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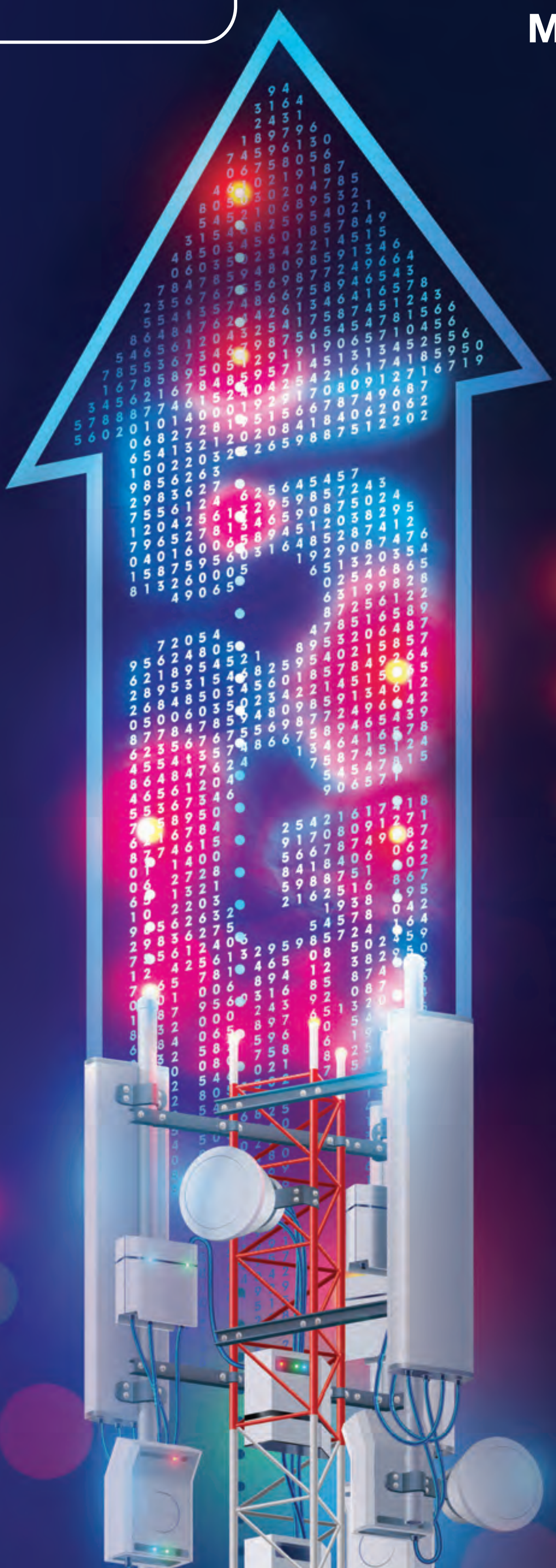
Methods

Mouser's technology & solutions eZine



THE FUTURE WITH 5G

In this issue

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Foreword: 5G Issue

By Jean-Pierre Bienaimé, Chairman, Institute of Economic & Social Research on Telecommunications (IREST)

The Fifth-Generation New Radio (5G NR) specification and its networking component, 5G Core, represent a new generation of communications that, like previous generations, does not entirely replace its predecessors. That said, it does make entirely new services possible and opens the door to a new, disruptive ecosystem. Operators who deploy 5G networks will continue to offer existing network services, but they will also be able to offer transformative new services in three main areas:

- **New consumer services made possible by enhanced mobile broadband (eMBB).** The first wave of 5G deployments will provide eMBB networks to enable enriched consumer services including high-performance communications, virtual reality (VR) and augmented reality (AR), home automation, high-speed Internet access, along with ultra-high definition (UHD) and streaming video. Initial deployments will occur in high-density areas where fourth-generation (4G) wireless is already congested.
- **Fixed wireless Internet access for broader coverage.** High-frequency bands in the 26- to 28-gigahertz (GHz) range make antenna miniaturization possible. Miniaturization, in turn, facilitates more advanced, adaptive multiple-input, multiple-output (MIMO) arrays that control the form and direction of radio transmissions, giving these high bands longer range and better coverage with less interference. The result is a wireless alternative to cable and fiber connections to homes and the delivery of high-bandwidth services to rural areas where fiber is unavailable.
- **New industrial services made possible by the 5G network architecture.** 5G Core enables virtualization and network slicing, which will be the foundation of new industry-specific services. These new services could be network services unique to vertical industries, distant medical services and surgery, utilities, or specific use cases such as robotic communications or communications for autonomous vehicles (AVs). Network slicing makes it possible to adapt virtual networks and mobile connectivity to usage needs and specific applications.

Technical aspects of the 5G specification must be realized during these early deployment and trial phases currently underway. However, a lot of the new design opportunities will come from the potential for new kinds of industrial applications that 5G network slicing and virtualization make possible. With network slicing, a service provider or network operator will be able to quickly deploy dedicated logical networks with performance and security characteristics tailored to fit specific applications and use cases. These logical network slices will span various technology and administrative domains including management and orchestration functions. A key area of 5G related engineering will involve orchestration of technologies and functions to provide "customer-facing" on-demand services that fulfill specific business needs across various industries.

"5G Core enables virtualization and network slicing, which will be the foundation of new industry-specific services."

This flexibility opens the door to innovations not possible with previous monolithic network architectures, and many are working to explore those innovations. For instance, the 5G Infrastructure Public Private Partnership (5G PPP) is a joint initiative between the European Commission and the telecommunications industry to develop new programs, partnerships, and markets in many areas including smart cities, e-health, intelligent transport, education, media, factories of the future, and others that will use smart network services and other aggregated features such as artificial intelligence (AI).

Many issues and challenges still need resolutions. For instance, the 3rd Generation Partnership Project (3GPP) Release 16 and subsequent releases will discuss in greater detail 5G vertical industry specifications, vehicle-to-everything (V2X) communications standards, and technical standards relevant to several other areas. In addition, much work still exists to achieve spectrum harmonization through regional and country-by-country spectrum allocations as well as handoff processes between regions. Important aspects in rolling out these processes include early deployments, trials, and pilot programs. Many regions in the world, including the United States and the European Union (EU), are actively engaged in 5G Phase 1 deployments of eMBB networks. Similarly, many industry- and infrastructure-specific trial programs are taking place. For example, there were 63 5G trials in 38 cities at the end of 2018 in the EU, and the number is rapidly growing. These pilots cover various programs involving health and public safety, automotive communications, energy, smart cities, industrial operations, and more. There are also eight corridors alongside highways in Europe that are testing connectivity.

2019 is the year in which 5G Phase 1 deployments of eMBB have begun. Although Phase 1 is a major step, it is important not to stop there, because the real transformations will come with 5G Phase 2, which will be complete by the end of March 2020 and include successive releases of 3GPP specifications along with the buildout of the 5G ecosystem. Continuous piloting along with commercial validation over the next several years will result in full commercial deployments capable of delivering industry-changing and disruptive 5G services.

Jean-Pierre Bienaimé is the Chairman of the Economic and Social Research Institute on Telecommunications (IREST), a think tank of influence based in Paris. He has been Secretary General of the 5G Infrastructure Association (5G-IA) since 2016, representing the digital and telecommunications industry (including operators, manufacturers, research and academic institutes, verticals, and subject matter experts) in the 5G Infrastructure Public Private Partnership (5G PPP) along with the European Commission. He has also been Chairman of the 5G PPP Steering Board.

Jean-Pierre was Chairman of the mobile industry association for The UMTS Forum from 2003 until 2016, with a mission to promote a common vision of the development of 3G UMTS, 4G LTE, and the corresponding evolutions to ensure their worldwide commercial success.

Joining France Telecom (FT) in 1979, Bienaimé has held responsibilities as the Director of the Planning Department at FT, Advisor to the Director General of Moroccan Telecommunications in Rabat, Director of Marketing and Product Development for International Networks and Services at FT, Chief Executive Officer of Nexus International, and Vice-President of Group Mobile Support at Orange. From 2010 until 2016, Jean-Pierre also served as Senior Vice-President at Orange Wholesale.

Jean-Pierre graduated from the ESSEC Business School with a master in management, from Sciences-Po (Paris), from Ecole Nationale Supérieure des Postes and Télécommunications (Paris), and from INSEAD with an Executive MBA.

A Forward Glance at 5G: Applying Backwards Thinking

By Paul Golata for Mouser Electronics

Paul Golata joined Mouser Electronics in 2011. He provides design engineers with the latest information and trends in electrical engineering by delivering unique and valuable technical content that facilitates and enhances Mouser Electronics as the preferred distributor of choice.

Connecting in the Future

It was the technology visionary Steve Jobs (1955–2011) who expanded the Danish philosopher Søren Kierkegaard's (1813–1855) philosophical quote which originally said, "Life can only be understood backwards; but it must be lived forwards." Steve applied this notion to technology saying, "You cannot connect the dots looking forward; you can only connect them looking backwards. So you have to trust that the dots will somehow connect in your future."

Well, the dots of our future are certainly going to be more connected. How they are connected requires backward thinking.

Fifth-Generation (5G) wireless technology is ensuring that mobile networks of our future will connect us all. One might say that our future is one of hyper-connectivity in which machines, computers, robots, and people will all interface together.

This article will take a quick glance at the transformational leap that innovative 5G technology is enabling towards superfast communications, and how Mouser's key electronic component suppliers are supporting this effort. As engineers, it's time to put on our thinking caps, turn them backwards, and look at how our wireless communication infrastructure requires higher performance in order to meet the needs of tomorrow.

The Race is On

Being the first to market presents exciting opportunities for businesses. Key network service providers, mobile phone manufacturers, and component manufacturers recognize the necessity to be involved early. Service providers, including Verizon and AT&T, have recently made announcements indicating that they are starting to support 5G services in select cities. In place are additional plans to continue the roll out to new cities on a regular basis every month. T-Mobile and Sprint will be following closely behind.
Mobile phone manufacturers, including Motorola and Samsung, are now offering hardware devices that are set to comply with coming 5G capabilities. Telecommunication equipment providers are adapting their products to meet the coming requirements. It will be prudent later to look at how electronic component manufacturers are addressing the changing competitive landscape.

One item requiring tremendous focus is the move from fixed wireless access to 5G mobile non-standalone (NSA) and 5G mobile standalone (SA). NSA will employ 5G mobile built upon a 4G Long-Term Evolution (LTE) core, while SA will receive support from the 5G specific core.

The Road Forward to 5G

5G is the natural evolution forward from the presently employed 4G technology. It offers the conceivable potential to handle and administrate three orders of magnitude (10^3 = 1,000x) more data and information than current technology. This not only represents wireless connections with evolutionary increases but an entirely new level of near-instantaneous connectivity.

While 3G provided users with accessible mobile access to the World Wide Web, 4G has allowed users to be connected socially. However, 5G's new level of connectivity will enable applications that change the way we live, work, and relax. It will bring forward the dynamic power of the Internet of Things (IoT). This technological revolution will revolve around the wireless infrastructure that will enable new applications such as autonomous vehicles that are capable of driving and navigating obstacles without issues. Industry will change by way of the Industrial Internet of Things (IIoT), in which robots and industrial automation will be taken to new levels. Work and leisure will change to the ability to employ exciting applications such as augmented reality (AR), mixed reality (MR), virtual reality (VR), and extended reality (XR).

A key to 5G is the group of standards already in place to ensure that this new infrastructure is secure, robust, and highly efficient. The 3rd Generation Partnership Project (3GPP™) organization works to guarantee the effectiveness of these standards. Technical Specification Groups (TSGs) within 3GPP work on issues related to Radio Access Networks (RANs), Service and System Aspects, and Core Network and Terminals (CT). 5G New Radio (NR) specifications are a development that rolled out in late 2017. 5G Phase 1 correlates with Release 15, which is currently in play. In parallel with Release 15, yet fully rolling out at a later date, is Release 16, which will bring into reality 5G Phase 2 (**Figure 1**).

5G Facts

Let's now look at some of the specific technical ways that 5G will propel connections forward.

Device Connections

5G's ultra-wideband capabilities will enhance mobile broadband. It will allow a massively larger amount of devices to connect to the Internet

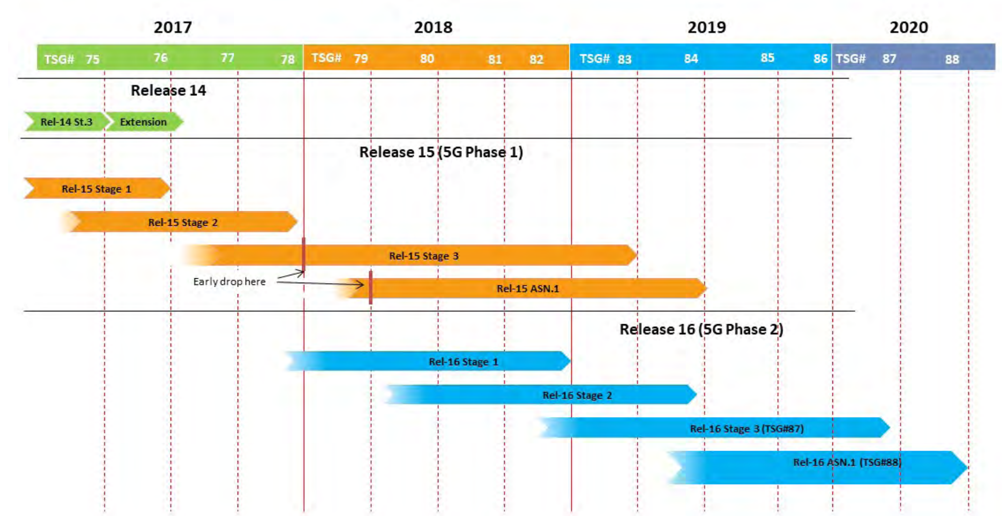

***Figure 1:** 3GPP's ongoing release schedule shows the multiphase rollout of 5G's Release 15 and Release 16, which are set to be complete by 2020. (Source: 3GPP).*

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without issues, fueling a dynamic explosion in the IoT. Plans are in place to support a reality that has >1M ($>10^6$) devices per square kilometer (km^2).

Speed

With much greater connection speeds, 5G potentially promises data rates of 1–10Gbps in contrast to current connection speeds of 50Mbps. Download speeds will also improve.

