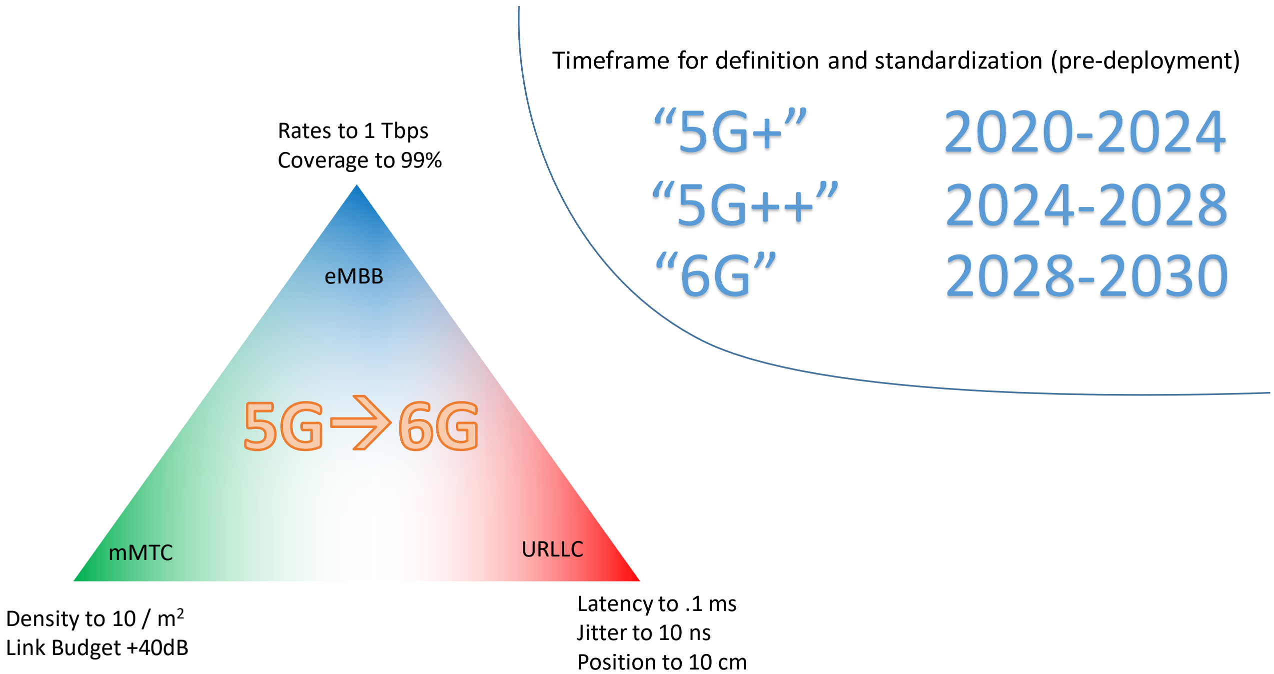

Figure 1 – Goals for 5G Evolution: Expanding Performance Limits

Second, both a technical need and a market desire exist to blur the distinctions between the three disparate slices. At present, one point of market confusion about 5G capabilities has to do with the three slices. 5G technology can provide extremely high data rates, long range and low power, and low latency, but it cannot do all of them at the same time and same place. Currently, independent 5G technology solutions are available, suitable for specific use cases. But many applications require performance characteristics in the overlap between slices. Ultimately, the direction of 6G will be to provide a unified technology to serve all slices as shown in Figure 2.

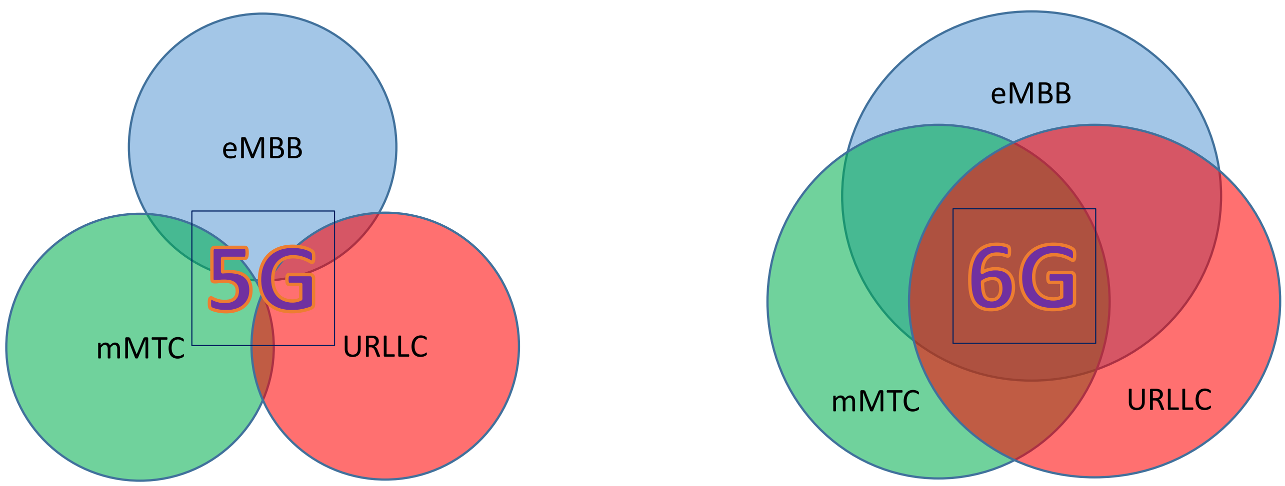

Figure 2 – 5G to 6G Evolution: Filling the Slice Distinctions

The evolution to 6G will "fill in" the overlapping areas, matching a capability with 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. Perhaps the easiest evolution from a technical sense is providing low-latency URLLC and high-rate eMBB concurrently. Those attributes tend to go hand in hand, since technology that delivers higher data rates also delivers the data faster. The most difficult overlap is providing extremely low latency with low-power operation, which is commonly and effectively achieved by carefully scheduling radio operation so the device can stay in a sleep state most of the time. Low latency and extended sleep intervals are mutually incompatible.

The ultimate goal is to see all capabilities merge within 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. IMT-2020 is nearing completion, and work will soon start on the next generation as shown in Figure 3.[4]

