Technical Preparation Needed for 5G Infrastructure Deployments

WIA Innovation & Technology Council

4/18/2018

Content

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Abstract

The introduction of fifth-generation (5G) mobile broadband technology is set to change how people and machines communicate and even how industries do business. 5G network deployments are expected to provide significant economic and efficiency gains in the markets where they are deployed. Smart-factory and smart-city applications, autonomous vehicles and machines, and telemedicine applications are just a few of the examples where 5G technology is expected to impact a range of industries. Work is underway to define specifications and performance requirements for 5G to ensure the networks can support the many applications expected to run on them. Massive investments are needed to upgrade and deploy new infrastructure, including macrocellular equipment, small cells and fiber, that will deliver the services promised with 5G. Stakeholders also are working to develop security and privacy guidelines designed to protect increasingly sensitive applications that will operate on 5G networks. This report will explore the technical preparations that are taking place to bring 5G networks to market, and defines technical terms needed to understand the technology.

Introduction

Fifth-generation mobile broadband technology solutions are expected to revolutionize communications and industries throughout the globe once they are deployed. 5G is expected to transform the economy as profoundly as the printing press, steam engine, telegraph, electricity, and the Internet. Further, 5G technology will enable a significant increase in productivity and Gross Domestic Product (GDP), according to IHS Economics & IHS Technology in its report, "The 5G economy: How 5G technology will contribute to the global economy."[1]

Wireless Service Providers (WSPs) and Original Equipment Manufacturers (OEMs) are testing various technologies to move beyond today's fourth-generation (4G) LTE technology to 5G technologies that can handle much more data moving across their networks. The International Telecommunications Union (ITU) – the United Nations agency that develops technical standards so networks and technologies can seamlessly connect worldwide – is working to define 5G standards.[2] Meanwhile, wireless operators and their partners are testing pre-protocol solutions. AT&T and Verizon have fixed-wireless 5G trials underway in the United States, while T-Mobile USA announced plans to build its own 5G network by 2020, in part using its newly acquired 600 MHz spectrum.[3]

Support infrastructure will be needed to deploy a much higher-density network structure, not only in the radio-frequency (RF) layer, but also in terms of backhaul and power delivery at transmission points. Security and identification management protocols – which are expected to be dramatically different in the 5G environment – will have to be developed. Businesses using 5G to automate their production lines, for example, or deliver telemedicine, need assurance that the network is secure and cannot be breached.

The Economic Impact of 5G Deployments

Much like the deployment of 4G LTE wireless networks led to a mobile-first mentality among consumers and businesses, 5G deployments are expected to transform industries and communications and have an immense economic impact across the world.

With 5G standards still under development, analysts, researchers and other visionaries are just beginning to dip their toes into the pool of economic prognostication regarding 5G and its potential economic impacts. While pundits have slightly different takes on how 5G will roll out, there is consensus on use cases, phases of implementation, and market uptake. At this point, all indications are that 5G will move more quickly than previously anticipated. Early in 2017, the industry agreed, through its 3GPP standards body, to complete the non-standalone (NSA) implementation of 5G New Radio (NR) by December 2017, which paved the way for large-scale trials and deployments based on the specification starting in 2019 instead of 2020, according to a *Fierce Wireless* report.[4] Other standards are in the process of being written.

Until those standards are set and commercial versions of 5G are available, manufacturers are working to add 5G capabilities to 4G LTE through increased carrier aggregation, massive Multiple Input Multiple Output (MIMO) antenna technology, and sharing licensed and unlicensed spectrum, both to prove these concepts in practice and to allow operators to take advantage of higher throughputs and lower latencies than LTE and LTE-A currently offer.[5] AT&T and Verizon have announced deployment of pre-standard, fixed 5G service during 2017 with meaningful pre-standard 5G deployment by Verizon in 2018.[6,7] T-Mobile announced plans to roll out 5G services nationwide, as well.

