5G RF for Dummies

Understand different 5G use cases
Examine 5G from the RF perspective
Leverage 4G LTE innovations for 5G

Qorvo Special Edition

Lawrence Miller
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5G RF

Qorvo Special Edition

by Lawrence Miller
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Introduction

There’s lots of industry buzz today about all sorts of new Internet of Things (IoT) applications — from driverless cars and smart homes to lifesaving nanobiotechnology devices and smart cities — and 5G is the secret sauce that will enable these smart, connected devices to be, well, connected.

Built on the foundation of 4G LTE, 5G, the next-generation mobile network, will be here before we know it, ushering in a new wave of disruptive technological innovation with ubiquitous high-speed connectivity. 5G will transform entire industries and enable resilient, high-speed, high-volume Internet connectivity from practically anywhere and on any device or sensor.

About This Book

5G RF For Dummies, Qorvo Special Edition, consists of five short chapters that explore the following:

» Which visions and trends are driving us to a 5G future (Chapter 1)
» How 5G technology will cohesively connect many industries in a diverse and flexible way (Chapter 2)
» How 5G will use and reshape the frequency spectrum more efficiently than current technologies (Chapter 3)
» Which RF communications technologies are enabling the use cases and path to 5G (Chapter 4)
» Important milestones to look for in the development of 5G (Chapter 5)

There’s also a convenient glossary at the end of the book, in case you get stumped on any technical acronyms or concepts.
Foolish Assumptions

It’s been said that most assumptions have outlived their uselessness, but I assume a few things nonetheless! Mainly, I assume that you’re a stakeholder in the mobile telecommunications industry with more than a passing interest in 4G and 5G networks and technology. Perhaps, you’re an engineer, a design architect, a technician, a technology leader, a salesperson, or an investor. I also assume that you have some knowledge of the mobile telecommunications industry and radio frequency (RF) technology. As such, this book is written primarily for somewhat technical readers.

If any of these assumptions describes you, then this book is for you! If none of these assumptions describes you, keep reading anyway. It’s a great book and when you finish reading it, you’ll know enough about 5G to be dangerous!

Icons Used in This Book

Throughout this book, I occasionally use special icons to call attention to important information. Here’s what to expect:

This icon points out information you should commit to your non-volatile memory, your gray matter, or your noggin — along with anniversaries and birthdays!

You won’t find a map of the human genome here, but if you seek to attain the seventh level of NERD-vana, perk up! This icon explains the jargon beneath the jargon!

Tips are appreciated, never expected — and I sure hope you’ll appreciate these tips! This icon points out useful nuggets of information.

Beyond the Book

There’s only so much I can cover in 48 short pages, so if you find yourself at the end of this book, thinking, “Gosh, this is a great book. Where can I learn more?,” just go to www.qorvo.com/innovation/5g.
Looking at the Visions and Trends Transforming Our Connected World

In this chapter, you learn how both enterprise and consumer trends and opportunities are driving cellular networks to become the platform for a connected world, as well as the quantum leap in technical requirements needed to make it a reality.

Understanding Current Trends Driving the 5G Vision

At the risk of stating the obvious — perhaps, you were talking or texting on your smartphone and didn’t notice — mobile communication has now become an essential part of our critical infrastructure and daily lives. The data traffic demand is growing at a truly phenomenal pace. According to Ericsson’s Mobility Report, monthly mobile data traffic increased from 3.5 exabytes (EB) per month to 5.5 EB per month in the prior year, a 57 percent increase. This dramatic year over year increase has been trending steadily since 2011 and is driven partially by a 5 percent compound annual
growth rate (CAGR) in mobile subscriptions, but primarily by a 35 percent CAGR increase in per-subscriber traffic by smartphone users. We can expect the average smartphone user to increase usage from 1.4 gigabytes (GB) per month in 2015 up to nearly 9 GB per month in 2021.

The challenge carriers face today is how to meet this growing demand while keeping the cost per subscriber relatively the same. To accomplish this, the cellular network must rapidly densify and create new high-value services, while minimizing both operational and capital expenditure costs.

But wait — there’s more! The cellular network will transform to be the central platform for connecting everything to everyone. The Internet of Things (IoT) and machine-to-machine (M2M) communications are helping drive this trend. Gartner predicts nearly 21 billion connected IoT devices by 2020, and Ericsson is predicting monthly data traffic will exceed 50 EB by 2021.

One terabyte (TB) equals approximately 1,000 gigabytes (GB); one petabyte (PB) equals approximately 1,000 TB; and one exabyte (EB) equals approximately 1,000 PBs (or approximately one billion GBs). To put this into perspective, a feature length 1080p high-definition (HD) movie requires about 3 GB of data.

But keeping up with demand by providing additional network capacity is just one goal of 5G technology. 5G networks will also be extremely fast — as much as 10 to 20 times faster than the fastest mobile networks today. The increasing use of video for everything from social media posts and on-demand movies, to video communications (like Web Real-Time Communication, or WebRTC) and security monitoring cameras, is one trend driving the need for speed in mobile networks. Cisco’s Visual Networking Index predicts that mobile video traffic will account for 75 percent of all mobile data traffic by 2020.

Coupled with high speeds, low latency in 5G networks — 50 times lower than today’s mobile networks — will enable 5G applications such as the following:

» Autonomous vehicle safety and collision avoidance
» Remote medical services and emergency response
» Virtual reality (VR) and augmented reality (AR) for high-definition, interactive immersive experiences
Of course, not all mobile applications require high speeds and low latency. In fact, this highlights one of the main challenges in transforming the cellular network to be an efficient platform for a vast and diverse set of applications and services: 5G networks must be scalable and efficient — matching the appropriate radio frequency (RF) and physical layer protocols, based on the unique requirements of different applications. To accomplish this transformation, 5G networks will leverage a much broader range of frequency bands, power levels, and modulation and framing protocols, as well as spatial multiplexing, beamforming, and interference coordination techniques. From an RF perspective, 5G radios will need to be broadband, multi-mode, highly efficient (“green”), and highly integrated.

Finally, 5G networks will provide connectivity everywhere and always, including in challenging environments such as large buildings, industrial and manufacturing environments, congested areas, remote areas (on land and sea), and high-speed transport, such as planes, trains, and automobiles (see Figure 1-1).

**From Smartphones to Smart Everything**

![Image of 5G network requirements comparison]

**FIGURE 1-1:** 5G is massively broadband and everywhere.

**Comparing 4G and 5G System Requirements**

5G isn’t just an incremental improvement over 4G — it’s the next major evolution of mobile communication technology with performance improvements of several orders of magnitude over today’s networks. 5G does not replace 4G, it simply enables a
huge diversity of tasks that 4G cannot perform. 4G will continue to advance in parallel with 5G, as the network to support more routine tasks. 5G will enable services yet to be imagined, in a world where national economies are driven by sophisticated communications networks.