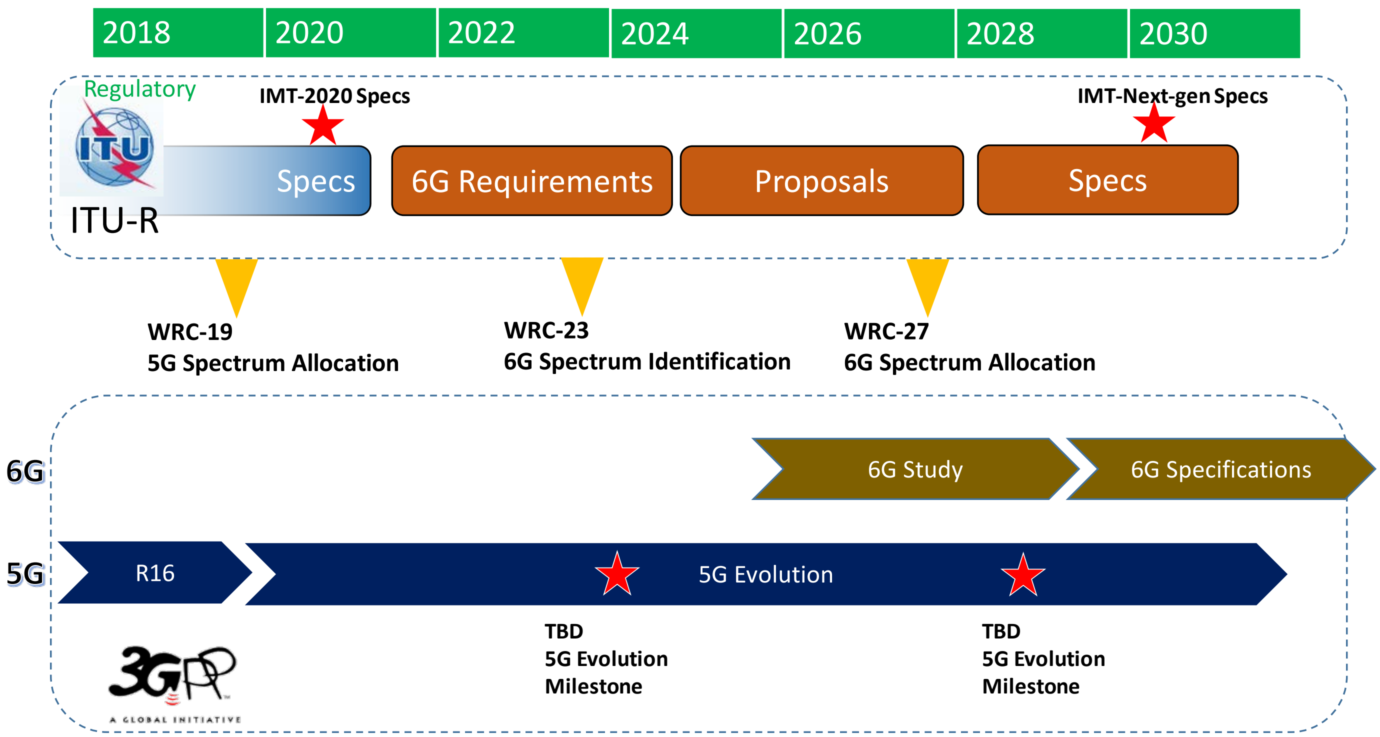

Figure 3 – High-Level Roadmap for 5G Evolution Toward 6G

Riding the "Pixel Bus" for Tbps Speed

One new concept that was proposed at ICC 2019 for taking advantage of terabit-per-second data rates—or, more cynically, justifying the need for Tbps speed—is transforming the radio link from the current "bit pipe" to a "pixel bus." Today, some mobile applications run as an Over-The-Top (OTT) service to a cloud service or application. This type of OTT application includes video streaming, conferencing, and mobile gaming. The mobile app communicates the underlying data through the Internet Protocol (IP) over the mobile network to the cloud. The mobile device performs the necessary computing and rendering locally. In the future model, the concept of Mobile Edge Computing[5] (MEC), Multi-Access Edge Computing (MEC),[6] or the "edge cloud" is introduced, as illustrated in Figure 4.

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[4] ITU, "IMT for 2020 and Beyond," https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx
[5] Ericsson, "Distributing clouds to industry," https://www.ericsson.com/en/future-technologies/mobile-edge-computing

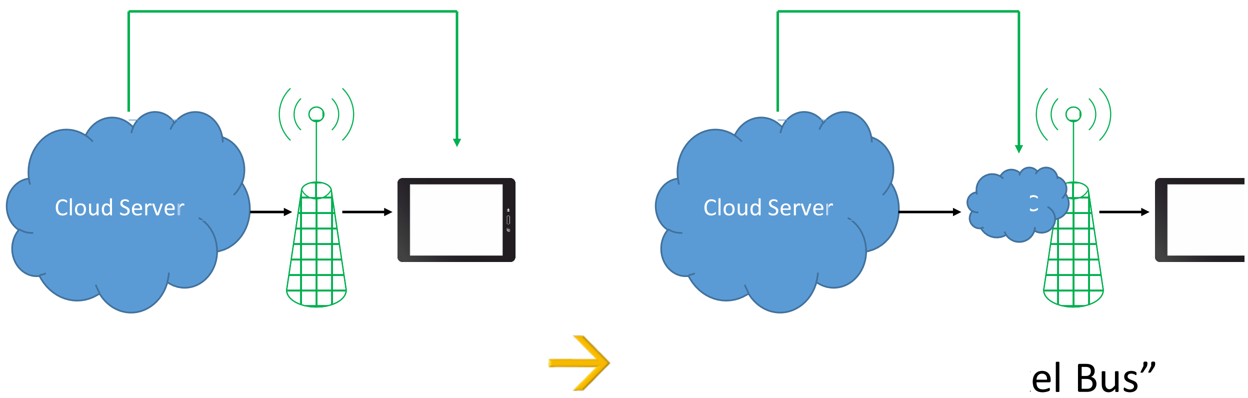

Figure 4 – Next-Generation: Extreme-Rate Mobile Broadband

The goal is to move computationally intensive and latency-sensitive applications to the edge of the network. The ultimate embodiment of this concept is to change the wireless network link to the user from a data bus to a “pixel bus.” This means the application computing and rendering are done in the edge cloud, and only the image data (pixel stream) is delivered over the air. This type of architecture could be beneficial for Augmented Reality/Virtual Reality (AR/VR) applications. The edge cloud supplies the high-performance computing, which is challenging in a mobile or portable device due to heat and power constraints. The edge cloud also helps to reduce latency by putting the computing and image rendering close to the network edge. Table 2 illustrates the required bit rate for a high-resolution AR/VR application.

Table 2 – Data Rate for "Pixel Bus" 5G Evolution Use Case

AR/VR Image Resolution	Bits per Pixel	Megabits per Frame	Frames per Second	Required Uncompressed Video Rate
4K (3840 × 2160)	24	199.07	60	11.944 Gbps

While ~12 Gbps falls in the range between today’s 1 Gbps rates and future 1 Tbps rates, technical and practical issues remain to be addressed. A key consideration is the amount of spectrum required to support that data rate. Presumably, this would be done in the Millimeter Wave (mmWave) bands, involving short range and high spectrum reuse. Such pixel bus applications would be most feasible in private networks, since the economics of the high data rates and volumes may be problematic for commercial networks.

Standardizing Non-Terrestrial Communications

Another aspect of the evolution of 5G toward 6G is the opportunity to standardize Non-Terrestrial Networks (NTN) and incorporate communications to satellites, aircraft, and Unmanned Aerial Vehicles (UAV) as part of the overall commercial network.[7] Very Low Earth Orbit (VLEO) satellites provide compelling advantages for providing wireless access. Moving access nodes into space, above terrain, eliminates many of the

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[6] ETSI, “Multi-access Edge Computing,” https://www.etsi.org/technologies/multi-access-edge-computing
[7] 3GPP (2018). “Satellite Components for the 5G System,” https://www.3gpp.org/news-events/1933-sat_ntn

propagation problems of ground-based radio signals. Of course, indoor operation through NTN communications remains a challenge.

SpaceX has already entered this market by launching the Starlink VLEO system and readying it for commercial service.[8] The traditional cellular industry sees this as throwing down the gauntlet and plans to respond with competitive offerings for “beyond 5G” access. The envisioned architecture is using even higher band spectrum than today’s 5G mmWave bands (70-140 GHz).