The immediate use case for 5G will be enhancement to fixed broadband service and mobile broadband with higher speeds and lower cost per megabit for in-building and outdoor coverage, enterprise/teamwork collaboration, and augmented/virtual reality (AR/AV).   As service rolls out, Machine-to Machine (M2M), Massive Internet of Things (MIoT), and Mission Critical Services (MCS) will take on an increasing share of 5G services and increasing importance to the economy.[8]

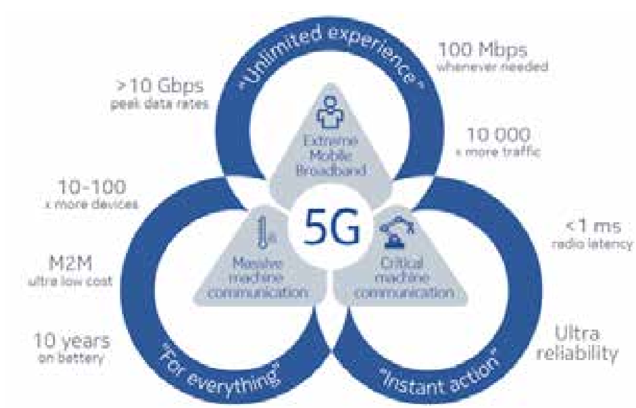
Many industry experts believe that as 5G is adopted, it will cause a paradigm shift, sometimes referred to as the “Mobile Industrial Revolution,” a “Fourth Industrial Revolution,” or “Industry 4.0.”[9] 5G will create the crucial communications links needed to connect billions of smart devices to the Massive Internet of Things to produce major productivity enhancements across industries and governments. 5G will also expand into a new area of Mission Critical Services that will require high reliability, ultra-low latency, strong security and availability. Use cases include industrial automation (smart factories) using sensors, inventory controls, and robots; urban infrastructure monitoring and management (smart cities); utility monitoring, metering, and control (smart grid); autonomous vehicles including cars, trucks, construction equipment, mining equipment, buses, and trains; agricultural automation including self-driving tractors and soil sensors that manage irrigation and alert the farmer when to harvest; autonomous drones for video inspections, surveillance, and product delivery; and remote patient monitoring (telemedicine).[10]

Predictions of the economic impact of 5G are listed in Table 1:

					ECONOMIC BENEFIT	
SOURCE	AREA	TIME HORIZON	DESCRIPTION	JOBS	LOCAL CURRENCY	$US
O2[11]	UK	2026	5G Infrastructure per year		£7B	$8.7B
			Supply Chain per year		3B	3.7B
			Total per year		£10B	$12.4B
O2[12]	Global	N/A	Investment		€200B	$214B
			GDP		€3.5T	$3.7T
			Jobs	200M		
EU[13]	EU	2025	Socio-economic benefits per year		€113B	$121B
ABI Research[14]	Global	2025	Service Revenue per year			$247B
Electric Power Research Institute[15]	US	N/A	SmartGrid: additive revenue to US economy per year			$1.8T
			Savings to average consumer per year			$100s

5G Technical Performance Requirements

In February 2017, the ITU's Radio Communications unit (ITU-R) issued a document outlining minimum technical performance requirements to achieve a consistent definition, specification, and evaluation of the candidate IMT-2020 radio interface technologies (RITs)/ Set of radio interface technologies (SRIT).[16] Recommendation ITU-R M.2083 defines eight key capabilities for IMT-2020, which form a basis for the technical performance requirements:



Ilustration courtesy of Nokia

- **Peak data rate** - The minimum requirements for peak data rate are as follows:
    - Downlink peak data rate is 20 Gigabits per second (Gbps)
    - Uplink peak data rate is 10 Gbps

- **Peak spectral efficiency** - The minimum requirements for peak spectral efficiencies are as follows:
  - Downlink peak spectral efficiency is 30 bits per second per Hertz (bit/s/Hz)
  - Uplink peak spectral efficiency is 15 bit/s/Hz
- **User experienced data rate** - The target values for the user experienced data rate are as follows in the Dense Urban – enhanced Mobile Broadband (eMBB) test environment:
  - Downlink user experienced data rate is 100 Megabits per second (Mbps)
  - Uplink user experienced data rate is 50 Mbps

Average spectral efficiency – The minimum requirements for average spectral efficiency for various test environments are summarized on the following table (both downlink and uplinks are expressed in bits per second per Hertz per transmission reception point):

Table 2: Minimum Requirements for 5G

TEST ENVIRONMENT	DOWNLINK (BIT/S/HZ/TRXP)	UPLINK (BIT/S/HZ/TRXP)
Indoor Hotspot – eMBB	9	6.75
Dense Urban – eMBB	7.8	5.4
Rural – eMBB	3.3	1.6