5G technology is

» **Enhanced Mobile Broadband (eMBB)** requiring hundreds of megahertz (MHz) of channel bandwidth using new frequencies for mobile wireless — from 2.5 gigahertz (GHz) for 4G LTE Pro and 3.5GHz for 5G, to tens of gigahertz and beyond into the millimeter wave (mmWave) spectrum

» **Ultra efficient** for streaming data, taking full advantage of carrier aggregation (CA) and massive multiple input/multiple output (MIMO)

» **Fixed wireless**, giving more choices to get 20 gigabit per second (Gbps) connections to your home and business

» **Wireless infrastructure**, using beam steering and high-power gallium nitride (GaN), ideally suited to adaptive-array steerable antennas

» **Low latency** for real-time connections enabling autonomous vehicles and AR/VR

» **Internet of Things (IoT)** connecting more than a trillion devices to the Internet in the next ten years with extremely low data rates, battery life greater than ten years, and the longest possible communication range

Figure 1–2 provides a comparison of the performance characteristics and technical specifications of 4G and 5G technology.

**FIGURE 1-2:** Comparing 4G and 5G.
Table 1-1 summarizes the major differences between 4G and 5G technology.

**TABLE 1-1 Comparing 4G and 5G**

<table>
<thead>
<tr>
<th></th>
<th>4G (Today, Before Further Developments)</th>
<th>5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency</td>
<td>10 ms</td>
<td>Less than 1 ms</td>
</tr>
<tr>
<td>Peak data rates</td>
<td>1 Gbps</td>
<td>20 Gbps</td>
</tr>
<tr>
<td>Number of mobile connections</td>
<td>8 billion (2016)</td>
<td>11 billion (2021)</td>
</tr>
<tr>
<td>Channel bandwidth</td>
<td>20MHz</td>
<td>100MHz below 6GHz</td>
</tr>
<tr>
<td></td>
<td>200kHz (for Cat-NB1 IoT)</td>
<td>400MHz above 6GHz</td>
</tr>
<tr>
<td>Frequency band</td>
<td>600MHz to 5.925 GHz</td>
<td>600MHz-mmWave (for example, 28GHz, 39GHz, and onward to 80 GHz)</td>
</tr>
<tr>
<td>Uplink waveform</td>
<td>Single-carrier frequency division multiple access (SC-FDMA)</td>
<td>Option for cyclic prefix orthogonal frequency-division multiplexing (CP-OFDM)</td>
</tr>
<tr>
<td>User Equipment (UE) transmitted power</td>
<td>+23 decibel-milliwatts (dBm) except 2.5GHz time-division duplexing (TDD) Band 41 where +26dBm, HPUE is allowed</td>
<td>IoT has a lower power-class option at +20dBm</td>
</tr>
<tr>
<td></td>
<td>+26dBm for less than 6GHz 5G bands at and above 2.5GHz</td>
<td></td>
</tr>
</tbody>
</table>

Currently, use cases are being defined, new radio access technologies are being developed, and carrier field trials are being conducted. The Third Generation Partnership Project (3GPP) standards body is harmonizing and globalizing these new ideas into a unified specification.

By adopting LTE Advanced (LTE-A), carriers are making considerable progress toward the speed goals for 5G (see Figure 1-3), but more work is required.
Enhancing the mobile wireless experience is a step-by-step pathway for carriers, requiring further expansion and development of 4G and moving toward LTE-A technologies. Carriers are currently in the midst of developing software-defined networks (SDNs), heterogeneous networks (HetNets), and low power networks. Finally, in 2019 and beyond, global 5G rollouts and initial commercial releases will begin (see Figure 1-4).

FIGURE 1-3: Downlink speeds by technical generation.

FIGURE 1-4: The path to 5G deployment.
The vision of 5G is overlaying the 4G network to support a connected world with applications that 4G LTE cannot support, as shown in Figure 2-1.

The various use cases and services enabled by 5G technology and networks can be broadly categorized into three groups: massive Internet of Things (IoT) devices, mission-critical services, and enhanced Mobile BroadBand (eMBB). In this chapter, you learn about these use cases and services (see Figure 2-1).

**FIGURE 2-1:** A 5G connected world.
Massive Internet of Things (IoT)

Unlike other 5G use cases, including mission-critical services and eMBB (discussed later in this chapter), the massive IoT use case is envisioned primarily for machine-to-machine (M2M) communications, connecting anything anywhere and requiring little or no direct human interaction.

Ericsson predicts there will be around 28 billion IoT connected devices by 2021. Fifteen billion of these devices will connect M2M and consumer electronic devices. Another large portion of these IoT-connected devices will reside in applications such as smart cities, industrial automation, management services, financial services, virtual reality, and even farming.

Many of these applications will use short-range radio technologies, such as Wi-Fi and Bluetooth/Thread. Others will be enabled by wide area networks (WANs) and cellular carrier networks.

Massive IoT applications typically consist of low-cost, low-power sensors and devices that provide good end-to-end coverage and transmit data back to a cloud. However, not all massive IoT devices and applications are low power. Devices and applications operated by Wi-Fi, for example, do not necessarily have a low-power requirement. Other non–low-power devices conserve energy with automatic on/off capabilities.

Massive IoT will consist of many different devices operating in different environments, enabled by new cellular 4G LTE standards (such as Cat-M1 and Cat-NB1), which will evolve into 5G capabilities, as well as several other key technologies (such as ZigBee and Wi-Fi).

The Next Generation Mobile Networks (NGMN) Alliance has defined a 5G network slice for massive Machine-Type Communications (mMTC) to provide wireless connectivity to tens of billions of machine-type terminals and trillions of connections.

A major challenge for 5G mMTC is the ability to provide connectivity across a vast ecosystem of devices, such as smart home systems, and various sensors and devices in smart grids, buildings,
cities, manufacturing, logistics operations, agriculture, mining, and more. 5G networks and devices supporting mMTC must be

- Massively scalable, capable of supporting 200,000 connected devices per square kilometer
- Low cost and energy efficient, with potentially thousands of sensors and devices deployed for a single application and with a battery life of ten years or more
- Capable of sending massive amounts of “small” data with throughput rates of 1 to 100 Kbps and broad coverage in challenging environments, such as large buildings and remote areas

Unlike eMBB (discussed later in this chapter), the very low data rate for IoT uses very narrow channel bandwidths, which is easily accommodated in low-band less than 1 GHz, where total spectrum availability is limited, but Inter-Site Distance (ISD) or range, is large.

5G eMBB is calling for a 100 to 400 megahertz (MHz) channel bandwidth, whereas 4G Cat-NB1 IoT uses only 200 kilohertz (kHz, or 0.2 MHz).

Low-cost, low-energy radio frequency (RF) components in the IoT space must be extremely compact and require process technologies like silicon or gallium arsenide (GaAs). Making these devices creates many challenges for RF designers — power amplifiers (PAs), filters, switches, and digital processing must all fit into a small package. In addition, the RF front end in this market operates using several frequency bands and standards.

To learn more about smart home technology, download a free copy of Internet of Things For Dummies at www.qorvo.com.