VLEO means an orbit of around 300 km, which allows a one-way latency of 1 ms due to speed-of-light propagation (300 m/s). By contrast, a geosynchronous satellite orbit at 36,000 km—achievable at much higher cost—results in one-way latency of about 120 ms. Table 3 displays additional attributes of VLEO satellite systems. The compelling value from a MNO’s point of view is the cost when compared to a conventional terrestrial system. At present, the cost of building and putting a VLEO satellite in orbit is ~$1.1 million in U.S. Dollars (USD). To launch a full constellation of 9000 satellites, the estimated cost would be $9.9 billion USD. By contrast, the estimated global investment in the existing terrestrial cellular network (towers and backhaul) is $450 billion USD. Achieving full coverage with 5G mmWave for commercial networks would require orders of magnitude more infrastructure sites, with correspondingly high investment.

Table 3 – VLEO Satellite Value Proposition for Wireless Access[9]

Parameter	Attribute
Capacity for Single VLEO Satellite	Data Rate Per Beam = 19.25 Gbps
	Capacity = 4.232 Tbps
Total Capacity, ~300-Satellite VLEO System	Total Effective Capacity = 1.18 Petabits/second
Area Capacity	VLEO System with Uniform Coverage: 2 Gbps/km^2
	Per Beam Throughput: 32 Megabits/s/km^2
VLEO Costs	Launch Cost: $500,000
	Satellite Cost: $600,000

Given that mmWave 5G from pole- or building-mounted small-cell sites is generally outdoor-only as it is, the option of providing that coverage layer with VLEO satellites is appealing. This is good news for utilities that currently have to rely on more expensive niche-market satellite services for very remote locations. Commoditizing 5G access through VLEO satellites has the potential to lower costs and increase available bandwidth to practically any point on the surface of the Earth.

Leveraging Vehicle-to-X (V2X) Communications for Peer-to-Peer Applications

Device-to-Device (D2D) communications, also called Proximity Services (ProSe), was originally defined to support public safety use cases such as emergency communications out of coverage or partially in coverage. Starting with Release 12, D2D capability was introduced into the 3GPP standards using LTE technology as the PC5

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[8] Malik, T. (2019). “SpaceX’s Starlink Broadband Service Will Begin in 2020,” https://www.space.com/spacex-starlink-satellite-internet-service-2020.html

[9] Tong, W. (2019). “Keynote: Wireless Innovations for the Next Decade.” Presented at IEEE ICC 2019, Shanghai, China.

interface[10] (also known as SideLink). LTE has been designed from the start as an asymmetrical system. The radio standard on the uplink from the User Equipment (UE) to the base station (enhanced Node B or eNodeB [eNB]) is quite different from that on the downlink. Normally, LTE UE is only able to receive using the downlink modulation and to transmit using the uplink modulation. D2D UE can both receive and transmit to peer UE using the uplink modulation.

The D2D specification has continued to evolve in subsequent releases, as shown in Figure 5. Additional vehicle-specific capabilities were added for Cellular V2X (C-V2X) based on LTE. C-V2X targets the Dedicated Short-Range Communications (DSRC) bands allocated globally in the range of 5.8 - 5.9 GHz. Starting with Release 16, the C-V2X New Radio (NR) was introduced.

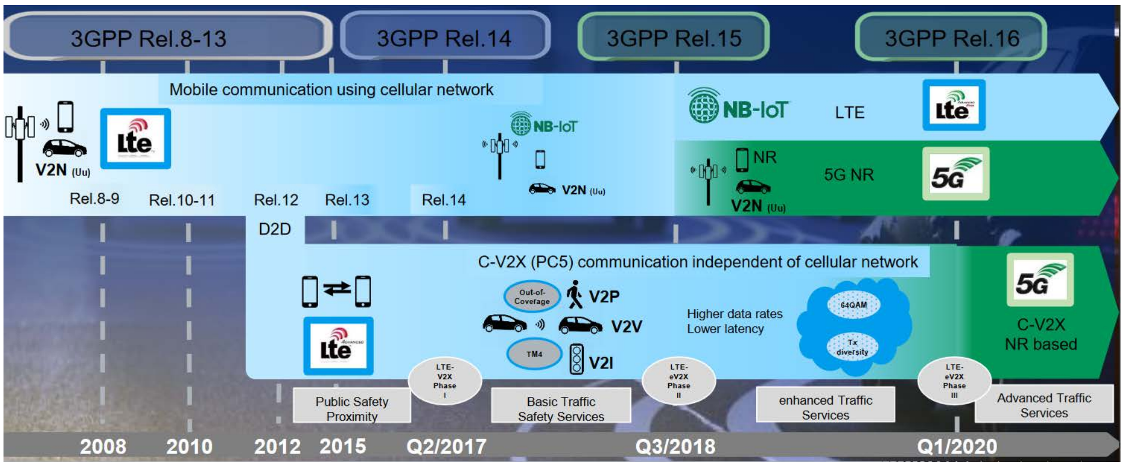

Figure 5 – DTD Evolution Toward C-V2X[11]

Figure 6 displays various application scenarios for ProSe communications by PC5 interface among vehicles or other devices. D2D and SideLink communication already have known utility telecom uses, ranging from edge computing connectivity such as Open Field Message Bus (OpenFMB), to range extension, to devices out of coverage. D2D capabilities also provide opportunities for improving network resilience, operating standalone, or self-forming groups of devices if the network infrastructure is damaged.

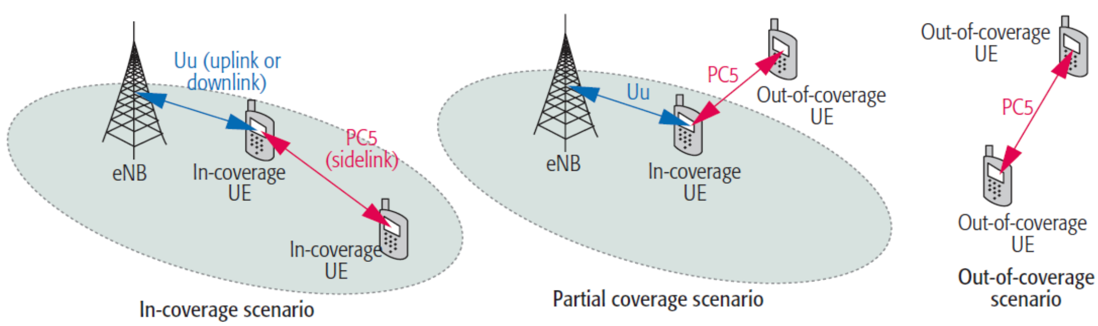

Figure 6 – D2D (ProSe) Use Cases

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[10] 3GPP (2016). "Initial Cellular V2X Standard Completed," https://www.3gpp.org/news-events/1798-v2x_r14
[11] Stuhlfauth, R. (2019). "5G, the New Communication Technology for C-V2X." Presented at Rohde & Schwartz Automotive Tech Day 3, April 2, 2019, Linas-Montlhéry, France, https://www.rohde-schwarz-usa.com/rs/324-UVH-477/images/C-V2X_R%26S_March2019.pdf

The U.S. Federal Communications Commission (FCC) recently approved a Notice of Proposed Rulemaking (NOPR)[12] that re-allocated the upper 20 MHz (5.905-5.925 GHz) of the 75 MHz DSRC band (5.850-5.925 GHz) for use by C-V2X technologies. This may spur the development of C-V2X, but interoperability issues remain to be addressed. The LTE version of C-V2X is incompatible with C-V2X for NR. The PC5 peer-to-peer communication operates without infrastructure, so the Dynamic Spectrum Sharing (DSS) approach for interoperability (see below) is not applicable.