- **Area traffic capacity** - The target value for Area traffic capacity in downlink is 10 Megabits per second per square meter (Mbit/s/m2) in the Indoor Hotspot – eMBB test environment;
- **User plane latency** - The minimum requirements for user plane latency are 4 milliseconds (ms) for eMBB and 1 ms for ultra-reliable, low-latency communications (URLLC);
- **Control plane latency** - The minimum requirement for control plane latency is 20 ms. Proponents are encouraged to consider lower control plane latency, e.g. 10 ms;
- **Connection density** - The minimum requirement for connection density is 1 million devices per square kilometer;
- **Reliability** - The minimum requirement for the reliability is $1\text{-}10^{-5}$ success probability of transmitting a layer 2 Protocol Data Unit (PDU) of 32 bytes within 1 ms in channel quality of coverage edge for the Urban Macro-URLLC test environment, assuming small application data (e.g. 20 bytes application data plus protocol overhead);

- **Mobility** - Mobility is the maximum mobile station speed at which a defined Quality of Service (QoS) can be achieved in kilometers per hour (km/h). The following classes of mobility are defined: Stationary: 0 km/h; Pedestrian: 0 km/h to 10 km/h; Vehicular: 10 km/h to 120 km/h; High speed vehicular: 120 km/h to 500 km/h;

- **Bandwidth** - The requirement for bandwidth is at least 100 megahertz. The RIT/SRIT shall support bandwidths up to 1 gigahertz for operation in higher frequency bands (e.g. above 6 GHz).

Infrastructure Requirements

The 5G work in 3GPP is well underway and focused on both new Radio Access Network (RAN) technologies and new System Architecture (SA) aspects. The studies on new RAN technologies for 5G are called New Radio in the 3GPP RAN working groups and are focused on defining a new radio access method flexible enough to support a much wider range of frequency bands. Given the wide range of frequencies, it is expected that Orthogonal Frequency Division Multiplexing (OFDM) will be the basis for the 5G New Radio air interface. New technologies and techniques are also being investigated, such as coding, MIMO and beamforming. In addition, the System Architecture groups in 3GPP have been studying the use cases and enablers that will drive the next-generation architecture. Key issues that need to be addressed in the 5G network architecture include Network Slicing, Mobility and Session Management, Security, Quality of Service, and more.

A large part of the planning in 3GPP for Release 14, Release 15 and Release 16 is related to next-generation system architecture for mobile networks. There are many issues that the next-generation system architecture must address, including the support of new Radio Access Technologies (RATs) defined by 3GPP RAN, the integration and or interworking with Evolved Universal Terrestrial Radio Access (E-UTRA), and plans for support of non-3GPP accesses. Evolution of the current E-UTRA architecture as well as clean-slate approaches will be studied.

Backhaul

Operators' networks are already under severe strain from the sheer volume of 4G traffic. This trend will only accelerate in the 5G era. Cisco, for example, believes that by 2021, the global population will be using more mobile phones (5.5 billion) than bank accounts (5.4 billion) or landline phones (2.9 billion.)[17] Although revenues created by the masses of low-cost devices will be attractive, they are unlikely to justify investment for wholly new 5G networks. The industry therefore must embrace more flexible, scalable and cost-effective backhaul. Today's backhaul infrastructure, which is often wireline (Gigabit Ethernet, traditional T1 lines and coaxial cable connectivity) is not adequate for 5G heterogeneous networks.

More fiber is certainly part of this solution, as is wireless backhaul. Wireless backhaul shows promise, but is still under development, and it must become more cost efficient, especially compared to fiber deployments. In order to use microwave-based backhaul at the macrocellular network, improvements will need to be made to microwave equipment so it can deliver new modulations, multi-channel support, bulk-compression technologies and wider frequency bands. In particular, industry is considering using E-band spectrum for mobile backhaul. The E-band is regulated globally and not widely used so it could be more cost-effective for operators as well. However, it still has limitations on how it can be used over longer distances.

One technology growing in popularity is licensed point-to-multipoint (PMP). With licensed PMP, an operator has guaranteed Quality of Service and the ability to build a 14.4 Gigabits per second (Gbps) hub site that aggregates backhaul traffic from multiple base stations. Because the number of base stations is likely to increase with 5G, the business case for licensed PMP will appeal to more operators because PMP becomes more profitable as more base stations connect to a single hub.

