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Kalyan Sundhar

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5G

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by Kalyan Sundhar and Lawrence C. Miller

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We're proud of this book and of the people who worked on it. Some of the people who helped bring this book to market include the following:

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Introduction

The next-generation mobile network (NGMN) is on the horizon. 5G, the next iteration of 4G Long Term Evolution (LTE) networks, will enable significantly greater mobile speeds — as much as 20 gigabits per second (Gbps) with less than one millisecond (ms) latency — to enable real-time connectivity for mission-critical and potentially lifesaving devices and applications. 5G will also provide truly ubiquitous connectivity in the most challenging and remote areas of the world whether on land, in the air, or at sea — even on the 42nd floor of an office building in downtown Chicago! Finally, 5G networks will connect billions of Internet of Things (IoT) devices with a wide variety of speed and data volume requirements.

But 5G is an ambitious goal. Work on key technologies to enable 5G has already begun. In much the same way that 4G LTE was rolled out in 2008, but is only now achieving the 4G LTE goal of 1 Gbps speeds with the 4G LTE Advanced standard, 5G will be a steady evolution that begins with commercial availability expected in 2020. Many technologies that have emerged in the evolution of 4G LTE, such as carrier aggregation (CA) and multiple input multiple output (MIMO), will continue to develop to achieve the massive speed and scale required in 5G. Innovative new technologies will leverage unlicensed spectrum — where Wi-Fi operates — to offload certain traffic from the carrier networks to create more capacity in their data pipes. Low-power technologies such as NarrowBand IoT (NB-IoT), LTE for Machines (LTE-M), Long Range Wide Area Network (LoRaWAN), Sigfox, and others, will be used in billions of IoT devices, and a new radio interface technology — 5G New Radio (5G NR) — will be developed for connections between User Equipment (UE) and carrier enhanced Node B (eNodeB) stations. Finally, carriers will fully embrace virtualization technologies in their core networks to enable massive scale and efficiency.

In this book, you learn about the technological innovations that are being developed today to enable a 5G future. You also learn about potential use cases that will transform entire businesses and industries, and create new business models and opportunities.

About This Book

5G For Dummies, Ixia Special Edition, consists of eight short chapters that explore

- How wireless communications technology has evolved and where it's going next (Chapter 1).
- How developments in today's networks are blazing the 5G trail to higher speeds (Chapter 2).
- Which technologies in unlicensed spectrum will be leveraged in the 5G networks of the future (Chapter 3).
- Why the Internet of Things requires 5G connectivity (Chapter 4).
- Where virtualization in mobile networks can help address the need for scale and elasticity (Chapter 5).
- What 5G New Radio (5G NR) is and how it will help create a 5G future (Chapter 6).
- How 5G will be used in various use case scenarios (Chapter 7).
- Ten common myths and the reality of 5G (Chapter 8).

Foolish Assumptions

It's been said that most assumptions have outlived their uselessness, but we assume a few things nonetheless!

Mainly, we assume that you either work in a technology profession or you're an avid user of wireless communications technology — if you have a smartphone within arm's distance of you, we're talking about you!

Beyond a basic knowledge of wireless communications and mobile technology in general, we don't assume you have a particularly strong technical background. As such, this book is written primarily for nontechnical readers — we explain any technical terms and concepts that come up in this book.

If any of these assumptions describe you, this book is for you! If none of these assumptions describe 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, we occasionally use special icons to call attention to important information. Here's what to expect:

REMEMBER

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

TECHNICAL STUFF

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.

TIP

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

Beyond the Book

There's only so much we 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.ixiacom.com`.

Where to Go from Here

With our apologies to Lewis Carroll, Alice, and the Cheshire cat:

"Would you tell me, please, which way I ought to go from here?"

"That depends a good deal on where you want to get to," said the Cat — er, the Dummies Man.

"I don't much care where . . . ," said Alice.

"Then it doesn't matter which way you go!"

That's certainly true of *5G For Dummies*, which, like Alice in Wonderland, is also destined to become a timeless classic!