Fulfilling the Reliability Promise of URLLC

URLLC is a 5G capability with clearly identified use cases for utility telecommunications. Many grid applications can benefit from low latency, and that requirement also includes high reliability. Historically, cellular systems have not provided any special capabilities to improve reliability. Connections can "hand over" to a different tower, but in the case of signal loss, the connection can be dropped, or latency bounds can be exceeded during a handover while the device is searching for a better connection.

Multiple Input Multiple Output (MIMO)[13] technology has been widely used in wireless communications for many years. Simply speaking, MIMO uses multiple antennas and multiple paths to increase capacity and reliability. In a MIMO system, the antennas are located near each other – on the same tower or user device. Figure 7 illustrates Coordinated MultiPoint[14] (CoMP) technology, which delivers capacity and reliability benefits while operating over much greater distances.

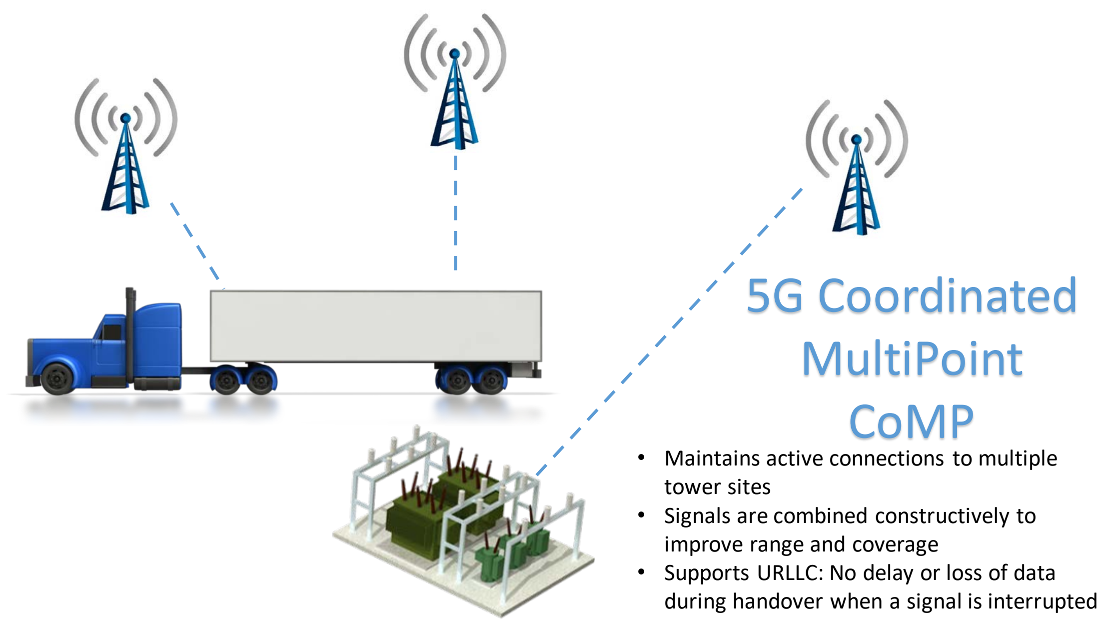

Figure 7 – Reliability Benefits of Coordinated Multipoint

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[12] FCC (2019). "FCC Seeks to Promote Innovation in the 5.9 GHz Band," https://www.fcc.gov/document/fcc-seeks-promote-innovation-59-ghz-band-0

[13] Electronics Notes, "What is MIMO Wireless Technology," https://www.electronics-notes.com/articles/antennas-propagation/mimo/what-is-mimo-multiple-input-multiple-output-wireless-technology.php

[14] Electronics Notes, "4G LTE CoMP, Coordinated Multipoint," https://www.electronics-notes.com/articles/connectivity/4g-lte-long-term-evolution/coordinated-multipoint-comp.php

With CoMP technology, a given user device has a simultaneously established connection with two or more base stations, which may be located kilometers apart. The signals are precisely synchronized so they reinforce each other, rather than interfere. In a large-scale network, CoMP reduces interference and improves cell edge performance. In a private network such as a utility implementing 5G in an in-plant environment, CoMP can provide a robust connection even in the case of movement into signal shadow areas or blockage of the signal by objects. The application of CoMP in a 5G network providing URLLC is one of the key ways that the promised "ultra-reliability" can be achieved.

Artificial Intelligence and Machine Learning in the Wireless Network

The opportunity to apply AI and Machine Learning (ML) in the wireless network has emerged as a leading area of Research and Development (R&D) and become more than an academic exercise: Many identified use cases and value propositions are waiting for solutions based on wireless edge intelligence. Commercial and private networks are rapidly expanding, and the demand for capacity and services is growing exponentially. This is especially true in the utility sector, where the requirements for reliability and Quality of Service (QoS) are mission-critical. As the industry moves into 5G technology, the number of deployment options, configuration settings, management parameters, and monitoring metrics increases by an order of magnitude. New concepts such as network slicing, CoMP, dual connectivity (4G and 5G), MEC, and others must be managed and optimized within the cellular network. 5G technology provides flexibility but at the cost of extreme complexity. Lack of workers with the appropriate skillsets exacerbates the challenge.

AI and ML are well positioned to provide significant value and benefit in the area of wireless network management and optimization. The huge capital investment in a utility private network warrants fully optimizing the resources, which range from connected devices, to the network infrastructure, to the people that manage and maintain it. Optimizing the use of the wireless spectrum is equally, if not more, important. The set of problems well suited for AI and ML can be organized by the layers of the Open Systems Interconnection (OSI) communication protocol stack (Figure 8):

- Network management: Link/device failure, root cause analysis, predictive maintenance
- Green networks: Managing energy consumption with selective cell site shutdown, optimized maintenance scheduling based on traffic patterns
- Geospatial: AI and ML based on device positioning and location, drawing on multiple data sources from wireless network, GPS, and network connectivity
- Managing storage allocation, edge computing, bandwidth
- Optimizing XR application conjunction with network: Optimized rendering, optimizing power consumption and battery life, optimizing user interaction/gestures, environmental sensing
- Deep reinforcement learning for network slicing: Automating the characteristics and provisioning of service-oriented slices
- Cyber security: Traffic pattern analytics, fingerprinting, automated intrusion detection
- Proactive network resource allocation: Optimizing spectrum use, managing shared spectrum, resilience/recovery from network damage
- AI-based handover enhancement: Accounting for the full slate of parameters (QoS policy, sector loading, interference, device movement, backhaul state, etc.) to determine when/if to cause device handover
- Cell coverage and capacity optimization
- Radio optimization: Modulation parameters, link adaptation, and configuration options within complex 5G networks
- Managing MIMO beams, managing interference with ICIC, applying CoMP where appropriate based on device use cases

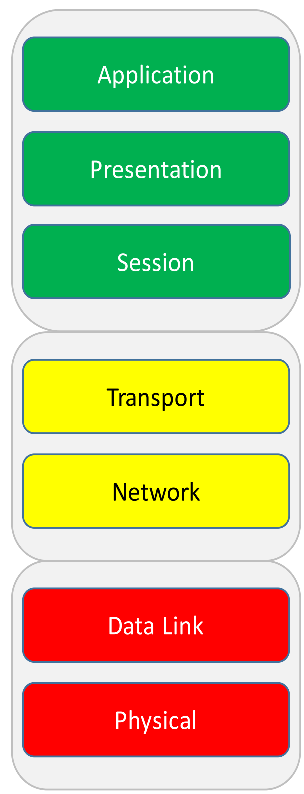

Figure 8 – OSI Stack

Wireless edge intelligence represents an evolution from edge computing and departs from today's centralized cloud-based training, inference, and control. Locating AI on edge devices provides a fundamental architectural shift—the devices can share and exchange learned models, not just raw data. This preserves the privacy and/or data security aspects of the edge devices while also reducing the memory and computer processing requirements at the edge, as well as the bandwidth and latency requirements of the network.