Latency

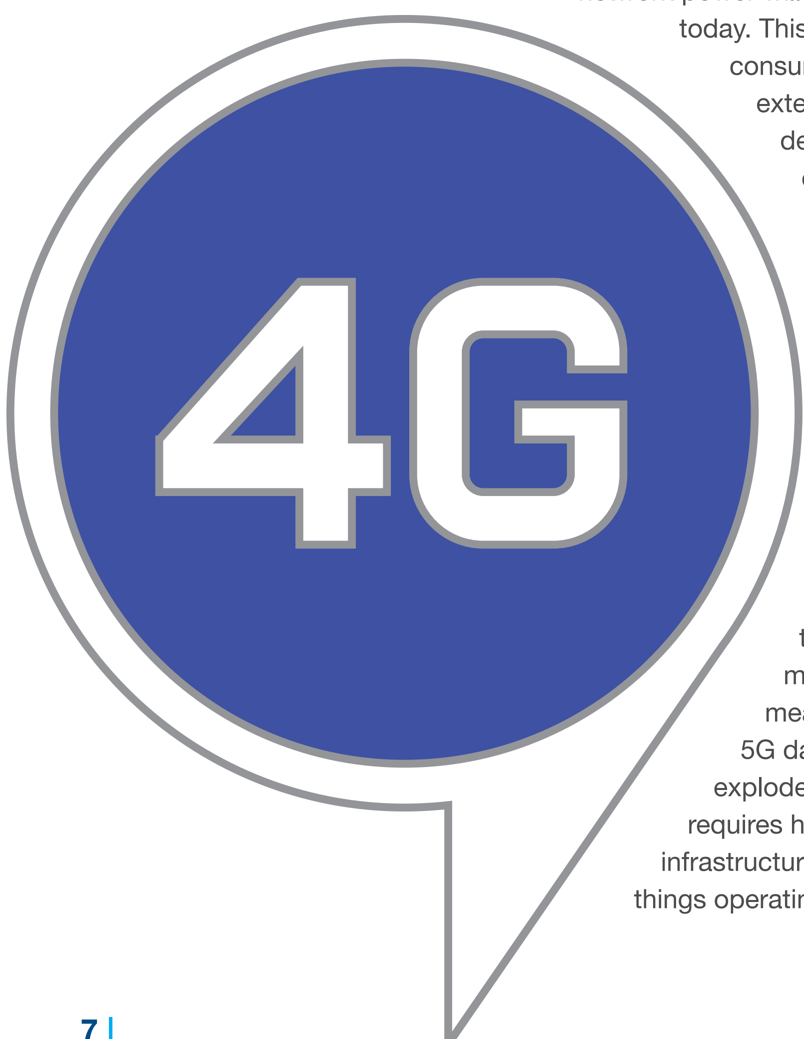
Latency, the time delay before a transfer of data begins, will be improved. Reliable, low-latency communications will drop to under 1ms, an improvement at least in an order of magnitude of $>10^1 = >10$. Because of low-latency, fast-moving, real-time devices, applications such as self-driving vehicles will have the capacity to locally process, decide, and respond with faster than human reflexes.

Spectrum Efficiency

5G's greater spectrum efficiency, through novel multiple-input and multiple-output (MIMO) antenna and associated technologies, will enable more bits of data to be transferred at specified frequencies.

Power Efficiency

5G's powerful network processing and control will realize significant gains in its network power efficiencies, enabling more data transfers while lowering energy consumption per data bit transferred. It is expected, despite the high device density coupled with high data streams, that overall 5G network power will be lower than today. This lower power consumption will also extend battery life for devices in the field, ensuring that field replacement issues do not overwhelm users after initial installation.



Throughput

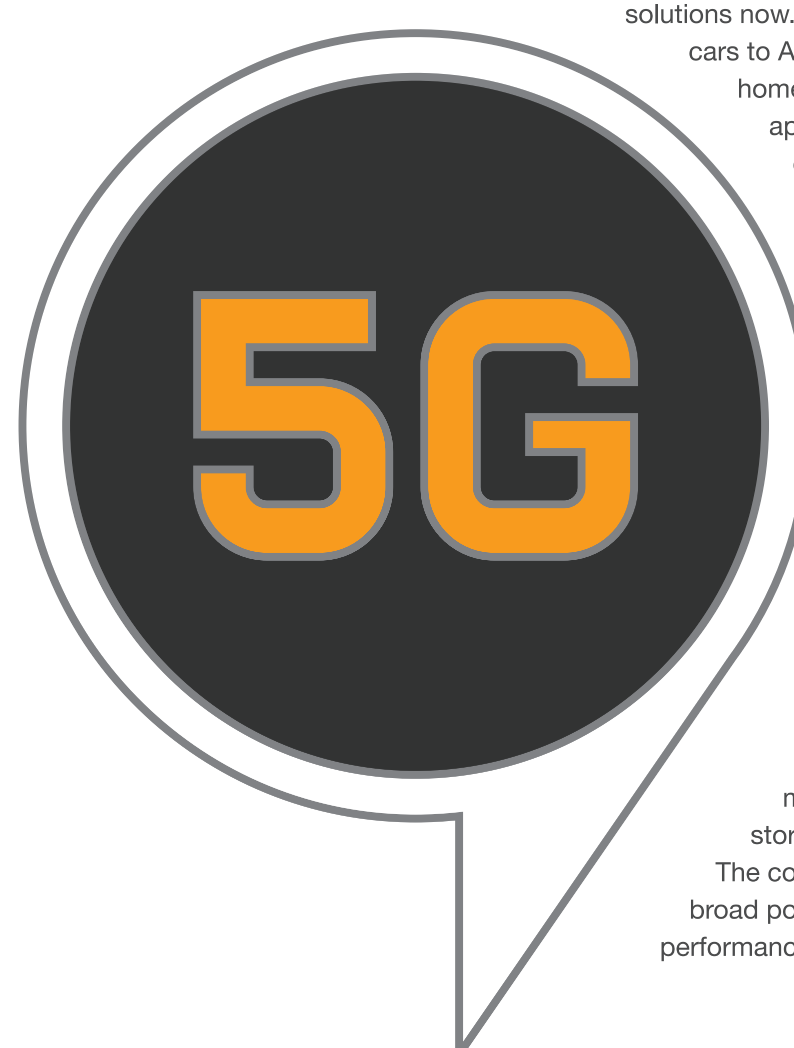
Taken into mutual consideration, all these previously mentioned facts mean that the level of 5G data throughput will explode. High throughput requires high-level infrastructure support to keep things operating smoothly.

5G Components: A Quick Glance at What Is Happening

Mouser Electronics is a leading authorized electronic component distributor, supporting an engineer›s design and supply chain component needs. To this end, Mouser Electronics is the premier source of advanced technology products from leading manufacturers who supply the latest products to enable your 5G applications. Let's look at how some of these leading companies are focusing their efforts to support the coming 5G infrastructure. *(Note: This list is not comprehensive but is only intended to be representative. The companies have been placed in alphabetical order by company name.)*

Analog Devices has built one of the longest standing, highest growth companies within the technology sector, utilizing cultural pillars such as innovation, performance, and excellence. Acknowledged industry-wide as the world leader in data conversion and signal conditioning technology, Analog Devices also specializes in radio frequency (RF) and power products. The company's 5G efforts are focused on the development and supply of amplifiers, clocks and timing, data converters, interfacing, isolation, microcontroller units (MCUs), power management, RF, sensors, and wireless connectivity. In the 5G space, Analog Devices will be introducing a 12-bit, 10.25 gigasamples per second (GSPS), JESD204B, RF analog-to-digital converter (ADC). Its high-speed converters include the AD9208 their ADC dual 14-bit 3Gsps ADC w/ JESD204B and AD9176 DAC 16-bit 12GSPS RF DAC w/3GSPS per channel. Analog Devices' ADF5356 microwave wideband synthesizers are phase locked loops (PLLs)/voltage controlled oscillators (VCOs). HMC8191/HMC8192 mixers support intermediate frequency designs. The ADMV1013 / ADMV1014 are up/down converters. The ADRF5024/5 SPDT switches offer high isolation and low insertion loss, while the ADL5920 RF detector provides forward and reverse power and return loss measurements.

Intel stands committed to making possible the most amazing experiences of the future. If a technology is smart and connected, then Intel's focus is to deliver the future needs for this technology within a growing world of connectivity—from networks, to the cloud, and to devices. The organization is investing in the promise of "always-on" 5G connectivity. Intel also offers field-programmable gate arrays (FPGAs), systems-on-chips (SoCs), complex programmable logic devices (CPLDs), and complementary technologies, such as power solutions, to provide high-value solutions to customers worldwide. Intel has become a recognized leader in the creation of 5G standards as it transforms purpose-built networks to become more agile, flexible, and scalable with Software Defined Networks (SDN) and Network Function Virtualization (NFV)—setting the stage for 5G expansion. The company is collaborating with an assortment of ecosystem and vertical industry partners to define, prototype, test, and deliver 5G standards and solutions now. From connected cars to AR/VR, smart homes, industrial applications, and cities, Intel delivers unmatched scale, innovation, and expertise to enable next-generation wireless products and services.



Micron Technology (Micron) is an industry leader in innovative memory and storage solutions. The company's broad portfolio of high-performance memory and storage technologies—including dynamic random access memory (DRAM), negative-AND (NAND) and negative-OR (NOR) flash memory, and 3D XPoint™ memory—is transforming how the world uses information to enrich lives. Micron's memory and storage solutions enable innovative trends including artificial intelligence (AI), machine learning, and autonomous vehicles across key market segments involving cloud, data center, networking, and mobile access. Micron's 3D-NAND-gate technology is expected to be an asset for data centers. This technology is expected to provide necessary and supporting increases in data storage density, allowing data centers to increase throughput and lower costs. Faster access times also allow the lower latency and high speed of 5G to be more easily realized.

NXP Semiconductors enables secure connections and infrastructure for a smarter world, advancing solutions that make lives easier, better, and safer. As the world leader in secure connectivity solutions for embedded applications, NXP is driving innovation in the secure connected vehicle, end-to-end security and privacy, and smart connected solutions markets. The company is a leading provider of the cellular enablement chipsets and is a founder in many areas of this technology. It will soon be developing and providing a wide variety of digital networking processors, secure interface and system management products, high-performance RF (HPRF) power amplifiers, and smart antenna solutions.

Qorvo is ready today with next-generation RF smarts and solutions to connect people, places, and

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things faster, further apart, and more reliably. Qorvo is all around you—making a better, more connected world possible. Qorvo is making 5G deployment a reality and is supporting the growth of mobile data with a broad range of RF connectivity solutions. Its robust RF portfolio for both wireless infrastructure and mobile devices include power amplifiers (PAs), phase shifters, switches, integrated modules, and other high-performance RF solutions. New 5G related releases include the Qorvo QPC1000 29–31GHz Phase Shifter with Integrated SPDT Switch, the Qorvo QPF4001 GaN MMIC (Monolithic Microwave Integrated Circuit) Front End Module, and a multifunctional device module targeted for 28GHz phased-array 5G base stations and terminals.

Skyworks Solutions (Skyworks) is empowering the wireless networking revolution. As a premier provider of wireless front-end solutions, Skyworks is an expert in connectivity. They are enabling the 5G evolution by advancing their technology leadership and extending their product reach to power some of the world›s most exciting communication platforms. Skyworks is a member of and key contributor to the industry›s most influential standards organizations, including the European Telecommunications Standards Institute (ETSI) and 3GPP, where they participate in the development of specifications critical for emerging 5G applications. Skyworks is focused on cellular 5G handsets and the requisite 5G infrastructure. An example of one of their 5G related products is the family of Skyworks Solutions PIN Diode Limiters, developed for use as passive-receiver protectors in wireless or other RF systems.

Silicon Labs (SiLabs) is a leading provider of silicon, software, and solutions for a smarter, more connected world. For 5G, SiLabs is focusing their efforts on MCUs, wireless, sensors, timing, and isolation products and solutions.

STMicroelectronics (ST) offers power management solutions; a large range of microcontrollers, sensors, and connectivity and security solutions; as well as interfaces and transceivers, protection devices, RF front-ends, and analog components. With a strong foundation in silicon carbide (SiC), ST is also moving forward with RF GaN-on-Silicon, enabling future high-performance 5G networks.

TE Connectivity provides connectivity and sensor solutions that are essential in today's increasingly connected world. TE Connectivity believes every connection counts. To support 5G efforts, TE Connectivity is focused on the necessary connectors, relays, passives, sensors, terminals and splices, as well as wires and cabling.

Texas Instruments (TI) is a leader in semiconductor solutions for analog and digital embedded applications and processing. Texas Instruments supports 5G efforts with amplifier, clock and timing, data converter, interface, isolation, MCU, power management, RF, sensor, and wireless connectivity products. Some current products that support 5G efforts include the Texas Instruments LMG3410R070 600V 70mΩ GaN Power Stage, and for power management, the LM5045 and LM5036 switching controllers.

Conclusion

The future is certain to be more connected than the past.

5G wireless technology will ensure that mobile networks of our future will connect us all together.

Superfast communications are the transformational leap that innovative 5G technology is enabling, and it›s being brought to realization by electronic component manufacturers dedicated to developing the advanced technologies and products for our future.

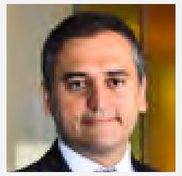
As their teams of engineers look back at previous technology limitations, I trust them to connect these dots so we will never need to look back again. Get ready as we move forward into the future of hyper-connectivity. M

NOTE: These 5G use case examples are categories that encompass a wide range of data throughput and latency requirements. For example:

- **Smart Cities** can include municipal lighting, smart parking, and smart traffic management which would have different throughput and latency requirements.
- **Smart Grids** can have low throughput - high latency functions such as metering, and low throughput - low latency functions such as real-time control of power distribution systems.
- **Healthcare systems** can include high throughput requirements such as imaging, but also low throughput - low latency requirements such as intensive care patient monitoring, or high throughput-low latency remote surgical applications.

Introduction to 5G

By Mustafa Ergen for Mouser Electronics



Mustafa Ergen is founder of venture funded startup Ambeent Inc., a company focused on 5G Wi-Fi, and he serves as professor at Istanbul Technical University. Previously, Mustafa co-founded Silicon Valley startup WiChorus, Inc., a company focused on 4G technologies; this company was eventually acquired by Tellabs for $200 million.

The 5G mobile communications standard is designed to fulfill several performance and use case requirements currently not possible in 4G networks, including:

- **Enhanced broadband** that brings fiber-optic speeds and bandwidth to over-the-air (OTA) connections
- **Low latencies and extreme reliability** for real-time OTA process control
- **Much higher device densities** that will enable the massive Internet of Things (IoT) connectivity that is anticipated in smart cities
- **More energy efficiency** to meet the increasing demand for low-power connectivity
- **High-speed adaptability** for high-speed mobile applications
- **On-demand network scalability** to meet the requirements of many industrial use cases

Specifications outlined in 3rd Generation Partnership Project (3GPP™) Release 15 provide details for 5G New Radio (NR), which addresses the 5G air interface, and 5G Core, which deals with network functions. Both 5G NR and 5G Core are required to meet 5G performance expectations. This article looks at how 5G differs from 4G with respect to its performance, radio access technology, and network core functions. It further reviews how 5G specifications make new applications possible and how the 5G standard impacts component designs.

How Does 5G Differ from 4G?

Table 1 lays out some of the key performance differences between 4G and 5G specifications.

Meeting 5G's performance expectations requires additional spectrum as well as different waveforms and a flexible framework that allows service multiplexing and more dynamic multiple access capabilities. 5G meets these requirements through a new approach to scalable waveforms that works across a range of frequencies, creating an entirely new approach to session and network management.