Key technologies enabling and supporting massive IoT use cases include the following:

- Ultra-low-power RF connectivity
- ZigBee
- Wi-Fi
- Cellular 4G Cat-M1, Cat-NB1
- Cellular 5G
- Thread
Mission-Critical Services

Some of the most visible, exciting, and newsworthy use cases for 5G today include autonomous (self-driving) vehicles — such as “headless” Google and Uber cars. Unlike M2M communications in the massive IoT use case (discussed in the previous section), mission critical services require the following:

- High-speed throughput with low-latency (as low as 1 millisecond), to enable real-time control at high speeds (up to 500 kilometers per hour)
- Ultra-high reliability and availability to ensure continuous performance and connectivity
- Extremely secure data communications and device components to ensure control, privacy, and life safety

The network slice defined by the NGMN Alliance for mission-critical services is ultra-Reliable Low-Latency Communications (uRLLC). In addition to autonomous vehicles, mission-critical use cases include autonomous public and mass transit systems, drones and other unmanned aerial vehicles, industrial automation, remote healthcare (for example, monitoring, treatment, and care), and smart grid monitoring and control.

Several mission-critical service initiatives are already underway in the industrial, academic, and medical areas.

Building a network with such high expectations and requirements will require many mobile and fixed devices. For example, before you put yourself or a family member in a self-driving vehicle or allow a doctor to perform surgery remotely with the help of robotics, safety must be assured and you need to be very confident in the network being used. To ensure this reliable service, new air interface technologies will be needed to deal with diverse and heterogeneous traffic for mission-critical services. The RF connections will be much more densified than what exists for 4G. Small cell connections will be more available, fixed wireless networks will be created, and frequencies from 600MHz to 80GHz will be utilized.
The gambit of technologies will include GaAs, silicon, gallium nitride (GaN), and others, and will enable a low latency end-to-end network. Key technologies enabling and supporting 5G mission-critical services use cases include the following:

- Massive multiple input/multiple output (MIMO)
- Carrier aggregation (CA)
- Millimeter wave (mmWave) and beamforming
- 5G network infrastructure, such as broadband access, global positioning systems (GPS), point-to-point radio, and satellite communications

Enhanced Mobile Broadband

The eMBB use case is perhaps the easiest to understand — faster service and better coverage for all of our Internet applications and services, on any device, from anywhere. The eMBB use case provides extremely high throughput for dense urban, rural, high-mobility (for example, in-transit), and indoor environments. Users will be able to download several gigabytes of data, such as 3D video, in seconds, and augmented and virtual reality (AR/VR) applications will become an everyday, uh, reality.

Key technologies enabling and supporting 5G eMBB use cases include the following:

- LTE Advanced and LTE Advanced Pro
- Extended bands/broadband
- Fixed wireless access (FWA) and millimeter wave (mmWave)
- Beam steering infrastructure
- Efficient femtocells (FEMs)/Small Cells

To support trillions of connected devices for eMBB, additional spectrum is required. Using flexible and efficient licensed, unlicensed, and shared spectrum is the target of 5G carriers.
The most important consideration is finding more available spectrum (see Figure 2–2). Key issues to be addressed including the following:

- Spectrum bands available by region
- Regional government regulator laws
- Spectrum impact and coexistence in regional areas
- New International Mobile Telecommunications (IMT) bands

![Licensed Spectrum](image1)
![Shared Licensed Spectrum](image2)
![Unlicensed Spectrum](image3)

**FIGURE 2-2:** Enhanced Mobile Broadband requires increased frequency spectrum.

Some licensed, unlicensed, and shared spectrum will be high frequency. Cellular technology transmits data over RF waves and the higher the frequency, the smaller the wavelength. The smaller the wavelength, the more difficult it is for those signals to pass through obstacles such as trees, walls, and buildings. mmWave technology refers to the frequency range between 30GHz and 300GHz.

In 5G, large amounts of spectrum in the mmWave range (for both unlicensed and licensed frequencies) have already been made available. 5G mmWave technology provides much higher data capacity by making use of up to the 400MHz of channel bandwidth for eMBB. This is orders of magnitude over the available channel bandwidth of most 4G LTE bands. Another advantage of mmWave is its shorter wavelength. This shorter wavelength means antennas can transmit and receive using smaller antennas. The fact that Inter Site Distances (ISDs) limit range to a few hundred meters, enables the same channel to be used repeatedly just a few blocks away in the same city.
In this chapter, you learn about 4G and 5G frequency spectrum, including various challenges and issues, and how to match spectrum to 5G services and use cases.

**Understanding Spectrum**

The International Telecommunication Union (ITU) coordinates frequency spectrum worldwide. The Third Generation Partnership Project (3GPP) allocates International Mobile Telecommunications (IMT) bands for each global region. The GSM-850 and PCS-1900 bands (and equivalent LTE B5 and B2, respectively) have been allocated to North America (including the Caribbean and Central America) and western South America (Argentina, Bolivia, Chile, Colombia, and Peru). The GSM-900 and DCS-1800 bands (and equivalent LTE B8 and B3 bands, respectively) are allocated to the rest of the world (except Japan, where GSM is unavailable).

3GPP has been steadily adding new time-division duplexing (TDD) and frequency-division duplexing (FDD) LTE bands over the last few years through a combination of re-farming from prior IMT uses, such as Global System for Mobile Communication
(GSM) and by clearing existing services such as digital television (the so-called digital dividend). These bands fall into four distinct groupings as follows:

- **Low band**: From 600 megahertz (MHz) to less than one gigahertz (GHz) (for example, B20, B28A/B28B, B12, B13, B8 and B5)
- **Mid-band**: From 1,710 MHz to 2,200 MHz (for example, B1, B2, B3, and B66)
- **High band**: From 2,300 MHz to 2,690 MHz (for example, B7, B30, B40, B38, and B41)
- **Very high band**: From 3,400 MHz to 3,800 MHz (for example, B42 and B43)

For a full list of LTE approved bands, refer to 3GPP specification 36.101.

Figure 3-1 shows new LTE bands recently added in the quest to assign more IMT spectrum.

<table>
<thead>
<tr>
<th>Band</th>
<th>Region</th>
<th>Access</th>
<th>UL (MHz)</th>
<th>DL (MHz)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>28A</td>
<td>EU</td>
<td>FDD</td>
<td>703-733</td>
<td>758-788</td>
<td>Auctioned Germany, France</td>
</tr>
<tr>
<td>46</td>
<td>All</td>
<td>TDD</td>
<td>5150-5925</td>
<td>5150-5925</td>
<td>Major Trend, Unlicensed</td>
</tr>
<tr>
<td>32</td>
<td>EU</td>
<td>SDL</td>
<td>–</td>
<td>1452-1496</td>
<td>Auctioned Germany, Italy</td>
</tr>
<tr>
<td>48</td>
<td>NA-US</td>
<td>TDD</td>
<td>3550-3700</td>
<td>3550-3700</td>
<td>Citizens Broadband Radio Service</td>
</tr>
<tr>
<td>71</td>
<td>NA-US</td>
<td>FDD</td>
<td>663-698</td>
<td>617-652</td>
<td>US Incentive Auction Complete</td>
</tr>
<tr>
<td>14</td>
<td>NA</td>
<td>FDD</td>
<td>788-798</td>
<td>758-768</td>
<td>Excess Capacity on Public Safety</td>
</tr>
<tr>
<td>40</td>
<td>EU</td>
<td>TDD</td>
<td>2300-2400</td>
<td>2300-2400</td>
<td>India, China, Extending into Europe</td>
</tr>
<tr>
<td>42</td>
<td>China/EU</td>
<td>TDD</td>
<td>3400-3600</td>
<td>3400-3600</td>
<td>Candidate 5G in 3.3-4.2 GHz Range</td>
</tr>
<tr>
<td>47</td>
<td>All</td>
<td>TDD</td>
<td>5855-5925</td>
<td>5855-5925</td>
<td>C-V2X</td>
</tr>
<tr>
<td>70</td>
<td>NA-US</td>
<td>FDD</td>
<td>1695-1710</td>
<td>1995-2020</td>
<td>USA</td>
</tr>
<tr>
<td>34</td>
<td>China</td>
<td>TDD</td>
<td>2010-2025</td>
<td>2010-2025</td>
<td>Refarming from TD-SCDMA</td>
</tr>
</tbody>
</table>