Figure 9 illustrates the application space for edge intelligence. The most demanding (and promising) application is in the Radio Access Network (RAN) itself, virtualizing and distributing the network infrastructure down to the lowest levels of the radio.

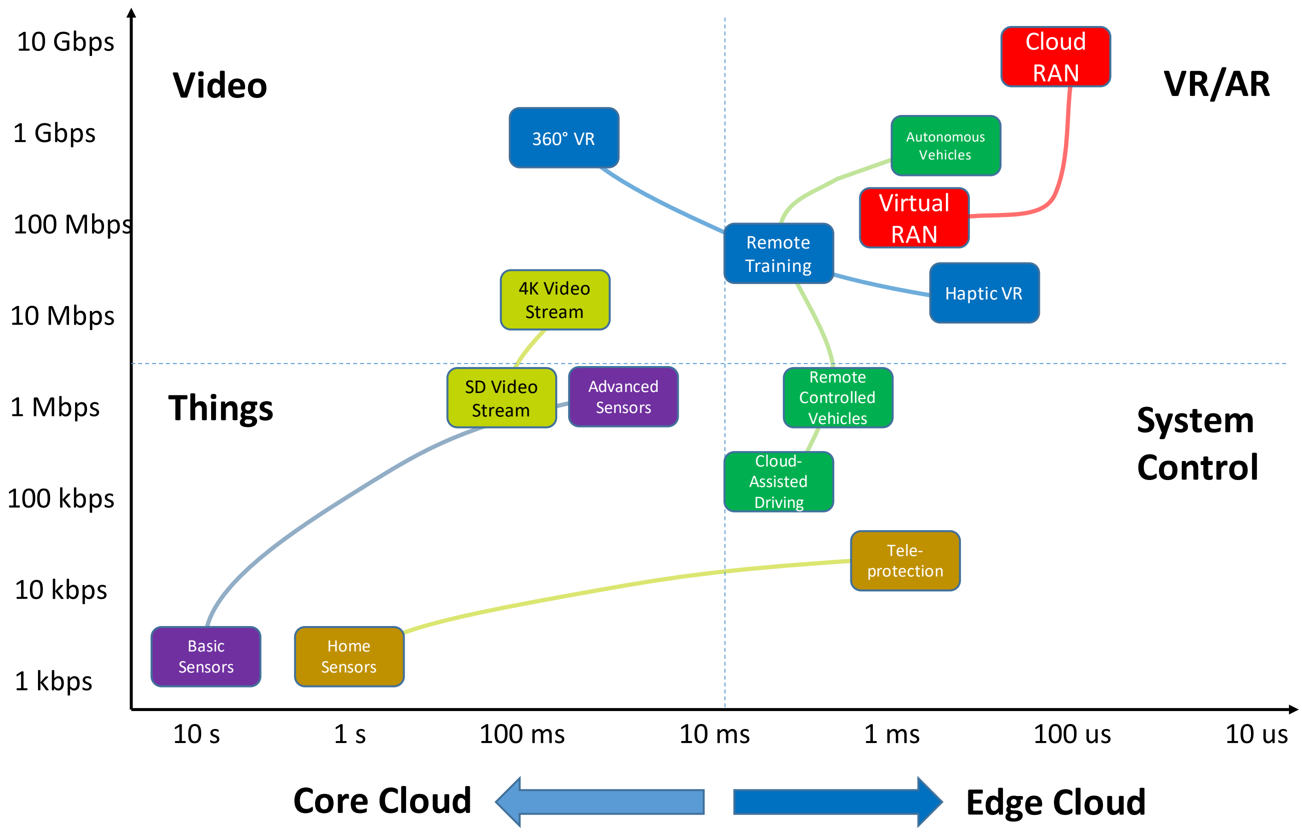

Figure 9 – Application Space for Edge Intelligence[15]

The "AI-Empowered Wireless Network" can be thought of as operating on multiple time scales. The algorithms and data are organized to perform analytics and take actions on the appropriate scale. Applications in the fast time scale, shown in Table 4, are best suited for the edge Intelligence paradigm.

[15] Luoning, G. (2019). "Machine Learning: Driving the Automation of Future Network, Applications, and Services." Presented at IEEE ICC 2019, Shanghai, China.

Table 2 – Time-Scale Groupings for the AI-Empowered Wireless Network

Timeframe	Application
Fast: 1 to 100 ms	Multi-user scheduling
	Link adaptation
	Physical Layer (PHY) optimization (MIMO)
Medium: 100 ms to hours	QoS policy optimization
	Load balancing
	Interference Management: Inter-Cell Interference Coordination (ICIC) and CoMP
	Multi-connectivity, CA
	Mobility management, handover
	Slice resource management, edge computing
Slow: Hours to months	Network planning
	Network configuration optimization
	Energy savings (dynamic cell power-down)
	Cell splitting and merging

The combination of AI/ML with intelligence at the edge has the potential to revolutionize the telecommunications network and enable new and advanced grid use cases. The applications above are primarily focused on wireless technology, but the concepts are equally applicable to the fixed-fiber backbone network.

5G Dynamic Spectrum Sharing

As with prior generational transitions in the cellular industry, true backward compatibility is not possible with 5G NR. Every generation has a unique radio technology designed for exclusive use of the wireless spectrum. Compared to technologies such as Wi-Fi, which is fully backward-compatible to the earliest generation, 5G NR is not compatible with 4G (or prior generations) in the sense that it cannot natively interoperate or coexist in the same spectrum at the same time. 4G-capable smartphones and cellular modems thus contain multiple radios to support 2G, 3G, and 4G. One of the first 5G-capable smartphones, the Samsung Galaxy S10 5G, incorporates radios for 2G, 3G, 4G, and 5G.[16] However, each radio adds to the cost—the S10 5G was priced at $1300 USD when introduced. Beyond device cost, the implications of backward compatibility extend to the network infrastructure, and most importantly, the spectrum. Utilities have recent memories of the disruptive decommissioning of 2G networks by commercial cellular operators, accelerated by the need to convert that spectrum to LTE.

[16] Phone Factor, LLC (2019). "Samsung Galaxy S10 5G," https://www.phonescoop.com/phones/phone.php?p=5965

One key characteristic of the 5G NR is that it requires a minimum channel bandwidth (the amount of contiguous Radio-Frequency [RF] spectrum) of 5 Mhz. For the most commonly used Frequency Division Duplexing (FDD) mode, this means two separate 5 MHz channels for uplink (UL) and downlink (DL), often referred to as 5x5. This contrasts with the 4G LTE radio, which supports channel bandwidths as low as 1.4 MHz. This is a significant difference given the challenges that utilities face in acquiring suitable licensed spectrum for private networks. Many of the licensed spectrum options now used or being considered for utility private LTE networks[17] are limited to 3x3 MHz, with no clear path to expand to the wider bandwidths required for the 5G NR.