5G NR Increases Flexibility and Reduces Overhead

5G NR applies a common waveform framework that scales across a range of bandwidths. Several techniques contribute to 5G's spectrum efficiency, flexibility, and reduced power consumption. Key differences between 5G NR and 4G Long-Term Evolution (LTE) include:

- **Scalable orthogonal frequency-division multiplexing (ODFM) numerology.** ODFM is a widely used waveform for encoding digital communications. Its waveform numerology defines the structure and timing of information resources that the waveform carries, such as the number of subcarriers and the subcarrier spacing. Both 4G LTE and 5G NR use ODFM, but there are big differences. In 4G LTE, the numerology is always fixed; in 5G NR, the numerology is scalable for optimization in different bandwidths. This means that the subcarrier size and spacing are scalable to fit bandwidths that different frequencies provide. It also enables scalable TTI, which makes it possible to adjust latencies from very low for short-duration transmissions to longer latencies that make transmitting large data packets more efficient. Scalable ODFM numerology is the heart of 5G's scalability and flexibility.
- **Self-contained subframes.** Introduced in the 5G NR specification, these structures enable the inclusion of data along with their transmission acknowledgments in the same subframe, further reducing latencies. They also enable the

Specification	4G	5G
Frequency ranges	600MHz to 5.925GHz	• Frequency range 1 (FR1): 450MHz to 6GHz • Frequency range 2 (FR2): 24.25 to 52.6GHz (and beyond)
Channel bandwidth	Up to 20MHz	• FR1: Up to 100MHz • FR2: Up to 400MHz
Subcarrier spacing	Typically fixed at 15kHz	Scalable to channel bandwidth
Spectral efficiency	30bp/Hz	120bps/Hz
Peak data rates (downlink)	1Gbps	20Gbps
Latency	10ms	<1ms
Transmission time interval (TTI)	1ms	Scalable from 100 micro-seconds (µs) to 4ms
Connection density	≈ 2,000 devices/km²	1 million devices/km²
Mobile connectivity	Up to 350km/h	Up to 500km/h

***Table 1:** 4G Versus 5G Specifications*

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"...new approach to scalable waveforms that works across a range of frequencies, creating an entirely new approach to session and network management."

multiplexing of different kinds of subframes, and they support blank subframes to accommodate undefined future services. Self-contained subframes can also contain beamforming data specific to a transmission, which supports multiple-input, multiple-output (MIMO) antenna transmissions and reduces interference.

- **Device-centric mobility.** In LTE networks, receiving devices measure reference signals that base stations transmit to decide where to connect. Base stations transmit reference signals continuously, regardless of the presence of a receiving device—which requires processing overhead on the receiving device and excess power consumption by the transmitting equipment. In 5G transmissions, receiving devices transmit a reference signal when they need a network connection, and this reference signal triggers communication and handoff activities using appropriate transmitting equipment. This arrangement reduces power consumption and the number of reference signal broadcasts.
- **New cell architectures and antenna designs.** To support larger numbers of connected devices, uninterrupted communications, and shorter operational ranges available from high-frequency bands, 5G will require denser cell architectures than are found in 4G LTE networks. Typical deployments could include a mix of macro-cells operating in low frequencies for wide outdoor coverage, small cells operating indoors and outdoors in mid-frequency ranges, and micro-cells (room sized) operating primarily indoors at millimeter wavelength frequencies. Beamforming techniques using massive MIMO (mMIMO) antenna arrays will provide uninterrupted coverage and much higher transmission efficiencies than 4G LTE produces with previous MIMO variations. 5G antenna designs will also produce more signal processing at the antennas to manage mobile device handoffs between cells.

5G Core Virtualizes 4G Evolved Packet Core Network Architecture

To meet 5G performance specifications, especially as they relate to use case flexibility, scalability, and reliability, the 5G Core network has been redesigned from the ground up in a way that completely supplants the 4G Evolved Packet Core (EPC). Whereas 4G EPC relied on physical network elements, 5G Core is a cloud-native virtualized architecture that uses multi-access edge computing to deliver network functions as services to a network's edge. Key features and capabilities of the 5G Core architecture include:

- **Separate control plane and user plane functions.** This separation and reallocation of functions previously performed by EPC service and packet gateways enable a redistribution of packet processing functions to a network's edge. The result is better traffic management and scalability.
- **Redesign of session management functions.** Mobility management and session management are now performed by different network elements, and new identity and authentication functions have been added. All this improves session management to deliver uninterrupted service in various operational scenarios—for example, as user equipment is moving through a small cell network or at high speeds. These session management enhancements create a reliable service flow in complex environments that contain dense IoT arrays and user equipment with diverse data formats.
- **Network slicing.** This technology enables 5G to offer a "slice" of the network as a dedicated service for a particular use case, customer, or industry. User equipment can simultaneously access multiple network slices. A network slice maintains all necessary functionality and quality across domains and technologies to efficiently allocate available resources for each use case.

New Applications and Business Cases Possible with 5G

The 5G standard enables a range of simultaneous communications that are highly reliable and optimized for use case performance and power consumption. This standard opens the door to a host of new smart services and partnerships that could not previously be accommodated on monolithic 4G networks.

Use Case Possibilities: Life in a 5G World

To illustrate some of the possibilities in a 5G world, consider a simple example of an architect's commute to work one morning in her autonomous vehicle (AV). It happens that she has scheduled a conference call to take place during her commute because this was the only time her clients in Spain and her supplier in Singapore could meet.

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Seamless Communications

The architect can carry on with her meeting as her AV navigates itself to her office. It does this by using a 5G vehicle-to-everything (V2X) communications platform for low-latency communications. The AV's communications platform is cloud-based and interacts with other vehicles and traffic control infrastructures, using data from sensor inputs for real-time situational awareness and navigational updates.

While the AV drives, the architect reviews her project plans, then puts on her headset to enter a virtual three-dimensional (3D) conference call that uses a 5G broadband full-duplex connection. During the meeting, the AV enters a tunnel on the route to work. There is no interruption in the meeting or the vehicle's control systems because the tunnel is lined with small cell mMIMO antennas, which maintain a continuous contact for all communications while the vehicle is moving underground. Soon after the AV enters the tunnel, its calculated arrival time triggers a signal that turns on a coffee machine in the architect's office.

Tasks Accomplished

Despite all the activity, the meeting goes as planned. The AV arrives at its destination, locates an available parking space, parks itself, engages the electric-charging equipment, and verifies the payment account information. Thereafter, the architect walks into her office, pours a cup of hot coffee, and updates her project plans based on information her supplier in Singapore provides.

This example shows how 5G technology's ubiquitous real-time command, control, and communications capabilities will reshape the way process control and workflows operate. It will also open the door to entirely new models. Fully entering this world, however, will still require a lot of engineering work.

"5G technology's ubiquitous real-time command, control, and communications capabilities will reshape the way process control and workflows operate."

Engineering Challenges for 5G Components

5G performance requirements combined with 5G network and device architectures are placing new demands on component design. Many design constraints are interdependent. They include:

- **Processing power and throughput.** Many aspects of 5G technology require more processing power, including scalable waveforms, higher data throughput, smaller cells that require complex session and handoff management, beamforming, network slicing, and higher connected device densities. More processing power requires more robust software, which in turn consumes power and generates heat.
- **Power consumption.** Although 5G devices are expected to use power more efficiently, they will also do more work. Early base stations with MIMO antennas and prototype 5G phones will consume two to three times more power than their 4G counterparts.
- **Heat.** More power consumption means more heat generation, which requires more heat dissipation to avoid damaging components.
- **Component complexity.** 5G components are more complex, with more filters and amplifiers to operate at more frequencies and with more complex waveforms. This complexity introduces risks of creating larger components when space is already at a premium, especially in user equipment.
- **Component density and compact designs.** Packing more complex components into more compact designs increases component density, which makes heat dissipation more difficult.

These challenges can have a cascading effect of design constraints. For example, in a device like a mobile phone, if components take up more room, there is less room for a battery, so the battery must be smaller. But, if the device needs more power, smaller batteries mean less available power, which in turn means a shorter service time between charges. Many of these heat, power consumption, and component size challenges are being addressed through new techniques and materials—for example, through:

- Transceivers that employ new phase-shifting techniques—which allow more accurate beam steering, tighter beam resolution, near-zero gain variations across a large MIMO antenna array, higher data rates, and package size reductions through components that share circuit elements—eliminating the need for switches,
- More efficient high-frequency power amplifiers that use gallium nitride (GaN) transistors and a variety of techniques for reducing nonlinearization when operating at less than full power, and
- New techniques for developing reconfigurable and tunable wideband filters that are compact and cost-effective.

Conclusion

5G communications are here, and initial deployments have already begun, but clearly a lot of engineering work remains to be done before 5G technology can deliver all the possibilities that its specification implies. Initial deployments focusing on FR1 (<6GHz) will be the proving ground for new 5G systems and components going forward. M

Where Does 5G Fit in the Connectivity Ecosystem?

By Sravani Bhattacharjee for Mouser Electronics

Sravani Bhattacharjee has been a data communications technologist for over 20 years. As the principal of Irecamedia Communications, she currently collaborates with Industrial IoT innovators to drive awareness and business decisions by producing a variety of editorial and technical marketing content. Sravani has a master's degree in electronics engineering.

By 2020, more than half of United States households are expected to have 4K- and 8K-capable televisions. Wired broadband can support 4K/8K video streaming in homes, but it can't support data-thirsty apps on the go.

For that, much of the world is banking on Fifth-Generation (5G) networks. In 5G cellular networks, the peak data rates are 10 gigabits per second (Gbps), which means downloading a 1.2 gigabyte (GB) ultra-high-definition (UHD) movie would require less than a second. Compared to its 3rd Generation Partnership Project (3GPP™) predecessors (2G and 3G/4G LTE), 5G's expanded capacity is a big step forward in mobile connectivity.

Much like Moore's law for computers, Nielson's law of Internet bandwidth predicts that bandwidth usage will increase by 50 percent every year. To help keep up with this exponential rise in bandwidth requirements, 5G wireless will need to deliver.

As device manufacturers and application developers prepare for 5G-capable products and services, it is important to assess the applicability of 5G in their respective use cases. The enormous promise of 5G as an ultra-low-latency broadband wireless technology must be gauged in relation to other technologies in the connectivity ecosystem. For example, several product categories exist for which 5G networks may not be a realistic choice. Price over performance is a crucial consideration when determining whether to adopt 5G over other connectivity options.

This article helps systems engineers evaluate the viability of 5G in the existing connectivity ecosystem.

What Distinguishes 5G Connectivity?

We have moved into an era dominated by cloud-based, connected applications. Every industry vertical is transitioning to service models in which the essential functions are dispensed from the cloud. This shift forces us to think differently about connectivity.

That's where 5G fits in. The 5G standards provide a totally new framework for connectivity. In that sense, 5G paves a disruptive evolutionary path for existing connectivity concepts.

In addition to using spectrum in the existing Long-Term Evolution (LTE) range, 5G uses unlicensed spectrum in the millimeter wave (mmWave) bands. According to an article in IEEE Spectrum entitled "5G Bytes: Millimeter Waves Explained," mmWaves, broadcast in the 30 to 300 gigahertz (GHz) frequency range, provide much higher bandwidths than the spectrums of former generations along with the added benefit of lower latencies. However, the mmWaves (1 to 10mm in length) cannot travel easily through buildings and other obstacles and are easily absorbed by rain, foliage, etc. That's why 5G small cells would be the norm. Compared to traditional cell sites, small cells are much smaller in size, more power efficient, and are becoming more affordable. Due to their inherent spectrum efficiency, small cells also increase wireless capacity to connect more "things" and data traffic.

A few other factors distinguish 5G networks in the digital landscape (**Figure 1**).

Ubiquitous Connectivity

The adoption of the Internet of Things (IoT) is already ramping up across all industry verticals. The IoT currently connects physical devices such as sensors, actuators, pumps, and cars. Billions of such devices will need network connectivity by 2020/2021 to be able

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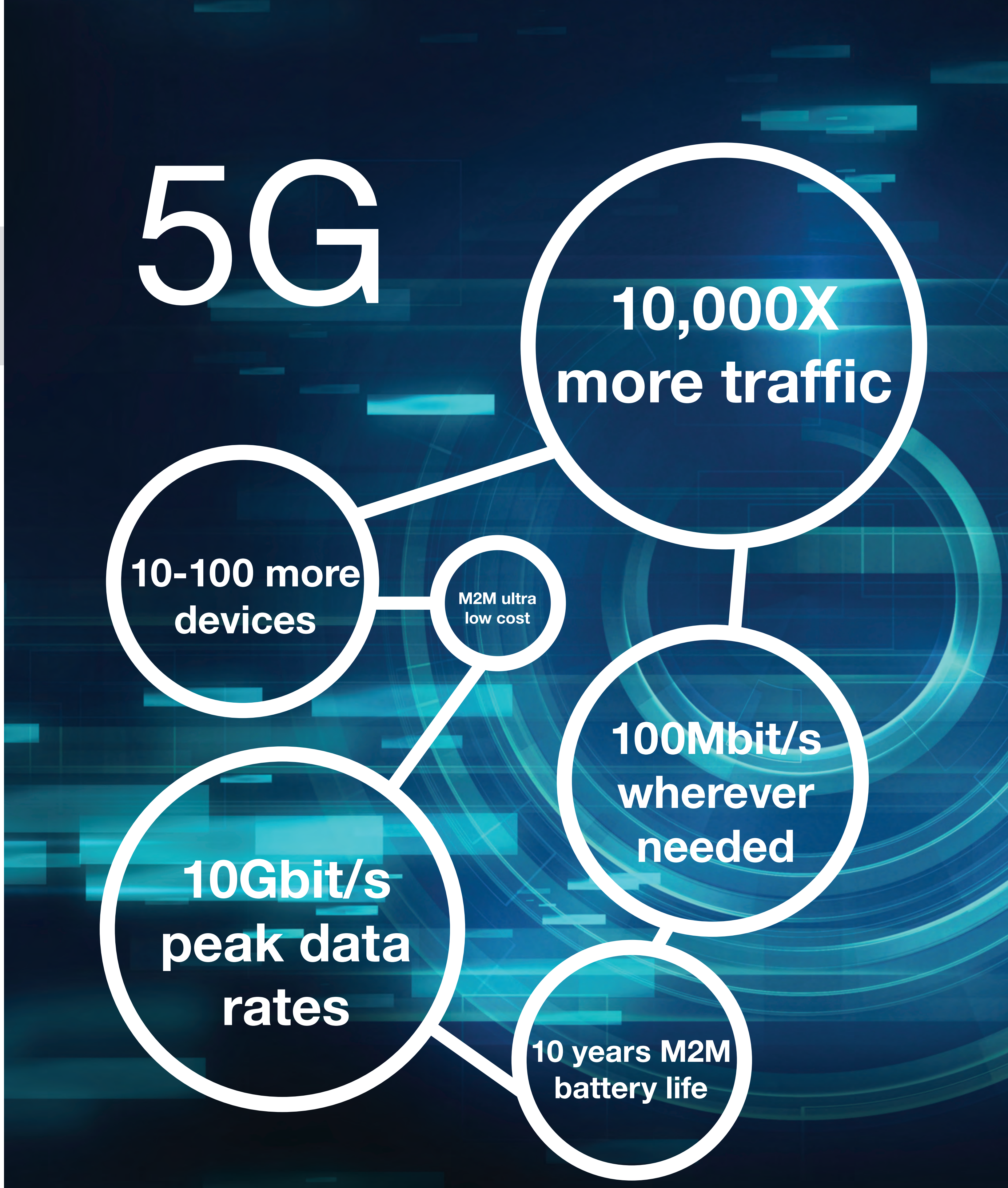
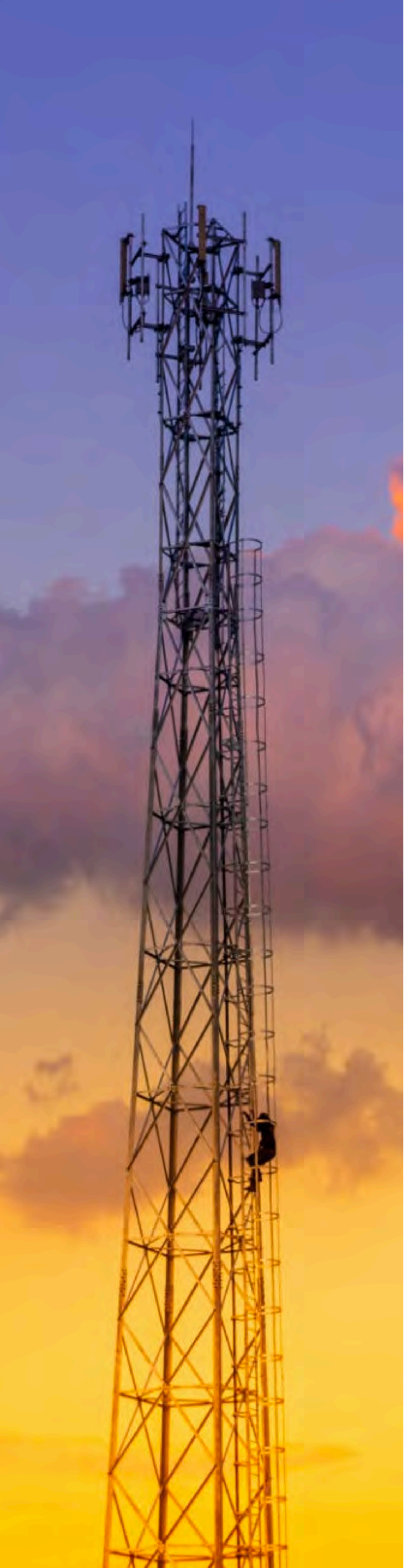