**FIGURE 3-1**: New 3GPP bands across the world.

To reach the diverse goals 5G is set to achieve, the spectrum needs to be divided in the following new manner:

- **Below 6 GHz**
  - **Low band**: Sub 1 GHz ultra-high-frequency (UHF) bands are well suited to long range at a high data rate. These bands are also ideal for the low data rate and narrow channel bandwidth requirements of IoT in 4G, and onward to 5G massive Machine Type Communications (mMTC).
- **Mid band:** One to 6 GHz. For 5G enhanced Mobile BroadBand (eMBB) where at least 100 MHz of channel bandwidth is needed, the 2.5 GHz 4G LTE Pro (B41) and 5G 3.5 GHz (B42/B43) bands are the first targets.

**Above 6 GHz:**

**High band:** The centimeter wave (cmWave) and millimeter wave (mmWave) bands starting at 28 GHz and 39 GHz, respectively, are ideally suited to 5G Fixed Wireless Access (FWA) and Mobile eMBB densification for inner city and stadium use cases.

C-band is the primary area for extended 5G mid-band spectrum (see Figure 3-2), with two proposed band groupings in the 3.3 GHz to 4.2 GHz and 4.4 GHz to 4.99 GHz ranges.

![FIGURE 3-2: Proposed band groupings for extended 5G spectrum in C-band.](image)

C-band is the original frequency allocated to communications satellites and radars. The specific band 4.2 GHz to 4.4 GHz is, and will remain, assigned to Aeronautical Altimeters. As part of the development of 5G systems, it is of paramount importance to prevent interference into this aeronautical band (refer to Figure 3-2).
Comparing 4G and 5G spectrum

The 4G LTE spectrum is composed of 52 3GPP bands as defined in document 36.101 as 35 for FDD/SDL and 17 for TDD. This spectrum is designed to support six channel bandwidths: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz. Thus, carrier aggregation (CA) is required to get combined bandwidth in support of higher data rates. Currently, 3GPP has approved CA up to 32 component carriers (CC) in the Release 14 specification. Standards requests from operators have been submitted for up to 5CC CA. This can aggregate up to 100 MHz of bandwidth as 5x20 MHz.

4G LTE is expected to reach over 1Gbps peak data rate downlink (DL) by the end of 2017, by combining CA with 4x4 DL multiple input/multiple output (MIMO) and 256 quadrature amplitude modulation (256QAM). To support even higher peak data rates, additional spectrum is required.

In 4G LTE, spectrum is fragmented among the various operators. Despite the availability of licensed bands and CA to increase channel bandwidth and data throughput, operators have begun to aggregate licensed and unlicensed spectrum (Licensed Assisted Access [LAA]) to improve data throughput. Band 46 (5,150 MHz to 5,925 MHz) as shown in Figure 3-3, is about to be aggregated with licensed bands for this purpose.

3GPP has started the 5G study item and work item phases to develop the 5G radio specification (5G NR) for both Non-Standalone (NSA) and Standalone (SA) operation. One of the key differentiators is that the maximum channel bandwidth limitation below 6 GHz will be 100 MHz and above 6 GHz the maximum channel bandwidth will be set at 400 MHz. Up to 400 MHz of instantaneous bandwidth can be achieved at less than 6 GHz, using four 100 MHz channels. This will allow much higher peak data rates than 4G.
NSA is an evolutionary step for carriers without building out a 5G core network. This path is a cost-effective way to quickly add air-link capacity using a 4G LTE Control Plane anchor, and to later add the full Standalone (SA) 5G core.

Unfortunately, below 6 GHz, 100 MHz of contiguous bandwidth is only found in B41 (2.5 GHz) and proposed extensions of frequency ranges in C-band (3.3 GHz to 4.2 GHz and 4.4 GHz to 4.99 GHz).

Above 6 GHz, it is easier to find 100 MHz or more of contiguous bandwidth in the centimeter and millimeter wave bands, typically at 28 GHz, 39 GHz, and onward to 80 GHz. The channel bandwidth will be allowed to 400 MHz.

The first 5G New Radio (NR) spectrum is expected to be at 28 GHz for Fixed Wireless Access (FWA).

The availability of the centimeter (cmWave) and millimeter (mmWave) bands worldwide is depicted in Figure 3-4.
In this chapter, you learn about the key enabling RF technologies for 4G Long Term Evolution (LTE) and 5G networks.

**4G: You’ve Come a Long Way, Baby**

To many casual observers and everyday mobile users, it may seem like 4G has been around forever. After all, the first 4G mobile phone was introduced way back in 2010 and early 5G networks aren’t expected to be operational until at least 2020. Ten years is a lifetime in technological evolution!

Looking back at the history of mobile networks, however, reveals that next-generation mobile technologies have consistently delivered more data capacity and enabled even more rich digital content (see Figure 4-1).
So, unless you’ve been working in the mobile telco industry for the last 40 years, or your name is Gordon Gekko (from the movie *Wall Street*) and you were one of the 91,600 cellular subscribers in the United States in 1984, it probably *does* seem like 4G has been around forever.

It’s more likely that you bought your first smartphone sometime in the mid–2000s (remember, the first iPhone was announced in 2007), near the tail end of the 3G development lifecycle, and you really didn’t pay much attention to mobile networks before then.

But here’s the dirty little secret about LTE: It’s not really 4G. Instead, LTE (Long–Term Evolution) is a path to 4G (call it “The Road to the Final 4G”). The 4G specification, as defined by the International Telecommunications Union (ITU) requires, among other things, an all–IP–based packet–switched network delivering peak data rates of 1Gbps. The 3rd Generation Partnership Project (3GPP) defines the LTE standard (Releases 8/9) as providing downlink peak rates of 300 megabits per second (Mbps) and uplink peak rates of 75Mbps. LTE Advanced (Releases 10/11/12) is the next iteration of LTE networks and delivers true 4G 1Gbps speeds. Finally, LTE Advanced Pro (Releases 13/14/15) establishes the foundation for 5G (see Figures 4–2 and 4–3).