Another key component of the 5G architecture is outdoor small cells. **ABI Research recently predicted** a 43-percent compound annual growth rate from today through 2020, highlighting that momentum may start to build.[18] This momentum will only be compounded by 5G, where outdoor small cells will play an important role in providing capacity for traffic hot spots or those locations that suffer from limited or no coverage.

Fronthaul

For 5G networks to sustain more capacity, network flexibility and scalability, the connection between baseband and radio elements – known as fronthaul – will be highly impacted. Common Public Radio Interface (CPRI) has been the de facto standard for point-to-point fronthaul transport for macro base stations, but its bandwidth and flexibility limitations are driving standards groups to rethink this critical connectivity interface. Companies like Ericsson, Huawei, NEC and Nokia released a new eCPRI specification that supports increased efficiency. Meanwhile, the companies said work continues to further develop the existing CPRI specification.[19]

Contributing Technologies

A variety of technological pieces will form the foundations of IMT-2020. Nearly every component between source equipment and user equipment (UE) will undergo dramatic change. For purposes of brevity, they are mentioned below at a high level.

Portions of the Radio Access Network changes are still contingent upon several standards. RAN and user equipment hardware and software must be designed and produced to these standards initially, and with the consideration of forward compatibility. A waveform standard is a key piece of the puzzle that is pending. Another is available spectrum and its potential uses. Centimeter Wave and Millimeter Wave wavelengths could be used for RAN and/or backhaul delivery.

However, some other areas are ready today or soon will be. The theory of Massive MIMO use for increased spectral efficiency is tried and true, and in use in some circumstances. Shared spectrum access is ready for market when standards are set. Coordinated MultiPoint and scheduled advances in LTE Releases 8, 11 and 12, and all the other features included in future LTE-A releases, device-to-device communication and other necessary technologies are ready for use in the 5G environment.

One of these, Multi-RAT technology, has been used in previous generations and functions overlap heavily between the Core and RAN network layers. However, the current common use of a single plane for control and user interfaces make Multi-RAT utilization in the 5G environment difficult. Slicing — separating the user and control planes — to make 5G, LTE, 3G and Wi-Fi connectivity simultaneous and seamless is a daunting challenge for both the Core and RAN layers.

Other Core Network considerations for 5G are as diverse and numerous as the RAN considerations, but differentiated by the fact that they are less developed today. Core-to-edge networks must be smarter, more robust and capable of scaling at levels that today's technology cannot accommodate.

Flexible Software Defined Networks (SDNs) that use OpenFlow switching, which manages packet forwarding, are a basis for 5G network needs, but higher order SDN control will need to manage network interfaces in the 5G environment. These smarter Core Networks, which are more cost-effective than traditional networks, will use Network Function Virtualization (NFV) at higher levels, which also must be more developed for 5G. Both SDN and NFV must be more developed to deal with Centralized RAN (C-RAN), Digitalized RAN (D-RAN) and Virtualized RAN (V-RAN) as well as all other various heterogeneous network mediums and architectures.

Security, Access, Authentication and Privacy Issues

Security and identification management protocols will be dramatically different in the 5G environment. Examples such as e-health, industrial and transportation connectivity and trust certification in third-party applications are but a few examples of why security concerns must be addressed.

The evolution of wireless network security between the 2G and 3G environments was dramatic, with the introduction of SIM technology, encryption and randomly assigned keys. The changes in security and identification protocols between 3G and 4G platforms were less dramatic, mostly involving improvement in those tools, which included bringing data encryption to the base stations and more robust and comprehensive key management.

Security and access in 5G will be differentiated further by devices that are not in human hands. Automated devices for a variety of uses will need to access networks and be validated automatically. Many more of these automated pieces of equipment will operate with third-party applications than occur on the 4G network. This presents an additional layer of security and authentication consideration.

A major component in this discussion must be an appropriate working balance between security and privacy, areas that often work at cross purposes. Validating the identification of a device without compromising user privacy is a difficult balance. Even today, the use of metadata and location data have been considered to compromise privacy.

Moral and legal implications aside, allowing more unmanned devices in the IoT and commercial/industrial/social arenas presents a legitimate security risk, not just in terms of the volume of devices that must be managed, but the way they are managed and how the management of this information is controlled or disseminated.

"Trojan Horses" and other malware have been incorporated into third-party applications and used for unethical purposes in 4G devices. Detecting these and dealing with them has proven problematic. A greater number of devices, both manned and unmanned, and a greater number of third-party applications proliferating in the environment, will make managing security even more difficult.