Figure 1: This snapshot diagram captures the 5G connectivity performance metrics. (Source: Mouser Electronics)



to communicate reliably with cloud-based services. Increased capacity from 5G small cells technology can support IoT devices and machine-to-machine (M2M) connectivity at a massive scale. Compared with 4G LTE, 5G offers 1,000 times more bandwidth per unit area, 10,000 times more traffic, and 100 times more connected devices per unit area.

Real-Time Performance

As the IoT hits industrial scale, connectivity must support applications such as remote control of machines, drones and robotics applications, time-sensitive industrial control loops, driverless car navigation, remote surgery, and more. For these mission-critical applications, high bit rates are not enough. To achieve real-time performance, latencies must also be very low. 5G standards extend broadband wireless services beyond mobile Internet capacity to IoT applications that require ultra-reliable, fast, and mission-critical communications.

Energy Efficiencies

Whereas 4G is primarily a mobility solution, 5G (in addition to enhancing mobility) caters to fixed wireless and industrial IoT applications where devices operate in rugged environments, have a limited power supply, and run for decades. That's why 5G is designed for up to a 90 percent reduction in power usage compared with 4G and up to 10 years of battery life for IoT devices.

Security and Reliability

Relatively speaking, communication over wireless connectivity is easier to intercept and more susceptible to man-in-the-middle attacks. In IoT use cases, low-power wireless connectivity is prone to bit rate errors and connection drops. The robust design of 5G is expected to offer 99.999 percent availability and include mutual authentication, local secure elements, Transport Layer Security (TLS) encryption, and over-the-air (OTA) firmware updates for 5G electronics. Much like virtual machines on virtualized hardware platforms, 5G network resources can be segmented into "network slices." 5G network slicing enables service providers to build virtual, application-specific, end-to-end networks that offer additional security.

Mapping 5G Networks in the Connectivity Landscape

Excitement about the 5G rollout does not necessarily translate to deprecating (or sunsetting) existing technologies. In fact, ongoing innovations in time-sensitive networks (next-generation of Institute of Electrical and Electronics Engineers [IEEE] 802.1 Ethernet); low-power, wide-area networks (LPWANs); Wi-Fi; and long range (LoRa®) technologies are gaining traction as well.

Even after 5G standards are rolled out at mass scale, 5G technology will coexist with other technologies for the foreseeable future. In many scenarios, 5G technology will complement those technologies.

Fiber Optics and Fixed Broadband

The study "Communications infrastructure upgrade: The need for deep fiber," published in 2017 by Deloitte, shows that only 11 percent of Internet traffic is carried over wireless connections, while 90 percent of the traffic traverses wired networks. Fiber-optic networks offer high throughput and bandwidth with low latencies over long distances. In terms of bandwidth and speed, 5G wireless and fiber optics are comparable technologies. However, as connectivity solutions, these technologies are less competing and more complementary. In fact, the quality and reliability of 5G networks would depend on fiber-based wireline networks for backhaul transport of traffic between the small cells.

In smart homes and offices, 5G small cell access points can enhance indoor-coverage fiber and coaxial cable-based broadband Internet solutions. The speed and flexibility of 5G wireless may replace legacy wireline networks in industrial and city infrastructures. In data center infrastructures and cloud computing servers, however, where the robustness and maturity of wireline technologies are critical, fiber-optic and fixed Ethernet technologies will continue to dominate.

LPWANs

The desired capabilities of LPWAN technologies for IoT applications are:

- Device chipsets with low-processing and transmission power as well as a battery life exceeding 10 years to support long-term usage.
- Extended coverage (more than 10km suburban; more than 5km urban) with good penetration in buildings and basements.
- Device abilities to send small bursts of data intermittently, so the supported data rates are low (0.3 bits per second [bps] to 50 kilobits per second [Kbps]—typically, approximately 10 kilobytes per day [KBpd]).
- Secure data transmissions with low total costs of ownership.

LPWAN technologies are already prevalent in IoT edge deployments, where many low-cost IoT devices (such as sensors and meters) are spread over extended areas in operational environments. LPWAN adoption is expected to grow across global IoT markets over the coming years, even when 5G wireless is ready for commercial use. LPWAN technologies cater to use cases where 5G's high data rates and low latencies are less compelling.

"Excitement about the 5G rollout does not necessarily translate to deprecating (or sunsetting) existing technologies."

These generic requirements have been implemented in several LPWAN technologies. Here's a quick roundup of common LPWAN technologies in the context of 5G connectivity:

Narrowband-IoT

Narrowband (NB)-IoT transmissions are designed using a more limited bandwidth, and hence are more energy efficient. NB-IoT user devices are designed for ultra-low complexity and cost less. NB-IoT has a significant spectrum efficiency. It can connect up to 50,000 devices per cell. NB-IoT can penetrate buildings and underground areas (offering 20dB or more coverage indoors) and are suitable for smart city applications with static assets.

Sigfox®

Sigfox is a proprietary technology that has already penetrated European markets and is supported by many electronics vendors. Sigfox uses a slow modulation rate for extended coverage. It is suitable for applications such as smart parking sensors, smart garbage cans, and utility meters, where the low-cost devices need to upload small, infrequent bursts of data to IoT gateways.

LTE for Machines

LTE for Machines (LTE-M) is a relatively recent innovation, and its power efficiency is still under evaluation. It can piggyback over existing 4G-LTE connectivity (and can evolve to be 5G compatible) to support roaming for mobile IoT assets like vehicles and drones. LTE-M electronics are among the most expensive options because they can offer data rates higher than other LPWAN options. Data-rich applications in the IoT edge can benefit from LTE-M.

LoRa

LoRa is a long-range, low power, low-data-rate connectivity standard from the Lora Alliance™. LoRa is designed to enable large network operators to offer subscription-based LPWAN services. LoRa uses the unlicensed spectrum (sub-GHz radio frequency; e.g., 915MHz in North America) but relies on an additional layer of security because LoRa devices do not use subscriber identification modules (SIMs) or machine identification modules (MIMs) for device authentications or encryptions.

5G networks and LPWAN can be expected to complement each other in various end-to-end IoT deployments. For example, in the case of a remote surgery, the time-sensitive nature of communication requires real-time data transmissions. Scenarios like this are where low-latency 5G cellular networks fit. However, a remote surgery also involves sensor networks at the edge such as on the hospital premises to collect and process critical information locally. For these sensor

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networks at the edge, LPWAN connectivity is a more viable option.

Personal Area Network (PAN) and Local Area Network (LAN)

For local connectivity in homes and enterprises, Wi-Fi® and Bluetooth® technologies (based on IEEE 802.11 standards) and Bluetooth Low Energy are common options. 802.15.4-based technologies (including Zigbee®, ISA100.11a, 6LoWPAN, WirelessHART®, and Z-Wave®) support enterprise IoT applications such as asset and resource tracking.

Just like cable and fiber-optic broadband solutions, 5G fixed broadband and cellular networks should complement Wi-Fi and Bluetooth. 3GPP's Release 16 will include the 5G New Radio (NR)–Unlicensed standard, which supports existing 5 and 6GHz ("greenfield") unlicensed frequency bands. One of the promising use cases of the 5G unlicensed spectrum will be "Wi-Fi-like" private networks in enterprises, large stadiums, and malls.

Satellite

In the connectivity ecosystem, while satellite technologies offer high bandwidth and reliability, they are expensive. As such, satellite serves only niche use cases. Onboard connectivity in aircraft, on freights, and on fleets using Global Positioning System (GPS) tracking across oceans, remote locations, underserved areas, and disaster zones, where mobile networks can fail, are some of the scenarios in which satellites are useful.

Satellite connectivity can augment 5G wireless to offer ubiquitous connectivity, by extending the coverage of 5G networks in areas where cellular connectivity is not feasible because of economic and other locational constraints.

Cellular: 4G-LTE

4G-LTE started rolling out in 2009, and in pre-5G days, it is the most advanced cellular technology available, with a peak rate of up to 1Gbps and latencies of 30 to 70 milliseconds (ms). With its 10Gbps data rates and less than a 1ms latency, 5G wireless is poised to evolve cellular networks into super-fast, responsive, power-efficient sources of connectivity.

Deployment of 4G networks is still in progress around the globe. It will take some time before 5G networks reach ubiquity and for 5G chipsets and devices to reach the market on a commercial scale. Use cases that do not require an ultra-high throughput and ultra-low latencies can continue to use 4G even after 5G has been rolled out. The 5G NR standard is designed to overlap and coexist with the 4G core network. So, at least from a technical design standpoint, compatibility has been built into 4G and 5G wireless-based cellular services.

Final Thoughts

2019 is the year of 5G connectivity. Mobile carriers and original equipment manufacturers (OEMs) are gearing up to roll out 5G networks commercially within a year. Nonetheless, the reality is that certain 5G standards are still in development, and testing is still in progress to certify 5G capabilities.

With its bold promises, 5G also introduces unprecedented challenges to achieving its ambitious performance goals in real-world scenarios. To adopt and create 5G-capable applications and electronics in the future, it is important to stay current with the ongoing 5G tests and developments. The 5G community also needs to think in innovative ways to overcome technical challenges and assess the applicability of 5G wireless networks in a quickly evolving connectivity ecosystem. M

Understanding the 3GPP™ Release 15 5G Standard

By Emad Farag for Mouser Electronics

Dr. Emad Farag is a senior 5G physical layer standards engineer at Nokia®. He has worked on the physical layer architecture, algorithms, and software of wireless base station modems. Dr. Farag is a subject matter expert in the 5G New Radio (NR) standard, developing techniques to build the 5G standards.

The new Fifth-Generation (5G) standard is a unified mobile communication framework for our connected, mobile society; it supports high data-speed applications as well as mission-critical communications with ultra-reliable and low-latency requirements, and it connects billions of devices that can communicate with each other autonomously. This is the vision the International Telecommunication Union Radiocommunication Sector (ITU-R) laid out in Recommendation M.2083, issued September 2015. Since then, standard-setting organizations have been racing to identify and develop the technology components necessary not only to support urgent short-term market needs, but also to meet the long-term objectives of 5G.

In late 2015, the 3rd Generation Partnership Project (3GPP™) embarked on a mission to define a new Radio Access Network standard—which came to be known as 5G New Radio (NR)—to meet ITU-R requirements. The standardization effort involved channel modeling of spectrum up to 100 gigahertz (GHz), with its vast potential for larger bandwidth allocation, higher throughput, and lower latencies. It also involved studying the scenarios and requirements for next-generation radio access technologies and the corresponding technology components. 3GPP follows a phased approach to standardization, with each phase referred to as a release. The first phase of 5G NR, which supports enhanced mobile broadband and basic ultra-reliable low-latency communications (URLLC) in spectrum up to 52.6GHz, is known as Release 15. The first version of the Release 15 specification became available in December 2017.

This article describes the spectra available in 5G NR and the physical layer enabling technologies developed for 5G NR.

5G NR Spectrum

Given the insatiable consumer demand for mobile data and higher throughput rates coupled with the vast amount of spectrum available in the 3 to 100GHz spectrum region, it seemed natural for regulators and standard organizations to consider opening and using spectrum in centimeter wave (cmWave) and millimeter wave (mmWave) regions for mobile communication, as well as to consider developing a framework for spectrum sharing with incumbent technologies.

In Release 15, 3GPP has defined two frequency ranges: Frequency range 1 (FR1), which extends from 450 megahertz (MHz) to 7.125GHz, and frequency range 2 (FR2), which extends from 24.25 to 52.6GHz (**Table 1**). Studies about the availability and regulatory requirements of spectrum in the 52.6 to 114.25GHz frequency range are ongoing, as are the potential use cases and deployment scenarios.

Frequency Range Designation	Frequency Range	Maximum Channel Bandwidth
FR1	450MHz to 7.125GHz	100MHz
FR2	24.25 to 52.6GHz	400MHz
Understudy	52.6 to 114.25GHz	TBD

Table 1: *NR Frequency Ranges*

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mmWaves

Moving to mmWaves poses challenges in terms of the characteristics of the radio channel and the fact that small-wavelength waves experience a higher rate of attenuation, e.g., due to atmospheric conditions. However, by exploiting shorter wavelengths with smaller antenna array elements that can be packed together more tightly, it's feasible to implement antenna arrays with tens or even hundreds of antenna elements in the mmWave band. This approach creates antenna systems with high antenna gains and narrow beams that not only compensate for the higher losses experienced by mmWaves but may reduce interference through their narrow beams.