The 4G “baby” has certainly reached adulthood, and now has a long and prosperous life ahead as the primary mobile telecommunications backbone well into the 2030s. Unlike 2G (and soon 3G), which are starting to see networks being shut down to re–farm spectrum for LTE, 4G will be sticking around for a while. That’s
why they call it “Long-Term”? 5G will be an overlay to enable all the smart new applications that 4G cannot support.

It’s helpful to think of “LTE,” “LTE Advanced,” and “LTE Advanced Pro” as “faster than 3G,” “4G, really,” and “almost 5G,” respectively.

![FIGURE 4-2: The path to 5G.](image)

![FIGURE 4-3: 5G-NR work plan for enhanced Mobile BroadBand (eMBB).](image)
Some important technological innovations on the LTE path to 4G — and 5G, for that matter — include the following:

- Carrier aggregation (CA)
- 4x4 downlink (DL) multiple input/multiple output (MIMO), 256 quadrature amplitude modulation (QAM) higher order downlink (DL) and 64QAM uplink (UL) modulation
- Small cells and densification, heterogeneous deployments, relays, and device to device (D2D)
- Inter-cell interference coordination (ICIC) and coordinated multipoint (CoMP)
- High Performance User Equipment (HPUE)
- Multi-user (MU) MIMO, full-dimensional (FD) MIMO beamforming
- License assisted access (LAA)
- Narrowband Internet of Things (NB-IoT, Category-M1 and Category-NarrowBand, NB1)

**Carrier aggregation**

Carrier aggregation (CA) is a technique used to combine multiple LTE component carriers (CCs) across the available spectrum to

- Aggregate chunks of bandwidth
- Increase data rates
- Improve network performance

CA allows increased data rates and improved network performance in the downlink (DL), uplink (UL), or both. It also allows frequency-division duplexing (FDD) on one carrier and time-division duplexing (TDD) on another, as well as a combination of licensed and unlicensed spectrum.

The Third Generation Partnership Project (3GPP) standard allows for up to 32CC — which will be a formidable challenge for radio frequency (RF) design! We probably won’t see the deployment of 32CC before the launch of 5G, but there is likely to be some progression beyond the 5CC seen in today’s operator plans, leading to more data (faster speeds for mobile users) while at the same time increasing the RF front-end design challenges (see Figure 4-4).
CA can be achieved in two different ways that have different impacts on the RF front-end components in the mobile device. These CCs can be found either within the same 3GPP band or between two or more different 3GPP bands:

- Intra-band CA (two or more CCs within the same band)
- Inter-band (two or more CC in different bands)

To learn more about carrier aggregation, download your free copy of *Carrier Aggregation Fundamentals For Dummies* at [www.qorvo.com](http://www.qorvo.com).

**4x4 Downlink MIMO and 256QAM**

Increasing bandwidth with carrier aggregation is the first and most robust technique to achieve higher 4G data rates. The next option to achieve higher 4G data rates in the DL is to upgrade to 256QAM DL modulation. Then, increase the number of spatial streams overlaying 4X4 MIMO on one or more of the CCs that have been aggregated.

4x4 MIMO effectively reuses the same 20MHz CC four times over to transmit more data. Thus, it is a more efficient use of...
spectrum. Some important considerations in 4x4 MIMO deployments include the following (see Figure 4-5):

- Only applies in the DL.
- Data rates increase by a factor of two for each CC it is applied compared to 2X2.
- Requires four unique data streams transmitted from a minimum of four unique antennas at the base station.
- Needs four corresponding unique receiver chains in the mobile device.
- Effectiveness is gated by the ability to de-correlate the four separate antennas in the handset — if the antennas can talk to each other (interference), then the benefit drops.

All this means more receiver components — such as filters, switches, low noise amplifiers (LNAs), and antenna control devices — are needed in the mobile front end. Because DL is only associated to the receiver side of the RF chain, transmit power amplifiers are not affected. 256QAM DL modulation has a 1.33x multiplier on the data rate of each CC. It requires no change to the RF front end in the mobile device.

The 4G “baby” is now approaching maturity. For example, an FDD network and mobile device can achieve a theoretical peak 4G DL data rate of 1Gbps using:

- 3CC aggregating 3 x 20 MHz to create a 60 MHz “fat pipe” and achieve 450 Mbps
- 4x4 DL MIMO applied to just two out of the three CCs, to achieve 750 Mbps
» 256QAM DL modulation on all three CCs to achieve 1Gbps
» A modem that supports ten spatial layers

The path to achieve even higher 4G DL peak data rates (in the 1.6Gbps range) is gated by the availability of transceiver/modem chipsets that support additional spatial layers (2017 chipsets can typically support up to 12 spatial layers), and the ability of handsets to accommodate the RF front end for more than two bands with four receivers.

Small cells and densification

Carriers can add capacity and make better use of their networks by shrinking the cell size. Network densification entails deploying lots of small cells (compact network infrastructure devices with limited range) to increase the total number of users that can be supported in densely populated areas or crowded venues. Densification of small cell outdoor and indoor technology increases existing carrier capacity and improves cell edge performance, allowing more reuse of their existing spectrum. Small cell characteristics differ widely, including

» Power level
» Geographic coverage
» Regional band allocation
» Number of users serviced

High-performance user equipment (HPUE)

Carriers operating TDD networks in bands at and above 2.5GHz find that the transmitter in a mobile device typically doesn’t have enough RF power to reach the base station tower from inside a building, when at the edge of the cell. The tower can reach the handset, but the handset cannot reach the tower.

In December 2016, the 3GPP ratified a new power class of +26dBm +/-2dB at the antenna in the 2.5GHz band. This new standard, known as Power Class 2 (PC2), doubles the mobile transmitter power (a 3dB increase).
Here are the characteristics of HPUE using Power Class 2:

» In TDD networks, the transmit and receive alternate in time.
» TDD networks are typically at higher frequency and need the additional UL power to offset signal losses through walls and windows when inside a building.
» HPUE in a TDD network matches the cell edge coverage performance of FDD and uses less or equal battery power, because the power amplifier is on for less time in TDD mode than in FDD mode.

Having established the capability and thermal reliability of RF front end components for +26dBm in HPUE PC2 in 4G, the stage is set for adoption of the higher power standard in the evolving 3GPP 5G New Radio (NR) definition where we will see significantly more TDD deployments.

**NB-IoT**

The IoT and 5G massive Machine-Type Communications (mMTC) will be a large market in 5G. NB-IoT is a Low Power Wide Area Network (LPWAN) radio technology 4G standard for IoT sensors and devices to communicate over cellular networks. However, unlike many other characteristics of 5G, NB-IoT is not necessarily designed for speed. Cat-NB1 uses a channel bandwidth of just 200kHz, more akin to the old Global System for Mobile Communications (GSM) standard than the 20MHz of LTE and 100MHz of 5G NR.

Cat-NB1 and its 5G derivative is the antithesis of 5G enhanced Mobile Broadband (eMBB). It uses the narrowest bandwidth and slowest data rate to lower costs and enable a ten-year (or more) battery life.

Kbps stands for *kilobits per second* — and one million kilobits equals one gigabit — a popular measure of speed back when modems used tone-modulated phone signals (accompanied by annoying screeching sounds) and people still used the yellow pages.