Early U.S. deployments of 5G have avoided the need to turn down LTE services in existing bands in order to convert them to 5G. That is possible because these 5G networks are using mmWave spectrum—the frequency range of 24 to 40 GHz—that was recently auctioned by the FCC.[18] Because this is new spectrum for the cellular ecosystem, backward compatibility is not an issue. The mmWave spectrum provides the extremely wide bandwidth that the NR requires to deliver the promise of ultra-high data rates. The downside is that mmWave spectrum is limited to line-of-sight propagation and operates over a short range, which necessitates many more cell sites per unit area, typically achieved with small cells on buildings and poles. This has the practical effect of limiting mmWave 5G deployments to dense urban environments. Recognizing that the future 5G network cannot operate exclusively with mmWave spectrum, the industry is planning to extend 5G NR into mid-band (1-6 GHz) and low-band (below 1 GHz) spectrum through the use of Dynamic Spectrum Sharing (DSS) as illustrated in Figure 10.

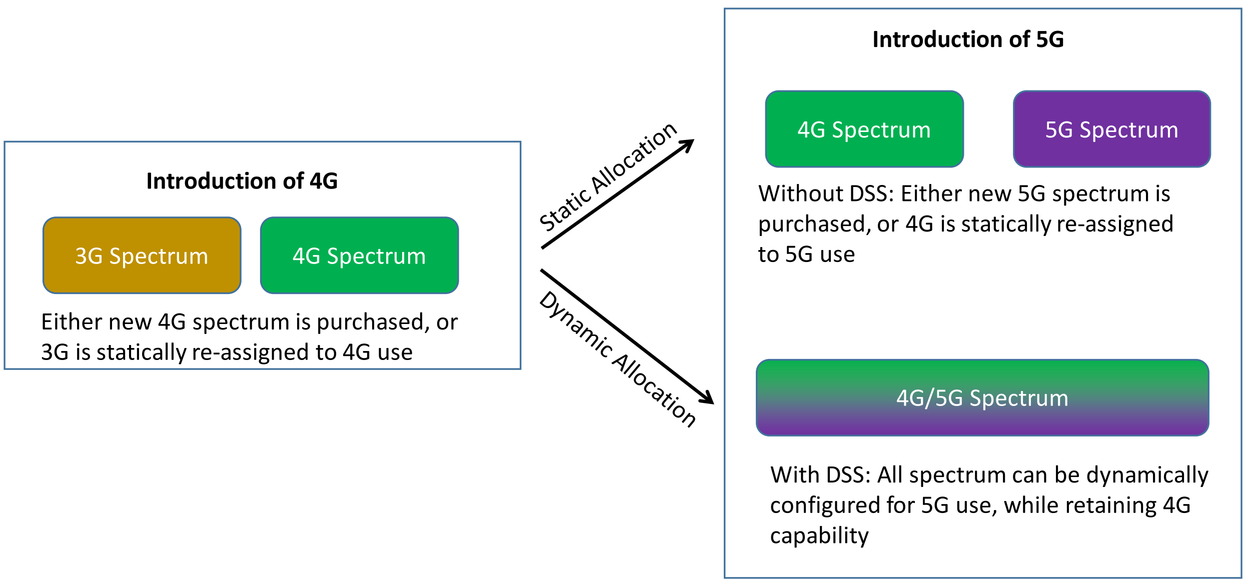

Figure 30 - Dynamic Spectrum Sharing for the 4G to 5G Transition

Rather than dedicating a band of spectrum to 5G, DSS allows instantaneous reallocation of spectrum resources between 4G (LTE) and 5G (NR) operating modes. This allocation can be based on traffic and demand, preserving 4G capacity and service for devices that require it while allowing a smoother migration to 5G as such devices are deployed. The DSS capability must be supported both in the network infrastructure and the device (phone or modem).

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[17] EPRI (2019). *Private Long-Term Evolution Guidebook, First Edition*. Palo Alto, CA: 3002015943.
[18] Dano, M. (2019). "AT&T, Verizon Perpetuate a 5G mmWave Mystery," *Light Reading 5G,* March 5, https://www.lightreading.com/mobile/5g/atandt-verizon-perpetuate-a-5g-mmwave-mystery/d/d-id/749917

The allocation of resource elements (units of spectrum and time) for DSS takes place at a very granular level. The assignable units are Orthogonal Frequency Division Multiple Access (OFDMA) symbols and subcarriers (resource elements), represented by the cells of the matrix in Figure 11. Some resource elements are reserved for fixed purposes for both LTE and 5G. The standards call for these resource elements to exist in the overall signal with a specific pattern in time and frequency. These are shown in magenta and green. The white resource elements are available to be allocated for use by either a 4G LTE signal or a 5G NR signal. Although 5G NR allows new choices for subcarrier spacing, the use of DSS in the network requires that 5G use the same 15 kHz subcarrier spacing as LTE to make this interweaving of standards possible.