If you don't know where you're going, any chapter will get you there — but Chapter 1 might be a good place to start! However, if you see a particular topic that piques your interest, feel free to jump ahead to that chapter. Each chapter is written to stand on its own, so you can read this book in any order that suits you (though we don't recommend upside down or backward).

We promise you won't get lost falling down the rabbit hole!

IN THIS CHAPTER

» Recapping a century of innovation in wireless communications

» Addressing speed, scale, and responsiveness with 5G networks

» Unlocking the five key fundamentals of 5G

Chapter 1
Understanding the Journey to a 5G Future

In this chapter, you take a glimpse back at the evolution of wireless communications and a look ahead to the 5G future.

Tracing the Evolution of Wireless Communications

For more than a century, radio technology has been enabling wireless communications over ever greater distances and with ever greater capabilities.

In the late nineteenth century, Guglielmo Marconi built the first wireless telegraphy system, capable of transmitting Morse code via radio signals up to one-half mile. Today, more than seven billion mobile devices enable us to communicate with anyone, anywhere in the world.

The first truly mobile two-way radio was developed in 1923 and used in Australian police cars — although it took up the entire back seat of a patrol car. Hand-held radios — "walkie-talkies" — were first used in World War II.

In 1973, the first call on a hand-held cellular phone was made — the cellular phone was described as a "brick" weighing nearly two pounds, with just 30 minutes of talk time and a ten-hour battery recharge time. Ten years later, Motorola introduced the DynaTAC phone, weighing just one pound and costing $3,500.

To support modern wireless communications, cellular networks have evolved over several generations, as follows:

- **1G (analog cellular):** The first analog cellular service was launched in Japan in 1979. In 1983, the Advanced Mobile Phone Service (AMPS) was launched in North America. Analog cellular signals permitted only voice traffic and were not encrypted, so they could be easily intercepted.

  TECHNICAL STUFF

  1G service consumed lots of spectrum and used the frequency division multiple access (FDMA) channel access method. FDMA allocates one or more frequency bands (or channels) to a user for communication.

- **2G (digital cellular):** The second generation of cellular technology was launched in 1991 with the commercial release of the Global Standard for Mobile Communications (GSM) in Finland. Major innovations in 2G networks included:
  - **Digital:** Digital signals generally have less static and background noise, and they use available spectrum more efficiently than do analog signals.
  - **Encryption:** 2G digital calls can be encrypted to make eavesdropping and intercept more difficult.
  - **Data:** Short message service (SMS) text messages were first introduced in 2G networks — O-M-2G!

  TECHNICAL STUFF

  2G technologies use either time division multiple access (TDMA) or code division multiple access (CDMA) channel access methods. TDMA divides a signal into different time slots, enabling multiple callers to share the same frequency channel. CDMA assigns a code to each caller and uses spread-spectrum technology to create a signal with a wider bandwidth.

  In 2000, the European Telecommunications Standards Institute (ETSI) created the General Packet Radio Service (GPRS), which implemented packet-switched domains, in addition to existing circuit-switched domains. GPRS was dubbed "2.5G" and had nothing to do with *Two and a Half Men,* introduced by CBS three years later.

- **3G (data driven):** Apple and Google brought smartphones to the masses with iPhones and Android devices, respectively, in the early 21st century. These powerful devices — and the mobile apps installed on them (including Global Positioning System or GPS, location-based services, and on-demand video) — created an insatiable appetite for faster download speeds. The first 3G networks, introduced in 1998, provided minimum information transfer rates of 200 kilobits per second (Kbps). The International Telecommunication Union (ITU) has never formally defined a standard for 3G data rates, so downlink data speeds vary widely — from 384 Kbps in a moving vehicle for Wideband Code Division Multiple Access (W-CDMA) to 42.2 megabits per second (Mbps) for Evolved High Speed Packet Access (HSPA+), also known as 3.5G, and 168 Mbps for Advanced HSPA+.
- **4G (Long Term Evolution):** Commercially available 4G mobile networks were rolled out in 2008, and 4G LTE followed in 2010. However, unlike 3G, the ITU Radiocommunication Sector (ITU-R) defined minimum 4G standards — but neither "4G" nor "4G LTE" meets those standards! The ITU-R International Mobile Telecommunications Advanced (IMT-Advanced) requirements include (among other things):
  - Packet-switched all-IP core networks
  - Peak data rates of approximately 100 Mbps for high mobility (such as moving vehicles)
  - Peak data rates of approximately 1 gigabit per second (Gbps) for low mobility (such as walking — or your authors sprinting)

  With the introduction of LTE Advanced, true 4G speeds of up to 1 Gbps finally arrived. LTE Advanced Pro is the next evolution of LTE technology, and it establishes the foundation for 5G. LTE Advanced Pro will deliver speeds in excess of 3 Gbps with less than 2 milliseconds (ms) of latency.