NB-IoT is designed primarily for IoT sensors and devices. The long range, using bands less than 1GHz, allows a vast network of low power sensors, each sending small data reports, to be
aggregated efficiently. For these devices, it isn’t critical that the data they transmit is received with ultra-low latency, or that every transmission be acknowledged by the receiver. Thus, NB-IoT is an ideal technology for massive IoT use cases (discussed in Chapter 2).

RF TECHNOLOGY, PACKAGES, AND DESIGNS ENABLING 5G

5G will be a platform firmly situated on the 4G LTE network. Previously mentioned technologies such as carrier aggregation will continue to evolve in 4G (4G LTE, 4G LTE Advanced, and 4G Advanced Pro) and build out nicely for 5G.

In Chapter 2, you find out about a broad set of 5G use cases, all of which require RF front ends. Depending on the RF function, frequency band, power level, and other performance requirements, the appropriate choice of RF semiconductor technologies changes. As shown in Figure 4-6, there are multiple semiconductor technologies available for each RF function and application.

*FIGURE 4-6: RF communication technologies by use cases.*
These applications demand a variety of process technologies, design techniques, integration, and packaging to meet the needs of each unique situation. Some of these areas, by application, include the following:

- **Low power**: Typically silicon system-on-a-chip solutions in plastic packages are used.

- **Smartphones, tablets, and mobile devices**: Mobile applications requiring carrier aggregation often use bulk acoustic wave (BAW) or surface acoustic wave (SAW) filters and multiplexers. RF shielding is used to tackle frequency interference coexistence and isolation issues. Flagship phones require a very high level of GaAs- and silicon-based RF front-end integration to meet stringent size constraints, while integrating many bands — up to 40-plus — into one device.

- **Macro base station**: LDMOS technology has been a key technology for high power PAs, but high-power gallium nitride (GaN) offers even higher performance and efficiency and is fast becoming the go-to technology. Packages range from copper-moly flange to plastic.

- **Small cells**: Small cells help carriers densify areas and extend their cellular reach. Small cells come in many power levels and help users connect quickly and conserve power. The diversity of small cells allows manufacturers to use a variety of technologies like GaAs, GaN, and silicon for power amplifiers; switches; BAW for filters; and many others.

- **New advanced antenna systems**: GaN used on antenna array systems offers the carriers the flexibility of scalability, power, wide bandwidth, and more (which you learn about in the next section).

To learn more about BAW and SAW, download a free copy of *RF Filter Technologies For Dummies* at [www.qorvo.com](http://www.qorvo.com).

To learn more about GaN, download a free copy of *GaN RF Technology For Dummies* at [www.qorvo.com](http://www.qorvo.com).
5G Begins with the Carrier Network

5G networks must handle many functions that require different Active Antenna Systems (AAS) to meet the challenges of enhanced Mobile Broadband (eMBB), massive Machine-Type communications (mMTC), and ultra Reliable Low-Latency Communications (uRLLC).

One of the first major applications will be Active Antenna Systems (AAS) in the millimeter wave bands, providing Fixed Wireless Access (FWA). FWA provides an initial stepping stone toward 5G in the mmWave bands. Carriers and infrastructure manufacturers alike have been conducting trials and plan to offer this service as a more scalable and economical way to deliver broadband. Although this service is for nomadic and fixed users, it is being designed with true mobility in mind. This allows carriers to get their feet wet in new mmWave technologies — such as phased array antennas and hybrid beamforming — that will be the basis of mobile 5G.

A very recent twist in 3GPP standards definition — the addition of an accelerated path, called non-Standalone (NSA) 5G — as a cost-effective way to bring early 5G benefits to market without the expense of building out the 5G network core needed for standalone (SA) 5G. NSA accomplishes this by using an existing 4G 3GPP band as an LTE anchor in the Control Plane.

GALLIUM NITRIDE (GaN): A CRITICAL TECHNOLOGY FOR 5G

In addition to higher speeds, greater capacity, lower latency, and improved reliability, 5G networks will be extremely energy efficient — providing 100 times the network energy efficiency of today’s networks.

To meet the diverse set of 5G requirements, GaN manufacturers need to offer several variations that span a broad range of frequencies and power levels. To read more go to www.qorvo.com/design-hub/white-papers/.
AAS/FD-MIMO

The Active Antenna Systems (AAS) is an advanced base station platform with optimized cost, structure, and performance. 4G Release 12 enhancements significantly impacted how enhanced NodeB (eNodeB) radios are designed. Release 12 items included new combinations of carrier aggregation, spatial multiplexing enhancements with downlink MIMO, and RF requirements needed in AAS. Figure 4-7 summarizes portions of the Release 12 items with respective features and benefits.

MIMO technology uses multiple antennas installed at both the source (transmitter) and destination (receiver), to improve capacity and efficiency. As shown in Figure 4-7, more antennas equals more data stream layers. This results in a bigger data pipe to a single user or multiple data pipes to separate users, also known as multi-user (MU) MIMO.

Massive MIMO takes MIMO to the next level. Today’s MIMO deployments typically consist of up to eight antennas on the base station and one or two antennas on the receiver. This allows the base station to simultaneously transmit eight streams to eight different users or double down and send two streams to four users. Massive MIMO scales to dozens or hundreds — theoretically thousands — of antennas, providing capabilities and benefits that include the following:

- Vastly improved capacity and reliability
- Higher data rates and lower latency

FIGURE 4-7: Evolution of LTE Advanced eNodeB radio antennas.
Better connections (especially with the challenging higher frequencies to be used for 5G)

Less intercell interference

Greater efficiency and better signal coverage enabled by beamforming

Figure 4–8 illustrates how an AAS/full-dimension (FD) MIMO base station can direct beams in both the horizontal and vertical directions. This operation dynamically points the antenna pattern on a per-user basis, providing a better link and higher capacity to that user. In turn, this allows him to offload his traffic and free the radio resources more quickly, which can then be used by others, resulting in a net increase in aggregate capacity for the entire cell.

![Antenna beam forming](image)

**FIGURE 4-8:** Antenna beam forming.

Figure 4–9 illustrates how AAS uses beam steering to provide end-to-end Fixed Wireless Access (FWA) connectivity to Customer Premise Equipment (CPE) located in commercial buildings and residential homes. One of the obvious advantages of 5G FWA is its ability to support very high peak data rates without requiring dedicated fixed facilities for each individual user. To enable higher peak data rates and greater system capacity, FWA radios will make use of new higher frequency bands from 24GHz up to 42GHz and potentially even higher.

Using larger antenna arrays provides additional beamforming to overcome more severe propagation challenges encountered at mmWave frequency ranges. These arrays can have hundreds of elements but due to the short wavelength are extremely compact. For example, a 64-element antenna array at 30GHz is only 40 mm x 40 mm. Large arrays provide very focused beams that
can be redirected in less than a micro-second. In addition, the large phased array can act as a single array or as multiple independent subarrays with unique beams directed to service multiple user terminals simultaneously on the same frequency resource. Figure 4-10 shows a block diagram of the 2x2 RF front-end modules in the per-antenna RF subsystem of an AAS antenna array that comprises an AAS cell tower.