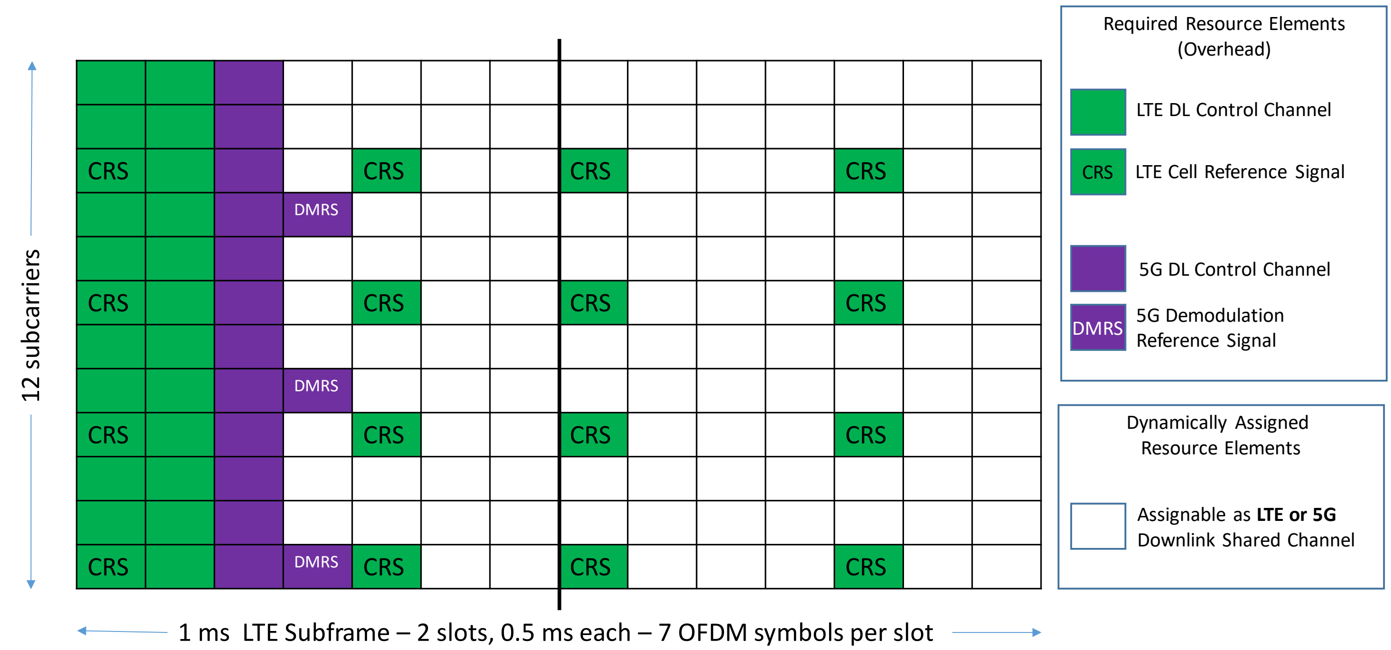

Figure 11 - DSS Granular Assignment of Resource Elements

DSS, currently in testing,[19,20] is not yet supported in commercially available 5G products. T-Mobile, which started offering 5G service in its 600 MHz spectrum in December 2019,[21] will initially have to statically allocate portions of this spectrum for 5G. That spectrum will not be utilized very efficiently, since devices that support 5G in the 600 MHz band are also launching in December 2019. T-Mobile is undoubtedly planning to employ DSS as soon as possible to efficiently serve both 4G and 5G customers. From a global perspective, DSS is expected to increase the pace of 5G availability in mid- and low-bands when 2nd-generation 5G chipsets that support DSS[22] are incorporated into products during 2020.

[19] Kinney, S. (2019). "DSS used on live 5G call between Switzerland, Australia," *RCS Wireless News*, December 3, https://www.rcrwireless.com/20191203/5g/dss-5g-switzerland-australia
[20] Kinney, S. (2019). "Ahead of large-scale deployment, Verizon trials dynamic spectrum sharing," *RCS Wireless News*, November 26, https://www.rcrwireless.com/20191126/5g/verizon-trials-dynamic-spectrum-sharing
[21] Entner, R. (2019). "T-Mobile's roundhouse kicks against rivals," Fierce Wireless, November 11, https://www.fiercewireless.com/wireless/industry-voices-entner-t-mobile-stages-roundhouse-kicks
[22] Qualcomm (2019). "Snapdragon 865 5G Mobile Platform," https://www.qualcomm.com/products/snapdragon-865-5g-mobile-platform

Resilience Week is an annual symposium organized by the U.S. Department of Energy (DOE) Idaho National Laboratory (INL) on the theme of "transforming the resilience of critical infrastructure systems and communities." A longer description of the topic, included in the invitation for Resilience Week 2019,[23] is as follows:

> *Large disasters may ripple across cities, regions, or even nationally through interconnected critical infrastructure systems. Right now, many of those connections are invisible, making it very difficult to put effective mitigation strategies in place. Critical links are often uncovered too late, causing greater impacts to infrastructure and challenging recovery efforts on the ground.*

At the event this year, EPRI participated in a panel presentation on the EPRI-Electricity Subsector Coordinating Council (ESCC) Resilient Communications Working Group Black Sky Emergency Communications Demonstration Project. This opportunity was also leveraged to attend the keynote, academic, and industry sessions with potential relevance to innovation scouting generally and utility telecom specifically. A few of the highlights follow.

Panel: Critical Infrastructure and 6GHz Operations

The topic was a discussion of the potential impacts to utility resiliency associated with FCC's proposal to allow unlicensed devices into the 6 GHz band currently assigned to licensed point-to-point microwave radio use (FCC ET Docket No. 18-295[24]; GN Docket No. 17-183). The diverse panel included a lobbyist for the utility sector, David Hoover (The Ferguson Group, with clients including the Los Angeles Department of Water and Power and NTCA—The Rural Broadband Association); a lobbyist for the tech industry, Paul Caritj (Harris, Wiltshire & Grannis, with clients including Google and Facebook); David Wells from DOE; and Dan Elmore from INL.

The consensus of the panel was that critical infrastructure needs to be protected in the face of this proposal. The most interesting points were raised by DOE's Wells, who divided utilities into urban and rural categories and noted that if interference occurs, rural utilities will not have as many opportunities to move operations onto Commercial Service Provider (CSP) networks. Also, with utilities becoming more dependent on CSPs, the critical interdependencies will increase. DOE's North American Electric Resiliency Model (NAERMS) project is researching that aspect of the problem.

Next, Wells noted that there are over 10 million Wi-Fi routers in the United States, and their use is not something that can easily be monitored and controlled. In an experiment, he found that a 10-year-old needed only 10 minutes to modify a Wi-Fi router and achieve a 50-watt increase in power. To counter the argument that Automatic Frequency Control (AFC) will prevent issues, Wells noted that the U.S. National Telecommunications and Information Administration (NTIA) has found that Dynamic Frequency Selection (DFS) has not prevented interference in the UNII-2 channels in the 5 GHz bands. In addition, Terminal Doppler Weather Radar (TDWR) systems continue to face interference issues. And finally, he said there is a

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[23] INL (2019). "Resilience Week 2019," San Antonio, TX, November 4-7, https://events.inl.gov/Resilience-Week-2019

[24] FCC (2018). "Office of Engineering and Technology Establishes ET No. Docket 18-295," https://www.fcc.gov/document/oet-establishes-et-docket-no-18-295

reason why enforcement alone is insufficient: Simply stated, FCC has continued to shrink its enforcement bureau, with current staffing of 183 down from 616 in 1998.

Communications Track: Communications Resilience Session

Alaa A. R. Alsaeedy of Colorado State University (CSU) presented a very interesting talk on "Survivor-Centric Network Recovery for Search-and-Rescue Operations." The research is centered around the issue of locating survivors after a natural disaster. Since most people now carry cell phones, Search and Rescue Operations (SARO) are greatly improved over the past. However, UE batteries may go dead before rescuers reach the victim, the victim's cell phone may be unreachable from the network, and/or the victim may be unconscious or have injuries that prevent them from using their UE to text or call.

Since SAROs are a race against time, the CSU research team developed a method to enable UEs to become human-based sensors at the scene, even when the cellular network has been destroyed. As illustrated in Figure 12, the proposed solution uses a UAV-hosted SARO base station—an Unmanned Aerial eNodeB (UA-eNB)—that also performs a searching procedure and generates crisis maps of the scene. This approach could have electric utility applications during disaster recovery and other operations.

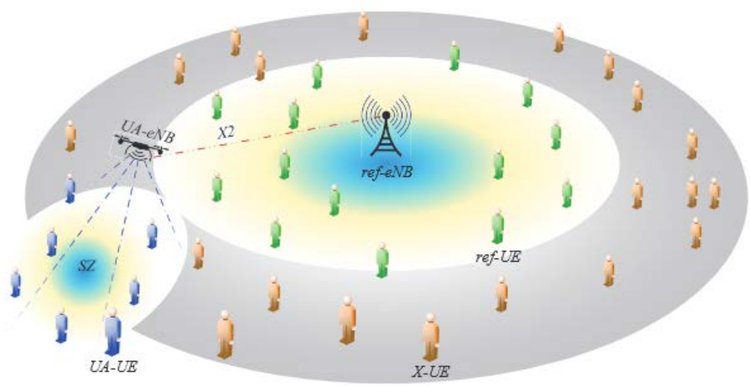

Figure 12 – Illustrative Example of UAV-Hosted Sensing and Mapping System for SARO

Control Special Session: Cyber Physical Resilience in Smart Grids

Anna Scaglione of Arizona State University (ASU), where she is the site lead in the Cyber Resilient Energy Delivery Consortium (CREDC), presented a "holistic" discussion that began with an examination of the five pillars of cyber physical resilience:

- Prevention
- Detection
- Mitigation
- Monitor
- Manage

While much progress has been made in the first three areas, the last two pillars need work. The cyber physical realm could learn from the continuous Industrial Control System (ICS) security management cycle, such as defined in the North American Electric Reliability Corporation (NERC) Critical Infrastructure Protection (CIP) compliance process. An example of successful cyber physical monitoring and detection is found with Phasor Measurement Units (PMU), which provide detailed resolution that enables detection of events, versus Supervisory Control and Data Acquisition (SCADA) systems, which lack such resolution.