REMEMBER

At this point you may be thinking, "Long Term Evolution — no kidding! Will 5G ever get here?" However, the trend has been for each generation of mobile technology innovation to take about a decade — most of us just didn't pay attention before we got our first smartphones midway through the 3G era.

Focusing on the 5G Vision

The vision for the 5G future is bold: It is much more than just the next iteration of mobile networks. 5G will achieve three main goals:

- **Speed (ultra-high speed radio access):** 5G will provide download speeds of up to 20 Gbps. If you're wondering "Why would anyone ever need that much speed?" first answer this question: When have you ever heard anyone complain that their phone was *too fast*? It's also important to remember that bandwidth is shared by all the users on a cell tower. Today, if a few users are streaming a video at the airport or watching replays of a touchdown in a stadium, chances are that the download is choppy with lots of buffering, and the experience isn't so great. With 5G, you could theoretically download a 40 gigabyte (GB) 4K Ultra-High-Definition (UHD) movie (like *Jaws*) in less than a minute — you're gonna need a bigger data plan!
- **Responsiveness (ultra-low latency):** 5G networks will be used to control autonomous cars and high precision, mission-critical industrial devices in real-time. High reliability and availability at all times is a necessity for these use cases. For this to happen safely, end-to-end latency — the time it takes for data or commands to travel across the network — has to be extremely low. Latency in 5G networks will be five times faster than today's networks — less than 1ms.
- **Scale (massive connectivity):** By 2020, Gartner conservatively forecasts that there will be more than 21 billion connected devices in the Internet of Things (IoT). Some estimates predict more than 50 billion connected IoT devices by 2020. That's anywhere from three to seven connected devices for every person on the planet in 2020 — not including smartphones, tablets, and computers! These devices will have widely varying network requirements — from environmental sensors for agricultural applications installed in remote areas that might send a few bits of data every few days or weeks, to extremely high-precision, low-latency devices in nanobiotechnology, autonomous cars, and mission-critical industrial environments that rely on real-time communication for potentially lifesaving functions. 5G networks will need to handle the massive scale and

challenging connectivity requirements for all these diverse devices, sensors, and applications.

Ordering Up 5G in Five Easy Pieces

5G will be a quantum leap beyond today's networks and will require many technological innovations. We serve them up here in five easy pieces (easier than making wheat toast for Jack Nicholson — "hold the butter, the lettuce, the mayonnaise . . . and the chicken") in this section and the chapters that follow (see Figure 1-1):

- **Speeds and feeds.** Speeds of up to 20 Gbps will be achieved using a combination of innovations such as carrier aggregation (CA), massive multiple input multiple output (MIMO), and quadrature amplitude modulation (QAM). You learn about speeds and feeds in Chapter 2.
- **Unlicensed spectrum:** MNOs are increasingly using unlicensed spectrum in the 2.4 and 5 Gigahertz (GHz) frequency bands. 5G networks will need to tap into the vast amount of spectrum available in these unlicensed bands to offload traffic in heavily congested areas and provide connectivity for billions of IoT devices. Advancements in Wi-Fi, LTE in Unlicensed spectrum (LTE-U), License Assisted Access (LAA), and MulteFire, among others, provide better quality and regulated access to unlicensed spectrum. You learn about these advancements in Chapter 3.
- **Internet of Things (IoT):** IoT devices pose a diverse set of requirements and challenges for 5G networks. It's only fair that IoT should likewise pose a diverse set of solutions as well! You learn about a few of these solutions — including NarrowBand IoT (NB-IoT), LTE Category M1 (LTE-M), Long Range (LoRa) and Sigfox — in Chapter 4.
- **Virtualization:** Network functions virtualization (NFV) enables the massive scale and rapid elasticity that MNOs will require in their 5G networks. Virtualization enables a virtual evolved packet core (vEPC), centralized radio access network (C-RAN), mobile edge computing (MEC), and network slicing — all explained in Chapter 5.