**FIGURE 4-9:** 5G end-to-end Fixed Wireless Access (FWA) networking using beam steering.

**FIGURE 4-10:** Active antenna system and beam steering RFFE (2x2 LTE RF front end).

Millimeter wave (mmWave) is the band located between the microwave (30 GHz) and infrared (300 GHz) spectrums.
CHAPTER 5
Ten Important Milestones on the Road to the 5G Future

In this chapter, we identify milestones for you to watch for as 5G becomes a reality.

Leveraging Current 4G Cellular Infrastructure

The 5G future does not require a “rip and replace” approach to network infrastructure. In fact, many of today’s 4G innovations will enable the 5G networks of the future for a broad range of applications. An all IP-based network core is an important requirement...
for 5G networks, and is already a goal that mobile carriers are aggressively working toward in the 4G cellular infrastructures.

You can find out more about 4G infrastructure innovations in Chapter 4.

**Greatly Expanding the Available Spectrum**

Some use cases in 5G access networks will require very wide contiguous carrier bandwidths. To support these wide contiguous bandwidths, new carrier frequencies below 6 gigahertz (GHz), as well as millimeter wave (mmWave) will be required.

**Expanding Carrier Aggregation**

Carrier aggregation (CA) combines multiple LTE component carriers (CCs) across the available spectrum for higher data rates and lower latency. CA technology is evolving rapidly with current CA deployments supporting 5 CA in the downlink direction and 2 CA in the uplink direction.

**Increasing Densification**

Densification using small cell technology enables carriers to provide more users with lower latency, better mobile device battery life, and expanded cellular coverage.

**Deploying Massive Multiple Input/ Multiple Output (MIMO)**

Massive MIMO, consisting of hundreds and even thousands of active antenna elements, will work together to provide vastly more mobile capacity, coverage, and reliability for the 5G future.
Enabling Vehicle to Everything (V2x) Communication

Today, autonomous (“driverless” or “headless”) vehicles, are increasingly in the news — unfortunately, often the subject of a sensational crash or accident. However, as 5G technology continues to develop, autonomous vehicles will become as commonplace as traditional vehicles with drivers that don’t use their heads! These vehicles will become less expensive, more popular, and — most important — much safer.

Smart cars with human drivers will also leverage 5G technology to improve vehicle safety and efficiency, as well as the overall driving experience.

Providing More Options with Fixed Wireless Access

Fixed Wireless Access (FWA) provides subscribers with more alternatives for connecting to the cloud using wireless broadband data communication to connect two or more fixed locations.

Using Your Mobile Phone as a Hub

If you think your life revolves around your smartphone today, wait until you get your first 5G smartphone! With high-speed mobile broadband access and truly ubiquitous coverage, the 5G smartphone will enable devices to communicate directly with each other, without routing the data paths through a network infrastructure.

Active Antenna Systems

Active Antenna Systems (AAS) is an advanced base station platform that meets carrier extended mobile broadband services and Massive full-dimensional MIMO technologies.
Low Latency: Key for AR, VR, V2x, and Mission Critical

Mission-critical services requiring very high reliability, global coverage, and very low latency, will become more native to support 5G infrastructure. Latency may be more important than throughput in some applications.
Glossary

**Active Antenna System (AAS):** An array of antenna elements, driven by multiple active solid-state RF chains to form adaptively steerable beam patterns.

**augmented reality (AR):** Technology that produces a composite view by superimposing high-resolution (even 3D) images on a real-world view.

**base transceiver station (BTS):** Equipment that facilitates communication between user equipment (such as a mobile phone) and a carrier’s network.

**beamforming:** The synthesis of multiple RF signals from multiple antenna apertures to focus or defocus the composite antenna pattern toward/away from particular receivers/transmitters.

**bulk acoustic wave (BAW):** A piezoelectric transducer that converts electrical signals to acoustic waves used to create filters and delay lines.

**carrier aggregation (CA):** A technique used to aggregate carriers (known as component carriers) to achieve greater bandwidth, lower latency, and better coverage. See also component carrier (CC).

**Category Machine 1 (Cat-M1):** A Category M (machine) solution, an LTE standard for narrow-bandwidth and low-power Internet of Things (IoT) applications. Also referred to as LTE-M and formerly known as Cat-M. See also Internet of Things (IoT).

**Category NarrowBand 1 (Cat-NB1):** A Category NarrowBand solution, an LTE standard for narrow-bandwidth and low-power Internet of Things (IoT) applications. See also Internet of Things (IoT).

**C-band:** The frequency band between 4GHz and 8GHz originally allocated to communications satellites and radar.

**centimeter wave (cmWave):** The band of super-high-frequency (SHF) between 3 GHz and 30 GHz.
component carrier (CC): An aggregated carrier or channel in carrier aggregation. See also carrier aggregation (CA).

customer premise equipment (CPE): Telecommunications hardware that is physically located at the customer's home or business.

cyclic prefix orthogonal frequency-division multiplexing (CP-OFDM): A method of encoding digital data on multiple orthogonal carrier frequencies with the prefixing of a symbol with a repetition of the end to combat multipath.

decibel-milliwatts (dBm): The power ratio of the measured power in decibels referenced to one milliwatt.

densification: A technique used by telecommunications providers to increase capacity by adding more cell sites in a given coverage area.

enhanced Mobile BroadBand: A label used by the standards community to describe the features, frequencies, and new capabilities that will provide an order of magnitude increase in capacity.

enhanced Node B (eNodeB): A hardware element in E-UTRA that is connected to the mobile phone network and communicates directly with User Equipment (UE), such as mobile phones. See also Evolved Universal Terrestrial Radio Access (E-UTRA) and User Equipment (UE).

Evolved Universal Terrestrial Radio Access (E-UTRA): The air interface of the 3GPP LTE upgrade path for mobile networks. See also Third Generation Partnership Project (3GPP) and Long Term Evolution (LTE).

fixed wireless access (FWA): A wireless strategy to provide broadband connectivity to fixed and/or nomadic subscribers.

frequency-division duplexing (FDD): A method for establishing full-duplex communication links using different frequencies for the transmit and receive directions.

front-end module (FEM): An integrated radio frequency (RF) module that contains amplifiers, filters, switches, and other components.

full-dimension multiple input/multiple output (FD-MIMO): An antenna system that can form a beam in both horizontal (azimuth) and vertical (elevation) directions.

Further Notice of Proposed Rulemaking (FNPRM): An amendment to a Notice of Proposed Rulemaking. See also Notice of Proposed Rulemaking (NPRM).
gallium arsenide (GaAs): A semiconductor compound of the elements gallium and arsenic used in the manufacture of devices such as microwave RF integrated circuits.

gallium nitride (GaN): A direct bandgap semiconductor that is increasingly being used in power electronics due to its higher efficiency and superior speed, temperature, and power-handling characteristics compared to silicon.

gigabits per second (Gbps): A measure of data transfer speed, or throughput. One gigabit is equal to one billion bits.

 gigahertz (GHz): A measure of frequency. One gigahertz is equal to one billion hertz.