But on the topic of resilience, which may be defined as the ability to sail through incidents with minimum costs, the practice of designing the physical infrastructure with redundancy is increasingly acknowledged as no longer adequate. Traditional approaches only provide N-1 security; what is needed are systems that are more modular, redundant, reconfigurable, and responsive. Is the goal a traditional but self-healing grid? Or is the trend towards distributed systems and the Internet of Things (IoT) a positive development?

ASU's Scaglione put forward a radical idea—to design and deploy a parallel, modular, and intelligent infrastructure that provides

- Distributed generation
- Distributed storage
- EV charging
- Broadband wireless
- DC power lines and fiber connecting modules

A diagram was shown that illustrated an endless checkerboard of self-contained yet interconnected modules containing the above elements. Besides improved resiliency, an additional potential benefit is that rural areas could produce surplus energy and provide it to urban areas, while the inclusion of the broadband wireless element could help overcome the "Digital Divide." To illustrate this, a map of the U.S. digital divide was shown, with significant alignment to the territories served by rural electric cooperatives.

Metamaterial-Inspired Networking (MetaNet) for Wireless Devices in Extreme Environments

While this topic was not featured at Resilience Week 2019, a hallway discussion with attendee Zhi Sun of the University at Buffalo provided a status update on technology being developed to support wireless communications from underground devices. MetaNet is based on antennas constructed from "metamaterials" engineered and structured to deliver magnetic coupling properties not found in naturally occurring materials. Experimental prototypes are spherical, 10 cm in diameter, and able to transmit RF through 20 m of earth and achieve Kbps data rates.

Theoretically, Metamaterial-enhanced Magnetic Induction (M2I) can amplify the magnetic signal used in wireless communications by three orders of magnitude. The University of Buffalo research team has achieved 10x amplification in the initial MetaNet prototype and is focused on reaching longer distances under a U.S. National Science Foundation (NSF) award, with target applications for tunnels, pipelines, and other indoor and marine environments.[25] This technology has potentially significant electric utility applications for transmitting data in and out of underground vaults as an improvement on existing commercial technologies such as provided by Ingenu (formerly OnRamp Wireless).

If MetaNet development results in commercialization of M2I antennas, then direct-buried wireless sensors could be deployed along underground transmission and distribution lines to provide fault location, temperature sensing, or other low-data-rate, SCADA-type information. EPRI will continue to monitor R&D progress and evaluate a possible field demonstration with utility collaborators.

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[25] University of Buffalo, "NSF CAREER: Towards Metamaterial-inspired Networking for Wireless Devices in Extreme Environments," http://www.acsu.buffalo.edu/~zhisun/Project_NSF_career.html

Summary and Conclusions

As 5G moves into commercial deployment and utilities look to early applications and approaches for managing the 4G to 5G transition, the R&D community is starting to think about the next steps. Initial goals and concepts for what 6G might look like are being considered, in parallel with exploration of and speculation on the types of applications and use cases that could build demand for 6G. In the meantime, one or more 5G "evolution" stages is likely to be deployed as the international specifications continue to advance. As with the 4G evolution through LTE, LTE-Advanced, and LTE-Advanced-Pro, the cellular industry will introduce marketing terms to help in commercializing evolutionary steps for 5G.

With the 5G rollout under way, utility opportunities are becoming clearer, and the scope of related R&D is expanding. The 5G URLLC capability is still in its infancy and has the most potential for enabling new grid control applications over wireless, including through the use of VLEO satellite and V2X technologies. The use of CoMP may provide further enhancement to the reliability aspect of URLLC, as well as for non-latency critical use cases. DSS is new to the 4G to 5G transition. Dynamic management capability does not solve the spectrum shortage, but it does go a long way toward reducing the challenge of migrating to 5G technology with a minimum impact on existing 4G users and devices. Novel approaches are being developed for increasing infrastructure resiliency, managing critical operational communications links in the 6 GHz microwave band, enabling underground wireless communications, and meeting other needs.

The application of AI and ML to the wireless network is possibly the most impactful anticipated development. As utility telecom systems continue to expand in scope and complexity, planning, operation, and optimization become increasingly burdensome for engineers and operators. The network itself generates vast amounts of data on traffic flow, RF signal conditions, and other sensor and monitoring information. This massive and rapidly growing data set is well-suited for the development of ML algorithms and use of other AI techniques to manage, control, and optimize network operations.

Index to Previous Newsletters

Issue	Publication Date	EPRI Product ID and Link	Topics
11	October 2019	(3002014754)	2018 IEEE SmartGridComm, 2019 Mobile World Congress, 3GPP 5G Standardization Roadmap
10	December 2018	(3002014753)	2018 IEEE International Communications Conference (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

Glossary of Acronyms

1G - 6G	1st, 2nd, 3rd, 4th, 5th, 6th Generation
3GPP	3rd Generation Partnership Project
AFC	Automatic Frequency Control
AI	Artificial Intelligence
AR	Augmented Reality
ASU	Arizona State University
CA	Carrier Aggregation
CIP	Critical Infrastructure Protection
CoMP	Coordinated MultiPoint
CREDC	Cyber Resilient Energy Delivery Consortium (at ASU)
CRS	Cell-Specific Reference Signal
CSP	Commercial Service Provider
CSU	Colorado State University
C-V2X	Cellular Vehicle to X (anything)
D2D	Device to Device
dB	Decibels

DC	Direct Current
DFS	Dynamic Frequency Selection
DL	Downlink
DMRS	Demodulation Reference Signal
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
ESCC	Electricity Subsector Coordinating Council
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)
ICIC	Inter-Cell Interference Coordination
ICS	Industrial Control System
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
INL	Idaho National Laboratory
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 re-branding for beyond mobile)
MetaNet	Metamaterial-Inspired Networking
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
NAERMS	North American Electric Resiliency Model
NB-IoT	Narrow Band IoT
NERC	North American Electric Reliability Corporation
NOPR	Notice of Proposed Rule Making
NR	New Radio
NSF	U.S. National Science Foundation
NTIA	U.S. National Telecommunications and Information Administration
NTN	Non-Terrestrial Networks
OFDMA	Orthogonal Frequency Division Multiple Access
OpenFMB	Open Field Message Bus
OSI	Open Systems Interconnection
OTT	Over-the-Top
PC5	3GPP D2D or SideLink protocol
PHY	Physical Layer
PMU	Phasor Measurement Unit
ProSe	Proximity Services
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
RF	Radio-Frequency
s	Seconds
SA	Standalone
SARO	Search and Rescue Operations
SCADA	Supervisory Control and Data Acquisition
Tbps	Terabits per second
TDWR	Terminal Doppler Weather Radar
UA-eNB	Unmanned Aerial base station

UAV	Unmanned Aerial Vehicle
UE	User Equipment
UL	Uplink
URLLC	Ultra-Reliable and Low Latency Communications
USD	U.S. Dollars
V2X	Vehicle to Anything
VLEO	Very Low Earth Orbit
VR	Virtual Reality

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