» **New Radio (NR):** Although the other 5G innovations introduced in this section all have strong starting points in LTE Advanced Pro, 5G NR is a true 5G native technology that has yet to be standardized. 5G NR addresses the need for a new radio access technology that will enable access speeds up to 20 Gbps — and you learn about it in Chapter 6!

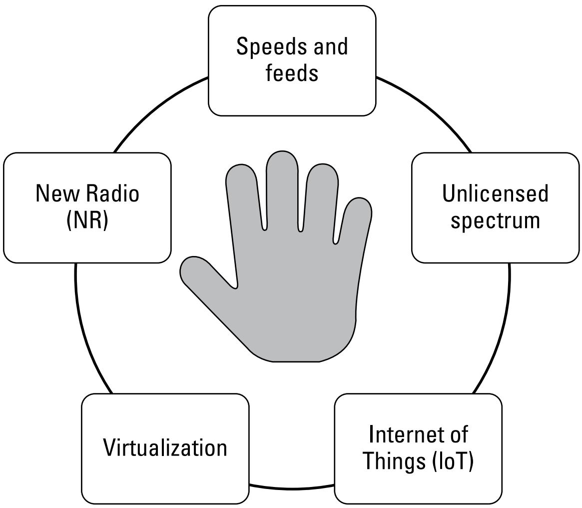


FIGURE 1-1: The five keys to 5G.

IN THIS CHAPTER

» Issuing a license to thrill — with higher speeds

» Cobbling together spectrum with carrier aggregation

» Going well beyond "rabbit ears" with massive antenna arrays

» Seeing stars with quadrature amplitude modulation

Chapter 2 Achieving Faster Speeds and Larger Feeds

Over the past decade, the need for speed in mobile networks has increased dramatically. To address this need, 5G will increase the speeds of today's most advanced Long Term Evolution (LTE) networks by an order of magnitude — from a few gigabits per second (Gbps) to as much as 20 Gbps. In this chapter, you get a glimpse of the engine — or, more correctly, the parts and components of the engine — that will power the 5G networks of the future.

Fattening the Data Pipe

Wireless spectrum is limited and highly regulated throughout the world. The International Telecommunication Union (ITU) allocates frequency spectrum worldwide, and governing bodies within the respective countries then license that spectrum for use by individual mobile network operators (MNOs). The ITU has identified three International Telecommunication Regions throughout the world with distinct frequency bands allocated to each region (see Figure 2-1).

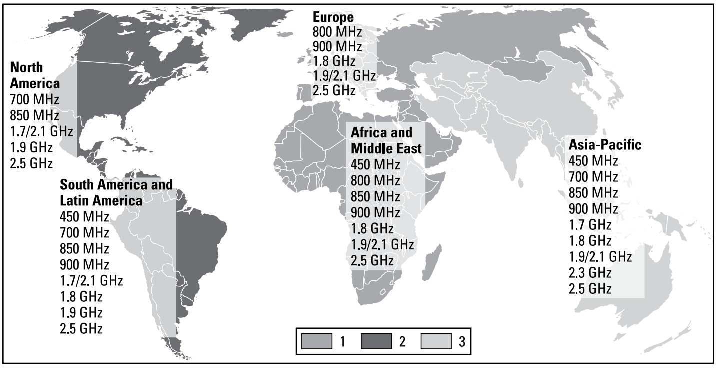


FIGURE 2-1: ITU International Telecommunication Regions and spectrum allocations.

MNOs must pay for the right to transmit and receive data using this shared medium in each country in which they operate. To fatten a wireless data pipe, an MNO must procure additional licenses to use a designated frequency spectrum.

In the U.S., the Federal Communications Commission (FCC) auctions spectrum to MNOs — and we aren't talking about eBay auctions here! In the U.S. alone, spectrum auctions have raised more than 60 billion dollars since 1994. Another challenge for MNOs is that available spectrum is limited and going once . . . going twice . . . sold!