Throughput Optimization

To achieve higher throughput, NR exploits the following techniques:

- **Higher spectrum utilization.** The spectrum use defines the ratio of the transmission bandwidth to the channel bandwidth with guard bands on the edges. In Long-Term Evolution (LTE) communication, spectrum use is 90 percent; in NR, spectrum use can reach 98 percent.
- **Higher post–fast Fourier transform (FFT) subcarrier occupancy.** In LTE, the number of occupied subcarriers after FFT is about 60 percent of the FFT size. For example, a 20MHz LTE system uses a 2,048-point FFT, of which 1,200 subcarriers are occupied. In NR, the number of occupied subcarriers increases by 25 percent in addition to the increase resulting from higher spectrum use. The channel bandwidth then increases by 25 percent for the same FFT size and subcarrier spacing.
- **Larger FFT size.** Advances in integrated circuit (IC) technologies make it feasible to support larger FFT sizes. NR supports a maximum FFT size of 4,096, which is double that of LTE.
- **Higher subcarrier spacing.** In LTE, there is single subcarrier spacing for data transmissions of 15 kilohertz (kHz). In NR, the maximum subcarrier spacing is 120kHz, which increases the channel bandwidth by a factor of eight without the need to increase the number of subcarriers. In FR1, the allowed subcarrier spacings for data transmissions are 15, 30, and 60kHz; in FR2, the allowed subcarrier spacings for data transmissions are 60 and 120kHz.

Table 2 provides two examples for FR1 and FR2 and shows how the preceding techniques increase the throughput.

	LTE Baseline at 20MHz	NR at 100MHz (FR1)	NR at 400MHz (FR2)
FFT Size	2,048	4,096	4,096
Spectrum Use	90%	98.28%	95.04%
Subcarrier Occupancy	58.6%	80.0%	77.3%
Number of Subcarriers	1,200	3,276	3,168
Subcarrier Spacing	15kHz	30kHz	120kHz
Transmission Bandwidth	18MHz	98.28MHz	380.16MHz
Channel Bandwidth	20MHz	100MHz	400MHz
Increase in Throughput for the Same Modulation and Coding Scheme	1	5.46x	21.12x

Table 2: *Throughput Increase in NR for FR1 and FR2*

5G NR Physical Layer Aspects

5G NR is an orthogonal frequency-division multiplexing (OFDM)–based air interface, where the channels and signals in transmission are allocated to individual subcarriers that make up the composite radio signal. OFDM access is the multiple-access scheme that NR has adopted. For downlink and uplink transmissions, without multiuser multiple input, multiple output (MIMO), different users are allocated to different subcarriers.

The waveform of the transmitted signal in NR uses cyclic prefix (CP)-OFDM for downlink and uplink transmissions. In addition, a discrete Fourier transform-spread OFDM (DFT-S-OFDM) waveform is used in the uplink because of the DFT-S-OFDM waveform's low peak-to-average power ratio (PAPR) for user equipment (UE) in power-limited regions. DFT-S-OFDM is used only with single-layer uplink transmissions. In the case of DFT-S-OFDM, a signal goes through a DFT precoder before reaching the subcarriers allocated for the transmission. After conversion back to the time domain, a CP appends to the OFDM symbol.

"...exploiting shorter wavelengths with smaller antenna array elements that can be packed together more tightly, it's feasible to implement antenna arrays with tens or even hundreds of antenna elements in the mmWave band."

Subcarrier Spacing

5G NR is a unified air interface that supports many frequencies, ranging from less than 1GHz to tens of gigahertz—about two orders of magnitude of change in the carrier frequency. Typically, the bandwidth scales with the carrier frequency to maintain a bandwidth-to-carrier frequency ratio within a certain range. Relying only on the number of subcarriers that support different channel bandwidths leads to a small number of subcarriers for small channel bandwidths, which has less multiplexing granularity. Such is the case when relying on a large number of subcarriers for large channel bandwidths, which increases hardware complexity, because it requires FFT/inverse FFT (IFFT) blocks with larger sizes. However, by allowing the subcarrier spacing to scale, it is possible to maintain a reasonable range for the subcarriers while still supporting a range of channel bandwidths. The subcarrier spacing is designed to scale in powers of two, where the supported subcarrier spacing is 15, 30, 60, 120, or 240kHz, with 240kHz in use only for synchronization signals and the broadcast channel.

Low-Latency Transmissions

5G NR introduces several technology improvements designed to support low-latency operations:

- Higher subcarrier spacing allows for shorter symbol and slot durations, which leads to lower latencies.
- Short physical downlink-shared channel and physical uplink-shared channel transmissions support as few as two symbols.
- Support of a flexible scheduling and timing framework with different UE processing capabilities empowers a 5G NR network to optimize a downlink and uplink transmission time, which is based on the UE's processing capabilities and the latency requirements of corresponding traffic.
- Support of preconfigured uplink resources (e.g., configured grant) enables the UE to transmit uplink data autonomously.

Channel Coding

5G NR introduced new channel coding schemes for data and control channels with a payload of 12 or more bits:

- For data channels, 5G NR supports Low-Density Parity-Check (LDPC) codes.
- For control channels with a payload of 12-bits or more, 5G NR supports Polar codes.
- For control channels with a payload of 3- to 11-bits, 5G NR supports Reed-Muller codes.
- For control channels with 1- or 2-bits, 5G NR supports Repetition or Simplex codes respectively

Massive MIMO in 5G NR

5G NR uses massive MIMO, the latest extension of the MIMO techniques, to establish a larger set of antenna arrays with a larger number of elements, thus increasing the efficiency of the 5G network infrastructure. The purpose of massive MIMO is to enhance wireless capacity by improving spectral efficiency through higher order spatial multiplexing and to enhance coverage using beamforming. 5G NR developed a flexible and scalable framework for massive MIMO, which supports:

- Carrier frequencies ranging from less than 1GHz to mmWaves
- Different kinds of antenna array architectures (digital, analog, and hybrid)

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- Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes of operation

There are two mechanisms to enhance spatial multiplexing, which 5G NR employs to optimize its MIMO framework:

- The first is to create a framework to support multiple transmission layers through multiple antenna ports for channel transmission.
- The second is to measure the channel to determine its rank, and then precode information and feed it back to the transmitter to optimally precode the transmission layers across the available antenna ports.

Downlink MIMO

In downlink MIMO, for single-user MIMO (SU-MIMO), the framework supports eight layers per UE, with up to four layers per code word. For multiuser MIMO (MU-MIMO), up to 12 orthogonal demodulation reference signal (DM-RS) ports exist across all UEs.

To determine the channel rank and MIMO precoding coefficients in the downlink, the network can use the Channel State Information (CSI) framework or the Sounding Reference Signal (SRS) framework. The CSI framework consists of two parts: CSI acquisition and CSI reporting. CSI acquisition relies on the CSI Reference Signal (CSI-RS) resource setting, which configures the CSI-RS resources. CSI reporting is done through the CSI report setting, which configures the resources on which the CSI reports. The network uses trigger states to configure a link between the CSI resource and CSI report settings. Alternatively, for TDD systems, the network can use the reciprocity of the downlink and uplink channels that transmit in the same frequency band and use the SRS framework. Using the SRS framework, the UE transmits SRSs on multiple antenna ports. The NR Node B (gNB) measures the channel quality and rank according to the uplink channel and uses this information to determine the channel rank and MIMO precoding coefficients in the downlink.

Uplink MIMO

The uplink MIMO can be either codebook-based or non-codebook-based. For the codebook-based uplink MIMO, the base station measures the uplink channel on the antenna ports of the SRS resource and determines the rank and codebook index of the uplink transmission. For the non-codebook-based uplink MIMO, the UE transmits multiple antenna-precoded SRS resources according to the downlink CSI-RS channel measurements. The base station measures the channel on the SRS resources. Uplink precoding of data at the UE follows the precoding of the SRS resources, which the base station indicates.

Beamforming in 5G NR

Beam management defines a set of procedures that enable transmission and reception of beams in a certain direction within a cell, with narrower angular coverage than cell-wide transmission and reception. One key distinguishing feature of NR is its ability to support beam-based operations. Channels and signals that the base station and UE transmit and receive are beamformed to focus the transmitted energy in a certain direction and thus improve antenna gain. This capability is extremely beneficial for mmWaves, which suffer high propagation losses. It's also a useful capability for sub-6GHz transmissions.

Beam management involves the following elements:

- **Beam determination.** Multiple beams cover a cell. Each beam is determined by a source RS and its index. These beams help the base station and UE properly set their transmit and receive beams for the subsequent transmission of downlink and uplink channels and signals.
- **Beam measurement and beam reporting.** The UE measures the signal quality of each beam and reports each measurement to the network. A measurement can be reported explicitly (e.g., as an RS receives power using the CSI framework) or implicitly (e.g., by transmitting on a resource associated with a beam that meets a signal quality criterion). The network uses this information when determining the beams to use and configure when communicating with the UE.
- **Beam sweeping and beam refinement.** This functionality allows for the refining of beams (i.e., using narrower beams) and the tracking of beams (i.e., as the UE moves around or changes orientation).
- **Beam association for downlink and uplink channels and signals.** This framework associates the RS of downlink and uplink channels with a beam's source RS. The association is based on Quasi Co-Location (QCL) and the Spatial Rx parameters (known as QCL Type D).
- **Beam failure recovery.** This feature allows for a rapid realignment of the base station and UE beams when a beam is lost, such as during a sudden blockage or upon a fast rotation or movement of the UE.

Coming Soon: Release 16

Release 15 is just the first step toward realizing the 5G vision. 3GPP is working at full speed toward completion of the second phase of 5G NR, known as Release 16. The organization is targeting the completion of Release 16 in two stages:

Stage 1: Late 2019 for the physical layer aspects
Stage 2: Early 2020 for the higher layer aspects

Release 16 introduces new capabilities to address the needs of vertical markets, thereby improving the operational efficiency of the Radio Access Network and further enhancing capacity and spectrum efficiency.

38 Series

3GPP introduced a new series of specifications for NR—the 38 series. Each 3GPP Radio Access Network (RAN) Working Group (WG) handles a different set of these specifications. Release 15 specifications have a version number V(15.x.y), where a larger x and y value indicate a more recent specification. The full list of the 3GPP specifications can be found on the 3GPP website:

- For RAN WG1, which deals with Radio Layer 1, the full list of specifications can be found here: http://www.3gpp.org/DynaReport/TSG-WG--r1.htm.
- For RAN WG2, which deals with Radio Layers 2 and 3, the full list of specifications can be found here: http://www.3gpp.org/DynaReport/TSG-WG--r2.htm.
- For RAN WG3, which deals with radio network architecture and interfaces, the full list of specifications can be found here: http://www.3gpp.org/DynaReport/TSG-WG--r3.htm.
- For RAN WG4, which deals with radio performance aspects, the full list of specifications can be found here: http://www.3gpp.org/DynaReport/TSG-WG--r4.htm.

5G Infrastructure Enables New and Radical Applications

By M. Tim Jones for Mouser Electronics

M. Tim Jones is a veteran embedded firmware architect with over 30 years of architecture and development experience. Tim is the author of several books and many articles across the spectrum of software and firmware developments. His engineering background ranges from the development of kernels for geosynchronous spacecraft to embedded systems architectures and protocol developments.

Not only will the new Fifth-Generation (5G) wireless infrastructure open the door to new applications, but it will greatly improve the applications that exist today for 4G and earlier wireless generations. With the 5G network's enhanced performance, communication will be faster, with improved interactivity resulting from a significantly lower latency. That's great for the consumer experience as well as for machine-to-machine (M2M) communication.

5G will include three classes of services, all delivered through a single mobile network:

- **Enhanced mobile broadband (eMBB).** Content and service access by humans
- **Massive machine-type communications (mMTC).** Data exchange between low-power devices with relaxed levels of service
- **Ultra-reliable low-latency communications (URLLC).** Data exchange between devices with strict levels of service

This article explores how 5G enhancements will improve existing applications and create a platform for even more innovative applications.

5G Wireless and Applications

5G communication is a means to an end (it's about communication between devices), but it's a true enabling technology that improves existing applications. Let's explore what the 5G wireless network means for both existing applications and emerging ones.

Internet Enablement

The earliest and largest implementation of the 5G network will focus on bringing Internet connectivity to consumer smartphones and tablets. With the speed and low latency of 5G wireless connectivity, consumers will also see 5G connectivity as the conduit to Internet access not just for consumer devices but also for homes (fixed wireless access). Technology such as beamforming (which can focus a signal as a beam that points toward a user rather than broadcasting in all directions) will improve the integrity of the user's signal while minimizing signal interference to other users.

Virtual and Augmented Reality

In virtual reality (VR), a headset constructs a synthetic (computer-generated) world with which a user can interact. The VR headset includes real-time head tracking that enables the view of the world to change based on the user's control. Augmented reality (AR) does not construct a synthetic world; instead, it overlays synthetic objects onto a user's view of the real world using either a headset or smartphone.

Both technologies will benefit from the advanced capacity of a 5G network: 5G speed will support construction and transmission of a synthetic world from a remote cloud (called cloud rendering) to a VR device. 5G low-latency communication will permit a quick response to head movements, rendering only what's necessary for a user's current view of the world.

The Internet of Things

The Internet of Things (IoT) refers to an Internet connectivity to everyday objects (e.g., dishwashers, doorbells). The speed and capacity available with 5G will lead to an explosion of new IoT devices and services, but not until the cost is reduced. In part, this expansion will be the outcome of the 5G network's ability to connect to a large number of devices in a small area (i.e., a million endpoint devices in a square meter area). One way 5G may support communication to a large number of devices in an area is through what's called multiple-input, multiple-output (MIMO). MIMO

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can involve increasing the number of antennas for a base station to widen its network capacity; it can also refer to sending and receiving more than one data signal over the same radio channel using multipath propagation. In either case, it means greater capacity to communicate with more devices without the requirement of additional radio spectrum.

Autonomous Vehicles

Autonomous vehicles (AVs) are automobiles that can navigate without human input—for example, a self-driving car. AVs work today without the 5G wireless infrastructure, but with faster, lower latency 5G communication, new services will become possible for the emerging AV technology. Such improved communication could offer a range of services for a driver or passengers, including entertainment (e.g., video, music) and broadband access. A driver could benefit from automatically adjusted navigation and routing through integrated accident or severe traffic updates or benefit from vehicle-to-vehicle (V2V) communication to optimize traffic flow, such as through creating a localized coordination of lane changes between vehicles.

Surveillance

Surveillance, or video- and audio-based monitoring of activities or behavior, will experience significant changes with 5G technology. Most surveillance solutions today rely on Internet Protocol (IP) networks, which are connected through Wi-Fi to an Internet service provider (ISP) that can offer limited bandwidth. Many of these solutions permit two-way communication, but this communication can be hindered by IP networks that are asymmetric (i.e., that have high download speeds but slower upload speeds).

The available bandwidth that a 5G network will offer will enable smooth streaming of higher-resolution video, such as 1080p high-definition (HD) video, which third-generation (3G) or fourth-generation (4G) wireless networks cannot easily support.

The speed of 5G communication will support real-time face detection and recognition in the cloud. As a camera grabs high-resolution (hi-res) frames of video, it will be able to upload each frame into the cloud for processing. This process can be optimized by performing face detection at the camera and then distributing the detected faces (the framed regions for each given face) to independent servers in the cloud. This step will facilitate better use of the 5G infrastructure because the images sent to the cloud will be smaller and can then be processed as they are received, parallelizing the complex recognition process.

Smart Cities

A smart city is one that deploys various types of IoT sensors (representing meters, controllers, lighting, displays, etc.) and uses the resulting data in a way to manage a city and its resources efficiently—including transportation, power, water, waste, crime, and pretty much any area of a city that can produce data. For example, as waste vehicles collect recyclables, they can calculate mass and predict the flow of trash to waste facilities and determine the facilities' ability to process the waste.