These threats can be mitigated in 5G networks with separation between hardware and software validation and authentication, something that is not always the case in 4G devices. Hacking a device or its applications with a user name and password is still occurring with alarming frequency.

Noting concerns about security, the 3GPP SA3 is working to define specifics around 5G's security architecture. Industry must consider adopting additional models that support slicing and separating network authorization and access from user authorization and access. A possible solution would be the adoption of a global, open-source public permissioned distributed ledger (blockchain) that manages the user's independent identity from the network identity and therefore allows industry to resolve problems of user trust and restore privacy where network systems that combine both user and network access together have failed.

Doing all these things while protecting personal and commercial data is the crux of the challenge. Use of dummy/rogue base stations to hack mobile devices has been documented and occurred despite International Mobile Subscriber Identity (IMSI) protection. More is needed than device authentication alone. 5G user equipment must be able to screen inbound access requests individually more than they do now, and inbound access requests must be more exclusive than inclusive. Network identification encryption improvement would be helpful.

Equally important is that both devices and networks become more self-aware. When abnormal activities are exhibited by either, they should be intelligent enough to stop the theft of data, track the source of the attack, and do so without humans compromising the data itself. Slicing will undoubtedly be a cornerstone for this. Customizing the security for different functions and content will afford a greater level of both security and privacy.

Conclusion

The rollout of 5G technologies and the services that will traverse this infrastructure will transform many industries across the globe. Given its importance to the world economy, the companies working to bring this vision into reality must get it right. Greater cooperation between the various sectors and consortiums on RAN and core network technologies must occur. Specifics must be agreed upon soon so standardization can be achieved rapidly. Security and privacy issues must be addressed in new ways as more devices touch more networks. Getting from the vision of 5G global deployments to that reality will require new ways of handling the radio access network, core networks and encompassing support technologies.

Terms

Carrier Aggregation: The combination of several LTE carriers to allow increased peak user data rates and overall capacity.

Massive MIMO: An extension of MIMO that groups antennas at the transmitter and receiver to provide better throughput and improved spectrum efficiency.

Spectrum sharing: Simultaneous usage of a radiofrequency band in a specific geographical area by a number of independent entities.

OFDM: A signal modulation technique that divides a single data stream into several separate narrowband channels at different frequencies to reduce interference.

Network Slicing: A virtualization technique that allows multiple logical networks to run on a shared physical network infrastructure.

Mobility Management: A network function that tracks physical user and subscriber locations.

Quality of Service: A network's ability to achieve maximum bandwidth and deal with latency, error rate and uptime.

Point to Multipoint: A topology wherein a single central transmitter communicates with multiple receivers.

Multiple Radio Access Technology: allows a mobile device to connect to more than one type of cellular network.

About the Authors

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Don Bach is a seasoned telecom executive who has spent the last three decades engineering cellular networks. He currently serves as the director of sales engineering for Boingo Wireless' DAS and small cell business, where he is responsible for overseeing the RF design of the company's cellular networks at large public venues around the world. He previously held leadership positions at Verticom and SAC Wireless. Bach's early career began as a technician in the public safety and LMR two-way radio industry, after he graduated from the Electrical Engineering program at DeVry University in 1986. In 1994, he became a system performance engineer on the iDEN Network by Fleet Call, which was later renamed Nextel. He spent 22 years in a variety of RF engineering positions at Nextel, which was acquired by Sprint in 2004. In 2007, Bach left Sprint to start a regional RF Engineering and implementation company focused on DAS networks. In 2012, he sold the company to SAC Wireless. SAC Wireless was purchased in 2014 by Nokia Networks.

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Joe Mullin oversees all DAS projects for InSite Wireless. He has more than 25 years of experience designing and deploying wireless networks, including expertise developing specialized in-building coverage solutions for medical, industrial, and entertainment venues throughout the U.S. Previously, Mr. Mullin was Vice President of Engineering for Arch Wireless, where he was responsible for network design, facility management, and regulatory compliance. Mr. Mullin also has developed and marketed wireless network products with Glenayre Electronics and Harris RF Communications. He managed construction projects for the U.S. Army Corps of Engineers in the U.S. and Europe. Mr. Mullin holds a B.S. in Civil Engineering from Worcester Polytechnic Institute and an MBA from Boston University. He is a Registered Professional Engineer and is a member of the IEEE and the Radio Club of America

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Endnotes

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