Global System for Mobile Communication (GSM): A second-generation digital mobile telephony system that uses a variation of time-division multiple access (TDMA).

GSM Alliance (GSMA): An organization representing the interests of mobile operators worldwide.

high-power user equipment (HPUE): A special class of user equipment for the LTE cellular network. Also referred to as high-performance user equipment.

Institute of Electrical and Electronics Engineers (IEEE): A technical professional organization that promotes the advancement of technology.

International Mobile Telecommunications (IMT): Standards issued by the ITU. See also International Telecommunication Union (ITU).

International Telecommunication Union (ITU): A United Nations agency responsible for coordinating worldwide telecommunications operations and services.

Internet of Things (IoT): A system of smart, connected devices.

Inter Site Distance (ISD): The nominal distance between base-stations in a cellular deployment.

kilohertz (kHz): A measure of frequency. One kilohertz is equal to one thousand hertz.

Licensed-Assisted Access (LAA): An LTE feature that leverages the 5 GHz unlicensed band in combination with licensed spectrum to deliver a performance boost for mobile device users.
licensed shared access (LSA): A concept that enables licensed spectrum to be dynamically shared.

Long Term Evolution (LTE): A telecommunications standard for high-speed wireless communication, developed by the 3rd Generation Partnership Project (3GPP).

low noise amplifier (LNA): An electronic amplifier that provides gain and has been specifically designed to introduce a minimum of additional noise to the signal.

Low Power Wide Area Network (LPWAN): A wireless telecommunication network designed to allow long-range communications at a low bit rate among connected battery-operated sensors and devices.

machine-to-machine (M2M): Direct communication between devices, sensors, or other machines, without requiring human intervention.

massive Machine-Type Communications (mMTC): The 5G network slice defined by the NGMN Alliance for massive-scale connected devices on the Internet of Things (IoT). See also Next Generation Mobile Networks (NGMN) Alliance and Internet of Things (IoT).

megabits per second (Mbps): A measure of data transfer speed, or throughput. One megabit is equal to one million bits.

megahertz (MHz): A measure of frequency. One megahertz is equal to one million hertz.

millimeter wave (mmWave): The band of spectrum between 30 GHz and 300 GHz.

milliseconds (ms): One thousandth of a second.

Monolithic Microwave Integrated Circuit (MMIC): A type of integrated circuit where multiple stages or functions are designed on a single die.

multiple input/multiple output (MIMO): Wireless communication technology in which multiple antennas are used at the source and destination, and their functions (transmit/receive) are combined to reduce errors and optimize data speed.

multiple radio access technology (multi-RAT): Multiple, heterogeneous network layers operating as a single network.

narrowband Internet of Things (NB-IoT): An LPWAN standard that enables a wide range of devices and services to be connected using cellular telecommunications bands. See also Low Power Wide Area Network (LPWAN).
New Radio (NR): The wireless standard for a new physical interface in 5G.

Next Generation Mobile Networks (NGMN) Alliance: An open forum created by mobile network operators worldwide.

Notice of Proposed Rulemaking (NPRM): A public notice issued by law when one of the independent agencies of the U.S. government wishes to add, remove, or change a rule or regulation as part of the rulemaking process.

Power Class 2 (PC2): A 3GPP standard for high-power user equipment. See also Third Generation Partnership Project (3GPP) and high-power user equipment (HPUE).

quadrature amplitude modulation (QAM): A digital modulation technique where information symbols are mapped to discrete amplitude and phase states.

single-carrier frequency division multiple access (SC-FDMA): An access scheme for assigning multiple users to a shared communication resource leading to a single-carrier transmit signal.

surface acoustic wave (SAW): An acoustic wave traveling along the surface of a material exhibiting elasticity, with an amplitude that typically decays exponentially with depth into the substrate.

Third Generation Partnership Project (3GPP): A consortium of telecommunications industry partners that collaborate on the development of GSM, 4G LTE, and 5G standards.

Thread: A networking protocol designed for IoT smart home automation devices on a local wireless mesh network.

time-division duplexing (TDD): A duplex communications link in which uplink and downlink are separated by different time slots in the same frequency band.

ultra high frequency (UHF): The ITU designation for radio frequencies in the range between 300 megahertz (MHz) and 3 gigahertz (GHz).

ultra-reliable low-latency communications (uRLLC): The 5G networks slice defined by the NGMN Alliance for mission-critical services. See also Next Generation Mobile Networks (NGMN) Alliance.

Universal Mobile Telecommunications System (UMTS): A third-generation (3G) broadband, packet-based transmission of text, digitized voice, video, and multimedia at data rates up to 2 megabits per second (Mbps).
**user equipment (UE):** Any end-user device in Universal Mobile Telecommunications System (UMTS) or Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) network. *See also* Universal Mobile Telecommunications System and Third Generation Partnership Project.

**virtual reality (VR):** A computer-generated three-dimensional (3D) image representation of an object or objects, which a user can interact with in a similar manner to real-world objects.

**Web Real-Time Communication (WebRTC):** A suite of protocols and application programming interfaces (APIs) that enable real-time communication over peer-to-peer networks.

**World Radiocommunication Conference (WRC):** A conference organized by ITU to review and revise the use of radio frequency (RF) spectrum. *See also* International Telecommunication Union (ITU).

**ZigBee:** A collection of high-level communication protocols for use in small, low-power personal area networks and smart home automation.
Connecting the Uses of 5G

Qorvo connects RF for all 5G use cases.

Enhanced Mobile Broadband
Capacity Enhancement

Qorvo: LTE-A, Pro, Extended Bands, Fixed Wireless mmW, Beam Steering Infrastructure, Efficient FEMs

Gigabytes in a second
3D video - 4K screens
Work & play in the cloud
Augmented reality
Industrial & vehicular automation
Mission critical broadband
Self driving car

Smart city cameras
Voice
Sensor NW

Massive IoT
Massive Connectivity

Qorvo: Ultra Low Power RF Connectivity, ZigBee, Wi-Fi, Cat M, Thread

Low Latency
Ultra-High Reliability & Low Latency

Qorvo: Massive MIMO, Carrier Aggregation, Infrastructure

(Source: Qorvo, Inc., from ITU-R IMT 2020 requirements)
Get ready for the future of IoT and mobile communication

The next-generation mobile broadband network — 5G — is on the horizon. 5G technology will bring vastly greater performance, coverage, and reliability than today’s mobile networks and will transform entire industries. 5G will support new use cases, including massive Internet of Things (IoT), mission-critical services, and enhanced mobile broadband. Learn how innovations like carrier aggregation (CA), massive multiple input/multiple output (MIMO), and densification of small cells are ushering in the 5G era in this book.

Inside…

• Recognize the key demand drivers of 5G
• Increase capacity with 4G LTE technology
• Reduce latency and improve coverage
• Provide capacity for trillions of IoT devices
• Support mission-critical applications
• Leverage licensed and unlicensed spectrum

Lawrence Miller has worked in information technology in various industries for more than 25 years. He is the co-author of CISSP For Dummies and has written more than 100 other For Dummies books on numerous technology and security topics.
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