The idea of a smart city has been around for more than a decade, but what has been missing is a way to efficiently communicate with the mass of sensors that exist within a city: For example, where sensors distributed around an area can detect flooding (including depth and flow). 5G technology provides the platform through which all these sensors can coexist and communicate between themselves and centralized cloud infrastructures. Only a 5G wireless network can support the scale of data that IoT sensors produce and amass at the scale of a city, with the cloud providing the scalable processing necessary to manage this elastic set of processing demands.

Entertainment

The application of a 4G network commonly occurs in delivering content to endpoints such as phones or tablets: Consider users watching videos on their devices. Some types of data, such as sporting events or concerts, delivered in real time cause issues. Even if many users are streaming the same content, the network delivers it independently to each user. Multimedia Broadcast/Multicast Service (MBMS) enables users to share the content delivered through one stream, reducing the bandwidth that the data uses. This functionality has been extended with MBMS on demand (MOOD), which allows dynamic switching from a unicast to a multicast delivery when the number of devices accessing the same content exceeds some defined threshold. With the growth of content that will travel through the 5G network, MOOD can transform digital television.

Cloud-Based Gaming

Cloud-based gaming (also called gaming on demand) enables users to play a game the cloud hosts on a peer device (such as a smartphone, computer, or smart TV), where the game video-streams to the peer device in much the same way other videos stream. The recently announced cloud-gaming platform developed by Google®—called Stadia™—could be a significant recipient of 5G capabilities. The platform pushes the high-level computation of a game and video rendering to the cloud using a peer device, such as a tablet, streaming the game video and taking user input for game control. 5G bandwidth and low latency make it ideal for gaming in the cloud.

Cloud Storage

Another interesting application of this new, fast 5G conduit is the so-called Storage as a Service, which extends the storage capabilities of a device by employing elastic storage in a cloud infrastructure. Equipping a device with cloud-based storage makes your data secure, not tied to a given device. The result is data sharing between devices as well as an increase of reliability and availability of the data through cloud-based data protection. It also opens availability to a user's full library of content, which can otherwise be limited by the storage capability of an end device. A 5G network offers the bandwidth and latency to empower this application.

Summary

As technology evolves, it eventually reaches the limits of what's possible. Product developers then attempt to work around the limitations to fit their features into the available technology. The new 5G wireless infrastructure provides the platform and technological leap to extend communication limits for a new frontier of product offerings. Whether the limitations result from bandwidth, latency, or density, the 5G network represents a catalyst for new products and new experiences for consumers. 5G technology also provides a new fabric for mixed computing environments such as the IoT, where devices continue to rely on cloud-based infrastructures.

Ecosystems of 5G Engineering: Infrastructure

By Barry Manz for Mouser Electronics

Barry Manz is president of Manz Communications, Inc., a technical media relations agency he founded in 1987. He has since worked with more than 100 companies in the radio frequency (RF) and microwave, defense, test and measurement, semiconductor, embedded systems, lightwave, and other markets.

The fifth generation (5G) of what used to be called cellular radio is like none before it. It encompasses not just smartphones and tablets but almost everything that can benefit from being connected to other things and the Internet. For the first time, connecting businesses is as important as connecting consumers, and while mobility remains the core focus of the 5G operating environment, 5G will also serve many fixed applications. Whether catering to mobile or fixed applications, the 5G infrastructure will still need base stations—orders of magnitude more of them, in fact, than currently exist—but deploying these base stations may be the most challenging task in developing a complete 5G ecosystem.

“...connecting businesses is as important as connecting consumers...”

Virtualization

The impact of 5G on the current wireless infrastructure affects all three major use cases: Traditional mobile, called enhanced mobile broadband (eMBB); massive machine-type communications (mMTC) Internet of Things (IoT) environments; and the newest and most demanding use case, ultra-reliable low-latency communications (URLLC). Serving all three of these use cases requires a change from a hardware-based network architecture to one that’s virtual and based on network function virtualization (NFV), software-defined networking (SDN), processing and analytics at the network’s edge, network slicing, and other technologies new to the wireless infrastructure.

The transition from hardware- to software-based (i.e., virtual) networks affects base stations of all sizes. The two “virtualizers” of this new paradigm—NFV and SDN—perform similar functions because they provide far greater network control using less hardware, thus reducing or eliminating changes to hardware as the network evolves. The capacity of these virtualizers also means less hardware may be necessary.

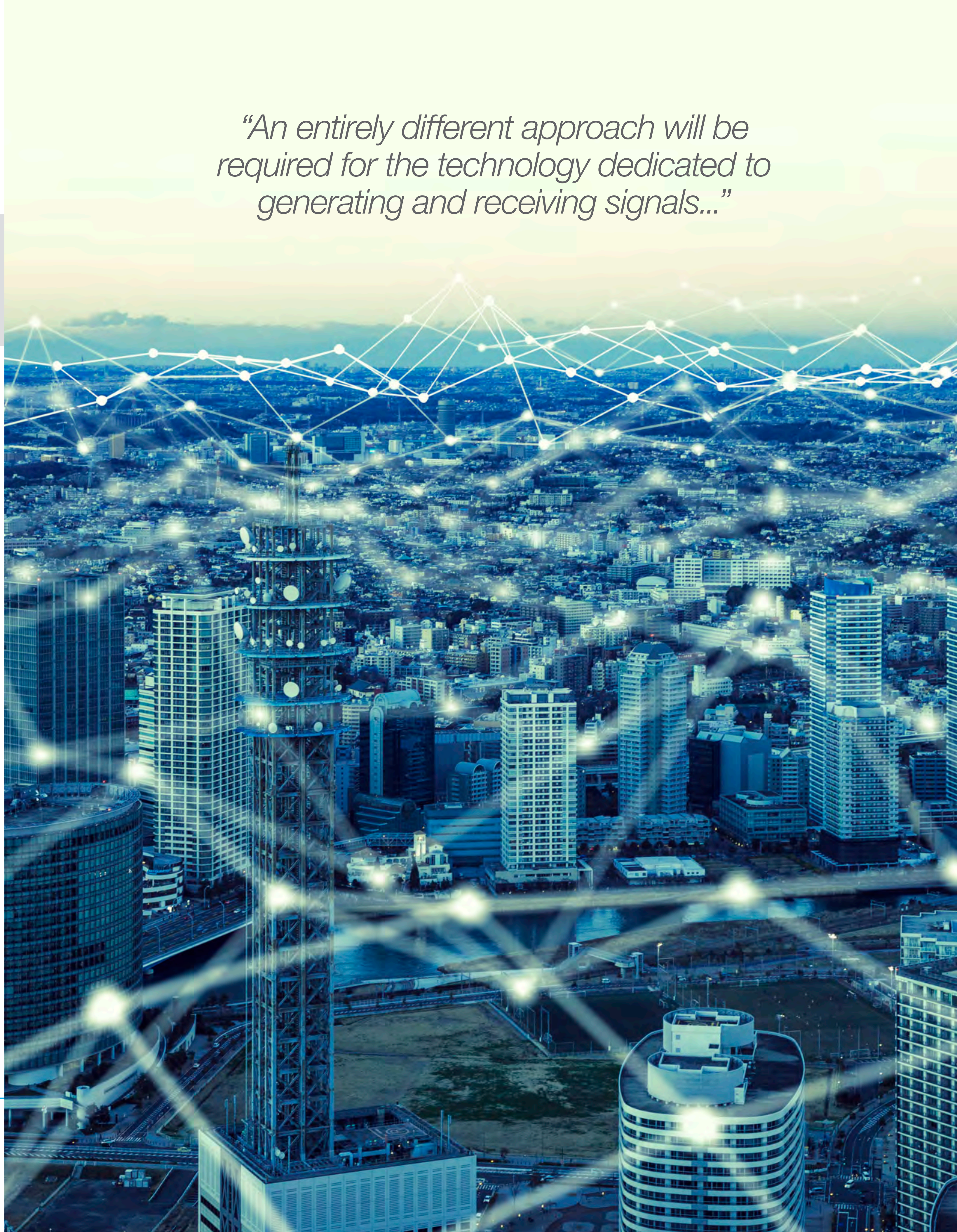
Network Virtualization Using the Digital Domain

The benefits of network virtualization are now being realized as virtualization empowers software to perform functions in the digital domain rather than through analog and digital hardware, as has been the case before. Still, this shift to virtualization will quite obviously require substantial computational resources, a point that has not been overlooked by Arm Limited (Arm®), an organization best known for its architectural designs for smartphones, network processors, and embedded processors.

Arm’s first computing ecosystems tailored exclusively for servers and infrastructure design are the Neoverse™ series of processors. Each processor in the series includes not just a central processing unit (CPU) core but an interconnected scheme, making it possible to scale up to many cores. Neoverse processors will likely find a home at the network’s edge, where high-performance computing is increasingly becoming necessary. These processors are also well suited for 5G base stations, which will ultimately handle much more data than 4G Long-Term Evolution (LTE) networks but with greater DC power constraints.

Toward Higher Spectral Efficiency

An entirely different approach will be required for the technology dedicated to generating and receiving signals



***5G promises** to allow everything that would benefit from connectivity to achieve it, and that require massive infrastructure. (Source: Getty Images)*

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A classic three-sector macro base station. Within each long, rectangular radome are multiple antenna elements that expand the capacity of the base station using techniques such massive MIMO and beamforming. (Source: Getty Images)

over the air. For example, techniques such as massive multiple-input, multiple-output (MIMO) that rely on digital signal processing (DSP) still need to convert the analog signal to a digital form. Fortunately, major advances are being made to address this need from lower frequencies to the microwave, and millimeter-wave regions, with semiconductors that generate and receive RF signals to and from the antennas.

RF Output Power

For the past two decades, base station RF power amplifiers (PAs) have used lateral double-diffused metal-oxide semiconductor (LDMOS) field-effect transistors to generate RF power in macro-base stations. This technology has advanced dramatically over the years with respect to the amount of power a single device can generate (currently, about 2 kilowatts [kW]) and use efficiently, beating every other potential competitor. But, LDMOS has a maximum useful operating frequency of about 4 gigahertz (GHz), which eliminates its use at most of the new frequencies proposed for 5G networks. The technology that will take the mantle is gallium nitride (GaN), which, in the less than 15 years it's been commercially available, has cemented its place as the next big thing in RF power.

For example, a GaN semiconductor die can produce 10 times the RF power output per unit of die than gallium arsenide (GaAs), with higher efficiency, higher-voltage operation, and superior thermal characteristics. GaN on silicon carbide (SiC) substrates offers better performance than GaN on silicon substrates, but it also costs more. This means that the latter will find a home in cost-critical small cells, where it will compete with GaAs, the predominant power semiconductor technology that has been used in smartphones for many years.

At millimeter-wave frequencies, where high RF output is difficult to achieve in a solid-state device, silicon germanium (SiGe), complementary metal-oxide semiconductor (CMOS), and GaAs will be the key technologies. All these technologies, except LDMOS, will also be important for either RF power generation or receiving applications, such as low-noise amplifiers (LNAs).

RF Front Ends: Packaging Functional Integration

The 5G infrastructure will require that manufacturers of microwave and millimeter-wave devices increase their functional integration to reduce costs, complexity, and size and meet the needs of small cell base stations (as well as end-user devices). Packaging technology will be an essential ingredient in achieving this goal because although 4G increased the number of bands that a radio must accommodate to about 30, 5G will increase this number to 40 and perhaps more. Accommodating all these bands in a single device is unlikely, especially considering each band has different characteristics and thus requires different technologies. Nonetheless, each band segment, from sub-1GHz to millimeter wavelengths, must be as highly integrated as possible.

To create these highly integrated RF devices, manufacturers of RF front ends (RFFEs) are taking a variety of approaches. Let's see what approaches Analog Devices, Skyworks Solutions, and Qorvo are taking to fabricate products that accomplish this feat.

Analog Devices®

Analog Devices is producing transceivers within its RadioVerse™ family (which is dedicated to accommodating all 5G applications from sub-1GHz to 6GHz). The three devices in the family are housed in 10 x 10mm packages and target picocells to distributed antenna systems and IoT gateways. They also operate from 325 megahertz (MHz) to 3.8GHz.

Analog Devices' AD9361 and AD9363 are highly integrated devices that include dual transceivers with four outputs, fractional N synthesizers, and 12-bit digital-to-analog and analog-to-digital converters (DACs/ADCs). They also have a tunable channel bandwidth up to 20MHz. Six differential inputs or 12 single-ended receive inputs are available along with CMOS and low-voltage differential signaling interfaces. The AD9364 covers 70MHz to 6GHz with a tunable bandwidth from 700 kilohertz (kHz) to 56MHz, and it's designed for use in base stations from 3G onward as well as in point-to-point microwave links.

Among the other products in Analog Devices' portfolio is the ADRV9009, an integrated transceiver with dual transmitters and receivers as well as DSP functions. It serves 3G through 5G macrocells (and other applications) and covers 75MHz to 6GHz with a maximum channel bandwidth of 450MHz.

Skyworks®

The goal of Skyworks Solutions' recently announced platform, called Sky5™, is to serve the transmit and receive sections of the low-band, mid-band, high-band, and ultra-high-band frequencies of 5G. Sky5 accomplishes

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this task by offering antenna management, MIMO, and diversity as well as modules for the Global Positioning System (GPS), Wi-Fi, and Licensed-Assisted Access (LAA) frequencies. Sky5's product family includes PAs with integrated filters and duplexers as well as switches.

Qorvo®

Qorvo introduced the industry's first 5G integrated RFFE module, called the QM19000, in 2017. The module was fabricated in the company's GaAs heterojunction bipolar transistor process and integrates a PA, LNA, transmit/receive switch, and filter into a single module with a 400MHz channel bandwidth between 3.3 and 4.2GHz. The QM19000 supports the two amplifier schemes necessary to serve both 4G LTE and 5G, envelope tracking (ET), and average-power tracking (APT). The QM19000 module can switch between the 4G LTE and 5G technologies using an advanced power management scheme (PMS). Both the ET and APT technologies are required because ET currently supports channel bandwidths of only 60MHz, which is fine for 4G but not for 5G's more than 100MHz channel bandwidths, which APT can accommodate.

For millimeter-wave operations, Qorvo offers the dual-channel QPF4005, which covers 37 to 40.5GHz and is designed for small cell base stations with phased-array antennas. The QPF4005 is notable for being the first RFFE fabricated in GaN-on-SiC as a monolithic-microwave integrated circuit (IC). It combines an LNA, transmit/receive switch, and multistate PA in a 4.4 x 6mm package that is configured to accommodate the tight spaces between antenna modules in a phased array.

Summary

The good news for manufacturers and carriers is that all the necessary technologies to fully implement the 5G infrastructure won't be needed all at once, so developments can continue apace as networks are deployed in the number that is essential to blanket coverage areas. Considering this flexibility in the 5G infrastructure, all signs point to 5G rolling out faster than early projections indicated.

Verizon™, AT&T®, and T-Mobile® continue to add more and more cities to the list of where 5G wireless is available, although these additions are more like advanced trials than commercial services because wide-area coverage has not yet been deployed, so the early adopters who take the plunge may be less excited than the 5G hype indicates. After all, these are the early days of 5G networks, so the best is yet to come.

The High Road to 5G Infrastructure

By Barry Manz for Mouser Electronics

The first tangible evidence of Fifth-Generation (5G) infrastructure has not been in mobile network base stations but rather in the Verizon™ fixed-wireless access (FWA) base stations for very high-speed broadband delivery to homes and businesses. This move has seemed counterintuitive for many people for two reasons:

- **First,** FWA at millimeter wavelengths was attempted before—in the late 1990s as a local multipoint distribution system (LMDS), which during its short life was supposed to be a wireless "last-mile" solution and operated between 27 and 31 gigahertz (GHz). This solution died a sudden death because the required technology wasn't ready; what was available was expensive; customers were few; and there was little prospect of delivering content because there was no content.
- **Second,** Verizon has hurtled headlong toward one of the most difficult challenges in deploying 5G wireless infrastructure: That is, deploying and operating equipment in the millimeter-wave region of the spectrum—a core element of the 5G ecosystem thanks to immense amounts of available bandwidth--presents significant challenges and has never been attempted before.

These challenges include fabricating and deploying cost-effective millimeter-wave equipment, and dealing with the short signal propagation distance achievable at these frequencies, along with severe attenuation almost anything from foliage to precipitation; and even low-emissivity glass used in modern homes and buildings. Propagation is also entirely line of sight, which limits range and requires more base stations to serve a given area as well as massive Multiple Input Multiple Output (MIMO) capabilities. Look a bit closer, though, and tackling millimeter-wave operation first may turn out to be a brilliant stroke. Think of it as a high-tech version of the camel's nose parable. Here's why:

Deploying wired technology has become prohibitively expensive, even though it delivers speeds that are far faster than hybrid fiber-coax (HFC) cable. Moreover, fiber to the home (FttH) has never taken off because, as a wired service, it—like HFC—is still expensive to deploy. Verizon, the major United States FttH provider, has deployed it in few places and now has nearly stopped (as AT&T® has likewise), although both companies are currently deploying fiber at lightning speeds for other applications—which in the case of Verizon—has been at a rate of more than 1,000 miles per month.

Millimeter-wave FWA

In contrast to cable and FttH, millimeter-wave FWA has the potential to exceed the speeds of both wired technologies, with no permitting issues or complex customer premise equipment (CPE). The millimeter-wave FWA base stations typically reside on existing utility poles, while CPE equipment consists only of a millimeter-wave transceiver with multiple-input, multiple-output (MIMO) or multi-user MIMO MU-MIMO) capabilities. The end-user device is also a router, and the antenna is mounted either

This small home-based antenna is typical for fixed wireless-access reception at low microwave frequencies. System installations at 28GHz are even smaller. (Source: Wikimedia Commons)

indoors or outdoors depending on the characteristics of the installation. FWA also provides a testbed for the deployment of the millimeter-wave technology, which will be vital once the mobile portion of the 5G rollout arrives and later for use in the industry's "cellular-to-everything" architecture for autonomous vehicles.

The main question is whether the latest attempt to use millimeter wavelengths to deliver broadband will prosper or suffer the fate of its LMDS predecessor. The latest results from the field show that achieving acceptable coverage will require much more infrastructure than projected, which alone could make the service economically unfeasible. The ultimate determinant, however, will be potential customers and whether "if you build it, they will come."

5G Antenna Design

By David Talbott for Mouser Electronics

David Talbott is an information technology (IT) and technology analyst with Mighty Guides®. David's focus is on emerging technologies including deep learning, cloud and edge computing, and ubiquitous connectivity and how these technologies converge to create powerful self-learning systems.

The Fifth-Generation New Radio (5G NR) communications framework provides an entirely new approach to cellular communications. It supports scalable waveforms, multiple access schemes, and service multiplexing across wide bandwidths. It also supports existing services while being forward compatible with future requirements.

Although 5G wireless requires more complex signal processing and the ability to handle much higher data rates than previous protocols, one of the keys to its success is antenna design. This article reviews how 5G use cases and the 5G specification are changing antenna designs and how these new designs are overcoming some of the greatest difficulties in implementing 5G networks.

The 5G NR Specification and What It Means for Antenna Design

5G was conceived as a specification to deliver the following capabilities:

- **Enhanced mobile broadband (eMBB)** for data-intensive applications such as augmented reality (AR), three-dimensional (3D) video conferencing, two-dimensional (2D) streaming video, fixed wireless access to Internet connectivity, and other high-bandwidth applications
- **Massive machine-type communications (mMTC)** for direct Internet of Things (IoT) connectivity on a massive scale, including high-density arrays of sensors and devices in connected cities and homes, devices for monitoring complex global supply chains, and connected devices moving at high speeds
- **Ultra-reliable low-latency communications (URLLC)** for mission-critical, real-time applications such as industrial control systems; autonomous vehicles (AVs); and applications that require high bandwidths, high reliability, and low latencies, such as remote real-time surgeries

Meeting these mandates requires a new spectrum. 5G wireless has been assigned a new spectrum in low and mid bands (up to 6 gigahertz [GHz]) and in high bands (with millimeter wavelengths above 24GHz). One challenge for 5G antenna designs is that some devices need to operate in multiple bands. Another is that millimeter wavelengths transmitted at cellular network power levels are subject to higher absorption by buildings, vegetation, and raindrops than low and mid bands. This limits millimeter wavelength communications to line of sight, which necessitates small cell networks that can increase chances of edge interference between cells.

There are also antenna size considerations. Although higher frequencies allow smaller antennas to achieve the same level of gain, smaller antenna areas capture less energy, resulting in a shorter effective range than lower frequencies. On the other hand, an antenna with a fixed physical area increases gains for both transmissions and receptions as a frequency increases and beam width shrinks. The optimum antenna size for different implementations will balance size versus gain tradeoffs.

5G Antenna Technology and Designs

Meeting 5G NR objectives requires new antenna designs that use active antenna arrays to provide better coverage, reduce interference, and increase data carrying capacity.

Accommodating the Full Spectrum of 5G Frequency Ranges

To operate in its full range of assigned frequencies, 5G NR uses a scalable framework that functions at frequencies between 450 megahertz (MHz) and 6GHz (frequency range 1 [FR1]) and between 24.25 and 52.6GHz (frequency range 2 [FR2]).

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5G NR does this by using scalable orthogonal frequency-division multiplexing (ODFM) waveforms that allow different subcarrier signal spacing to fit the various channel widths that different frequency ranges provide. Higher frequencies provide wider channels and greater subcarrier spacing. Lower frequencies use smaller channel widths and narrower subcarrier spacing. Scaling subcarrier spacing to available channel widths enables the 5G framework to operate across a broad range of frequencies. The result makes it possible to deploy 5G in existing 4G Long-Term Evolution (LTE) networks. It also makes it possible for 5G communications systems to switch between low- and high-frequency bands based on use cases or workload requirements.

The challenge for antenna designers is physics. A 1GHz signal, which is in FR1, has a wavelength of about 30 centimeters (cm). A 28GHz signal in FR2 has a wavelength of 1.07mm. The same antenna will not work for these two signals, so 5G devices operating in both FR1 and FR2 bands will require at least two sets of antennas. This is manageable in large equipment and base stations that have room for multiple antenna arrays. It becomes a significant design challenge for small devices and cell phones. Some manufacturers—Qualcomm®, for instance—have begun releasing compact radio-frequency (RF) modules capable of operating with antenna arrays in multiple 5G bands.

Device Density, Data Throughput, and Massive MIMO

One challenge presented by the 5G specification is the need to support much higher densities of connected devices that are operating simultaneously at much higher data rates. This will require higher cell densities and more extensive use of the multiple input, multiple output (MIMO) antenna technologies already in use in 4G LTE networks. MIMO is an antenna array of multiple transmitting and receiving antennas (which in current LTE networks, often contains an 8 x 8 antenna array). MIMO uses spatial multiplexing to break a signal into encoded streams that it simultaneously transmits through different antennas in the array. Both the transmitting and receiving devices have multiple antennas and signal processing for encoding and decoding multiplexed signals. This makes it possible to:

- Communicate with multiple users and devices simultaneously.
- Communicate with higher throughput.

Many variations of MIMO exist. A key variation for 5G is massive MIMO (mMIMO), an antenna design that packs many more antenna elements into a dense array than previous MIMO versions. Lower-frequency antennas are larger, which creates practical limits to how many antenna elements will fit in a reasonably sized low-frequency MIMO array. Millimeter wavelengths work with much smaller antennas, which makes it possible to build mMIMO arrays in small packages. Some manufacturers are building mMIMO antennas that contain 128 elements. By increasing the number of data streams, mMIMO increases signal capacity without requiring more spectrum, which in turn increases data rates and link reliability.

Beamforming, Directionality, and User Equipment Tracking

Beamforming is a method of shaping a transmission to create a well-defined antenna pattern targeted at a specific receiving antenna. It is done by adjusting phase and amplitude transmissions through different antenna elements in an array of equally spaced antennas. Beamforming can be used to reduce interference, and it also increases range by concentrating beam energy. Initial 5G deployments using mid-band frequencies will employ 4 x 4 or 8 x 8 MIMO antennas set up to enable beamforming, similar to what is currently available in LTE. High frequency (millimeter wavelength) 5G deployments will take advantage of adaptive arrays using larger mMIMO antennas with many more antenna elements and capable of tighter beamforming and real-time steering.

5G beamforming depends on a transmitting device's determination of the optimum signal path to its receiver. The transmitter does this by analyzing the sounding reference signals (SRSs) sent between the transmitter and the receiver, and then evaluating these signals to establish the channel state. Based on channel state information (CSI), the transmitter applies beamforming algorithms that transmit shaped radio patterns in the optimum direction and during the best schedule for the best reception. Beamforming will bounce transmissions off buildings if that is the optimum path to a receiver. In an environment where many devices use the same mMIMO channels, algorithms will time data packets to avoid packet collisions, minimizing signal interference.

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To avoid interference and signal interruptions, transmitters continuously track receiving equipment and recalculate optimum data paths. This enables transmission adjustments in real time to ensure consistent, uninterrupted data connections when 5G devices (for example, vehicles or cell phones) move or when objects block an optimum signal path. Beamforming is a calculation-intensive process that requires active MIMO antennas with robust signal processing capabilities.

Downlink and Uplink Requirements

The 5G specification facilitates a maximum downlink data rate that is twice the uplink data rate in given use cases. In current deployment phases below 2.6GHz, 5G requires at least a 4 x 4 downlink MIMO and recommends at least a 2 x 2 uplink MIMO.

Antenna Designs for Different Use Cases

5G deployments will require many antenna packages for indoor and outdoor use, small cell and macro-coverage, and many different kinds of terminal equipment. The following are some 5G antenna design considerations based on several common deployment cases.

Base Stations

Most cell phone towers today are highly congested. Building compact 5G antennas that integrate lower and higher frequencies is the most cost-effective solution. In addition, placing antennas on light poles and corners of buildings for small cell coverage will require compact designs. Several telecom operators have begun deploying small 4G cells to address bandwidth and latency issues. Early 5G deployments will involve placing 5G antennas beside existing 4G LTE antennas or installing replacement antenna units that serve as both 4G LTE and lower-frequency 5G antennas in one.

Eventually, different frequency ranges will be used for different implementations. For example, some outdoor coverage in 700MHz-range macro and small-cell implementations will operate in the 3 to 5GHz range. High-bandwidth indoor and outdoor applications will likely take advantage of micro-cell architectures that use distributed antenna systems. As this higher frequency 5G rolls out, mMIMO arrays with many antenna elements will help reduce network congestion and increase base station capacity.

User and Terminal Equipment

Data, communication requirements, operational frequencies, and equipment design will dictate antenna designs in different 5G applications. There are many uses for 5G connected sensors and control equipment, especially in manufacturing, infrastructure monitoring and control, agriculture, and fixed wireless Internet access, to replace cable connections. Sensors and controllers optimized for low-data rates and low latencies will need to operate at specific frequencies. Fixed wireless Internet access is likely to use a combination of sub-6GHz frequencies for control plane signals and millimeter wavelengths that deliver high throughput and low latencies for end-user equipment. Other applications, such as autonomous vehicles, will have more complex requirements involving vehicle-to-anything (V2X) communications, which include low-latency control functions and high bandwidth requirements. Vehicles offer flexibility for embedding antenna arrays into the bodies of the vehicles themselves.

Cell Phones

Cell phones are already packed with antennas, so adding antennas to support the full range of 5G frequencies will be a challenge. These phones also have limited real estate, but they will need MIMO antennas for high-level performance and antennas located on the phones' edges and corners that support beamforming, specifically to compensate for objects that block millimeter waves (mmWaves), like a user's hand.

The Challenges of 5G Antenna Designs

5G antennas have a key role to play in making 5G communications work, but they present engineering challenges. Antenna designers typically begin with antenna simulation software that, given certain assumptions, can project signal fields. But, this is only a first step.

A significant challenge in 5G antenna designs is antenna testing. 5G antennas are not static, omnidirectional devices. They are active, and they beam their transmissions to specific devices. Putting a 5G antenna in a test room and applying a static test does not show how it will perform when it is simultaneously communicating with a thousand moving devices in a noisy RF environment. Most antenna designers are not sure of the most effective means to test or validate performance for devices that use mMIMO arrays. Testing methods will likely involve scenario-based automated testing.

5G antenna designs are still very much a work in progress. The initial phase of the 5G deployment is just beginning, and it will involve installing low-frequency 5G to work in collaboration with 4G LTE. This is the testbed for future deployments requiring more complex antenna designs. M

Finding Convergence in 5G Security

By Stephen Evanczuk for Mouser Electronics

Stephen Evanczuk has more than 20 years of experience writing for and about the electronics industry, discussing a wide range of topics including hardware, software, systems, applications, and the Internet of Things (IoT). Dr. Evanczuk received his PhD in neuroscience with an emphasis on neuronal networks.

Enabled by the convergence of a broad array of advanced technologies, 5G networks promise to wirelessly interconnect devices, individuals, enterprises, and nations at unprecedented levels of performance and service. The technologies underlying the 5G infrastructure complete the digital transformation of communications networks, offering a more fluid fabric needed to respond to fast-changing demands. In protecting these networks and their users the challenge lies in ensuring that those diverse technologies combine to serve as a shield rather than a sieve to cyberattacks. Because 5G networks are expected to reach into every aspect of the connected society, the need to respond to this challenge is critical.

Across the layers of the 5G network hierarchy, core technologies shift the nature of mobile communications, sometimes in profound ways. At the lowest layer, the 5G wireless millimeter wave (mmWave) frequencies dramatically boost available bandwidth, but also bring a fundamental change in the network topology. Instead of the large cell towers of current cellular networks, the reduced range and limited structure-penetration capability of GHz-frequency signals dictate the need for a closer distribution of more 5G cells. Placed in neighborhoods or even individual buildings, small 5G cells are the most evident transformation of the new network architecture—one that more closely resembles a hierarchical distributed computing environment than a communications network. In the 5G infrastructure, a radio access network (RAN) built around those small cells interact with a software-based 5G core network cloud, using local multi-access edge computing (MEC) systems to reduce latency to end devices and to provide local processing that reduces the load on the cloud.

Although small cells are often closely associated with a user's view of a 5G network, the 5G core is the centerpiece of this new software-based communications framework. As with current public cloud services, the 5G core unshackles applications and services from the underlying hardware foundation using software technologies built around the concepts of software-defined networking and virtualization:

- **Software-defined networking (SDN)** separates control and data planes to provide greater flexibility in the communications network configuration and performance. This process permits data flow through the core in any number of defined paths.
- **Virtualization** separates application- or service-level functionality from hardware resources. This separation means that network providers can scale the computational backbone and deploy virtualized services to meet changing performance demands. As discussed further below, this capability also allows providers to add specialized services at any point in a network without the costs and delays traditionally required to provision resources at specific physical locations in a network.

MEC: A Security and Privacy Enhancer

SDN, virtualization, and cloud services are by no means new. Yet, their use in combination with other software-based elements in the 5G hierarchical architecture presents a novel set of capabilities that can enhance security. The availability of MEC resources can significantly enhance security and privacy in these networks. For better security, these edge computing resources can employ more extensive operational methods within their local RAN and provide vital maintenance support such as cell commissioning/decommissioning and secure over-the-air (OTA) updates of cell firmware.

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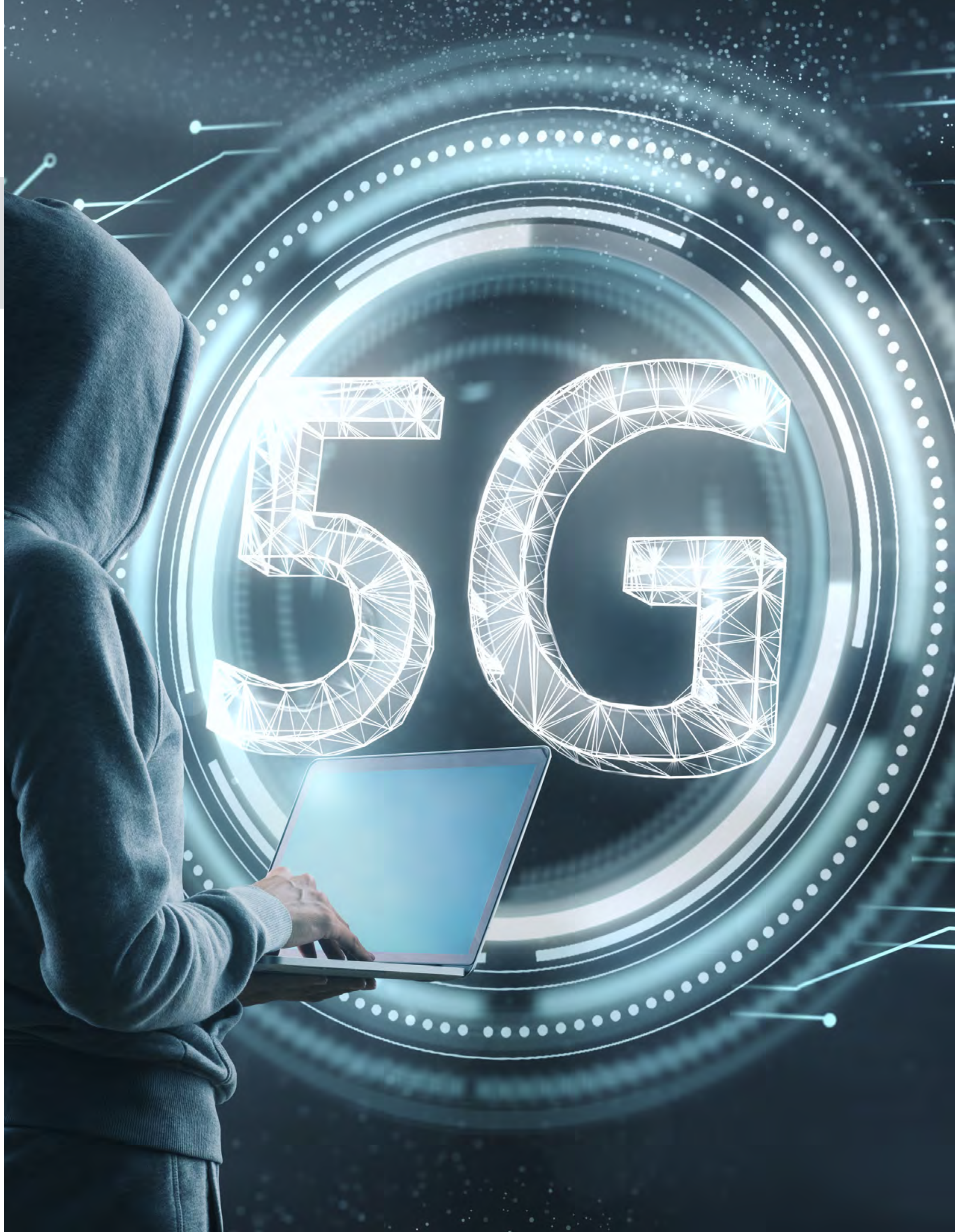

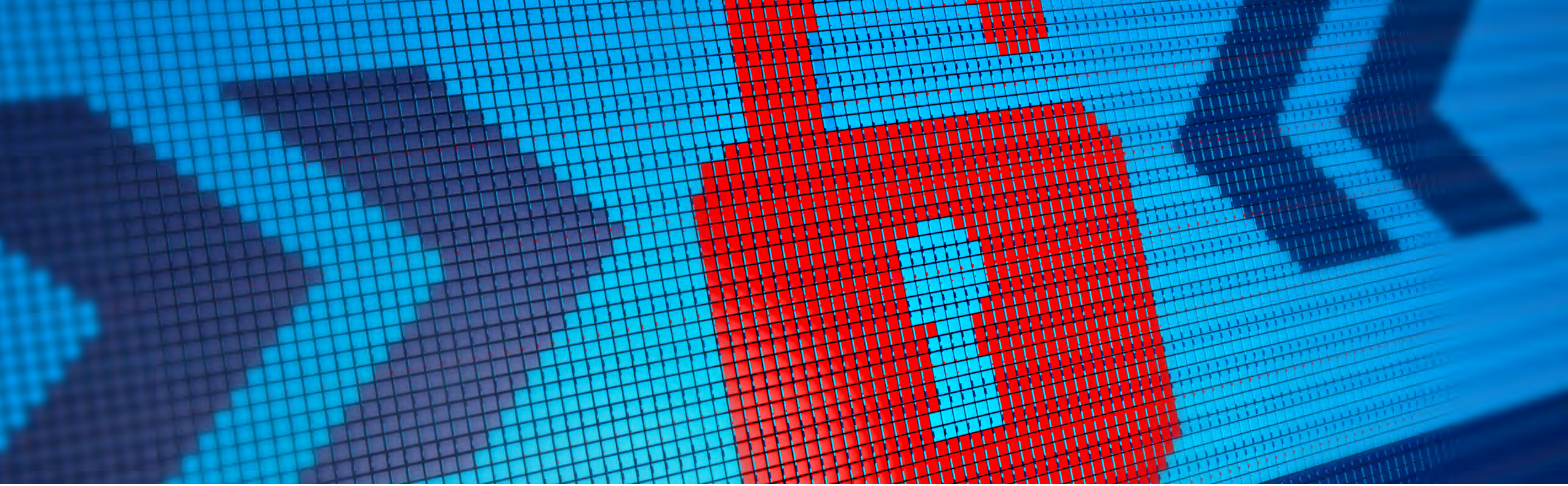

In the connection between end devices and cloud-based services, MEC systems can enhance both security and user privacy in several ways. For example, MEC systems can serve as mediators, leading to more secure authentications—not only reducing the chance of man-in-the-middle attacks but also reducing the amount of personally identifiable information (PII) available for interception. Beyond their role in these fundamental services, MEC systems can serve as connections between end devices and hybrid clouds that combine the public cloud core with private resources that protect sensitive data, including PII.

While MEC elements can help tighten security, the extensive software foundation of 5G networks enables novel new approaches for enhanced security. For example, in 5G networks, virtualization offers more than the isolation that is commonly associated with virtualized environments such as cloud virtual machines or containers. In 5G wireless, this concept extends to a capability called network function virtualization (NFV). NFV transforms traditional hardware-based network node functions such as load balancers or firewalls into software-based services that providers can deploy where necessary and scale to meet changing demand.

NFV: A Critical Enabler

NFV is a critical enabler of the 5G vision with its potential to tune network-service delivery to just the right level of performance, reliability, and functionality needed to meet specific service objectives. NFV already serves a role in providing development features such as monitoring and testing in 5G testbeds and early deployments.

For security, NFV conceptually offers a significant advantage over current approaches. Besides using virtualization broadly to scale performance, service providers can use NFV to scale threat detection and response capabilities. At the first sign of an attack, a provider's security monitoring system can upgrade an NFV firewall to provide deeper filtering and even scale its hardware resources to maintain the same quality of service during the attack. Using SDN features, the provider can even reconfigure the network to move defensive nodes closer to the source of the attack, eventually isolating bad traffic from good. Using this broad approach, service providers and third-parties can essentially parameterize configurations, node capabilities, and cloud-based applications to offer on-demand security-as-a-service offerings. This concept jells in a 5G capability called network slicing.

Network Slicing

A network slice is essentially a frozen network configuration, using the same 5G SDN and virtualization capabilities that enable dynamic real-time responses to network events. Unlike a virtual private network (VPN), which tunnels encrypted traffic through shared resources to a VPN server, a network slice comprises a set of dedicated virtual resources that are defined in an SDN configuration and served by NFV services. A high-security slice might include enhanced NFV firewalls and defensive nodes as part of its "frozen" configuration rather than as an on-demand response to an attack, as mentioned earlier.

Conversely, a slice built for Internet of Things (IoT) applications might relax some security policies, conforming to the relatively lightweight security capabilities of resource-constrained IoT sensors for example. At the same time, a slice for financial networks could use a different SDN configuration provisioned with NFV services optimized for security as well as for high-volume, low-latency transactions. The ability to match specific domain requirements with optimized slices provides a security capability of importance that cannot be overstated. Combined with concepts such as micro-segmentation for finer-grained isolation, 5G solutions give providers a wealth of emerging tools that support and protect unique application-specific networks (ASNs).

Security Challenges

Physical Intrusions

Despite all the advantages potentially available in underlying technologies of a 5G infrastructure, implementing a new architecture with these technologies presents its own share of challenges to security. Even the most fundamental element, the small cell, adds to security concerns. Although current cell towers present at least some level of challenge to physical attacks, small cells are physically more vulnerable, and with the need to deploy them in large numbers, they are readily accessible.

Practically speaking, however, the threat of network penetration through physical access of a small cell is likely minimal. This is because the industry has gained considerable insight and experience in the local deployment of smart utility meters, for example, and proven tamper and intrusion detection mechanisms used in smart meters are readily available to limit the impact of physical attacks on small cells. Of course, cyberthieves do not require physical access to a small cell to attack the 5G network infrastructure, its services, or its users. In fact,

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the combination of its software-heavy architecture and new operating model might expose a richer set of threat surfaces in 5G networks than mere physical access would.

Software Intrusions

The ascendancy of the 5G software-driven service-based architecture enables a radically new model that empowers multiple contributors, shrinking the influence and oversight that the single-provider model offers in today's mobile services. New opportunities will emerge for additional players to package 5G software components into service offerings at a sensible cost but that also optimize reach, latency, bandwidth, and any other parameters of interest to consumers. At the same time, qualified third-party developers will be able to take advantage of application programming interfaces (APIs) associated with each component and be able to offer unique NFV services, specialized SDN configurations, and even enterprise-scale "apps."

As with any complex software integration, the combination of many software components with different APIs, protocols, and stakeholders can leave security holes in the final offering. Although each software component might intend to offer the tightest possible security, security weaknesses can be built-in inadvertently through the component's own code or through the software libraries used for its development. The result of these types of internal weaknesses has given rise to the disturbingly commonplace discovery of "zero-day defects" in widely distributed, supposedly stable code, and such defects in evolving-code sets remain a concern.

In a system of cooperating software components as complex as a 5G network, the likelihood of security defects grows dramatically. Each boundary crossing between components, subsystems, or systems represents a potential threat surface arising from weaknesses in the API or related transaction protocols. Although tools have evolved for API development and protocol analysis, 5G networks face a potential flood of third-party software offerings, each with potential security holes waiting for discovery by determined cybercriminals.

Although a few of those security holes might be planned avenues for future exploits, some security vulnerabilities can arise simply as developers rush to stake their claim as first to the market with new capabilities. Unfortunately, the industry is replete with examples like these. Poorly secured connected products have been rushed into the market—only to be hijacked as part of botnets for massive distributed denial-of-service (DDoS) attacks. The rush to link 5G components into nascent 5G networks mirrors this flawed approach on a potentially wider scale.

Worse, this same goldrush mentality threatens the broader set of 5G services as major cellular players and new participants hurry to field their offerings. History shows that ensuring security in complex software systems is hard to achieve, and typically, the test phase pays the price for schedule shortfalls.

Evolving Standards

Aside from the expected difficulties of systems integration, 5G developers are dealing with an inherently complex framework where standards and fundamental issues are still evolving.

Industry stakeholders continue to work through many details involved in setting standards for critical features including key security agreements, authentications, and PII transports. Though challenging in itself, defining these standards also creates additional challenges, especially with the need to maximize security and privacy in the 5G domain while also maintaining compatibility with previous generation networks. 5G connectivity through multiple access networks, including Wi-Fi, further complicates the model's standards and its fundamental security protocols.

As standards evolve for 5G networks, 5G security will continue to face a broad array of threats from familiar attack vectors as well as new attack vectors looking to exploit the novel elements of 5G networks. For example, a 5G network formed from familiar technologies such as SDN and virtualization faces the same threats that have followed each of these embedded technologies, but the integration of these technologies into 5G networks also presents completely new avenues of attack.

Case in point, the files used to dynamically configure a network or build a slice face a series of threats similar to firmware updates in smart products. To secure the configuration process, 5G network providers will not only need to apply secure update mechanisms but also embed them within higher level security policies. In turn, these policies will need to encompass middleware and higher level services and even involve cooperating entities at the enterprise level. Defining the appropriate trust models and implementing them in dynamically changing networks will take some time to establish, much less optimize.

Is the 5G Network Secure "Enough"?

There are earnest and widespread efforts taking shape to build trust models and define comprehensive security measures for the new 5G network infrastructure. However, these efforts are not strongly established yet, especially to a level that prevents the most security-conscious organization from carefully weighing the total costs of security against the sheer magnitude of the coming 5G market opportunities. In fact, it would be unrealistic to expect that a framework intended to connect untold numbers of devices, services, and individuals could ever achieve "complete" security.

In practice, a system only needs to be secure "enough," shifting the requirement from one of attempting to identify every threat to one of building security into the foundation of the system. Even with the many 5G features available for enhancing security, the most fundamental approach lies in maintaining constant security awareness for each component of a 5G network. This approach means implementing security by design rather than patching security holes after attacks have already taken their toll. M


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