Thus, MNOs must find new ways to use existing spectrum more efficiently. LTE Advanced and LTE Advanced Pro are pioneering the path to 5G, using several innovations to get more data through existing spectrum, including:

- Carrier aggregation (CA)
- Multiple input multiple output (MIMO)
- Quadrature amplitude modulation (QAM)

We All Bundle — with CA

As you might imagine, the process of buying and selling spectrum, over time, causes spectrum to be sliced and diced in some pretty creative ways. MNOs also come and go, or get merged, acquired, and divested (for example, Cingular Wireless and MCI). All of this causes yet another challenge — contiguous spectrum is hard to find and MNOs must cobble together different bands to maximize their available bandwidth. It's sort of like a business being so unreasonable as to want a continuous range of direct inward dialing (DID) phone numbers to simplify its phone switch programming, company directories, and business cards! Except that in the case of frequency spectrum, non-contiguous bands aren't just a messy inconvenience — they limit available bandwidth.

For LTE networks, including LTE Advanced and LTE Advanced Pro, four carrier bandwidths (or sizes) are available for transporting data:

- 5 megahertz (MHz)
- 10 MHz
- 15 MHz
- 20 MHz

Larger bandwidths can transport more data. For example, 10 MHz can transport data at 37.5 megabits per second (Mbps) and 20 MHz can transport data at 75 Mbps. These data transfer rates assume a single antenna on the user equipment (UE) side and on the Evolved Node B (eNodeB) side. This is known as single input single output (SISO).

TECHNICAL STUFF

User equipment (UE) refers to an end-user device in a mobile network, such as a smartphone. *Evolved Node B (eNodeB)* is the MNO hardware — for example, a base transceiver station (BTS) — that wirelessly communicates directly with the UE.

Carrier aggregation (CA) is a technique that allows an MNO to use more than one component carrier (CC) — known as the *secondary carrier* — as an additional data pipe. For example, 2CA enables any of the four carrier bandwidths (5, 10, 15, or 20 MHz) to be used as the primary carrier and any of the other four carrier bandwidths to be used as the secondary carrier.

In the simplest deployment scenario, known as *intra-band contiguous CA*, a 20 MHz primary and a 20 MHz secondary carrier (totaling 40 MHz) would provide twice the maximum possible bandwidth and throughput of a single carrier.

For SISO, a 2CA of 20+20 MHz would provide 150 Mbps of data throughput.

TIP

MNOs in the U.S. are currently deploying 3CA and some are already moving to 4CA (see Figure 2-2). The challenge for MNOs now is to find three or more CCs that they own the license to operate in and can aggregate. The LTE Advanced standard specifies 5CA totaling 100 MHz, while LTE Advanced Pro calls for 32CA totaling 640 MHz of aggregated carrier bandwidth.

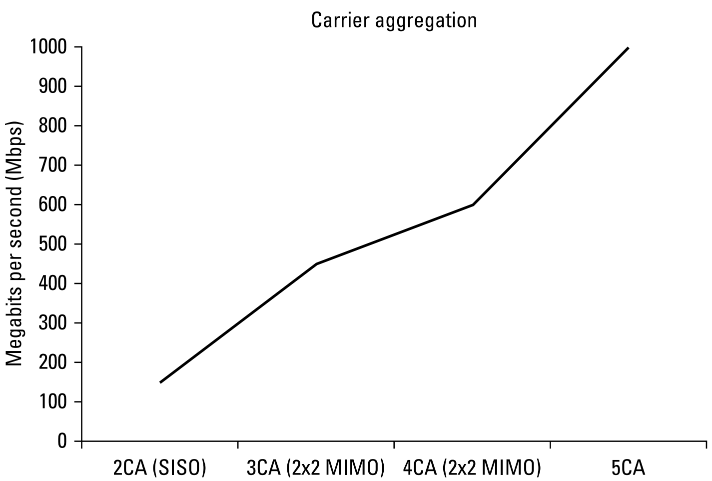


FIGURE 2-2: Carrier aggregation (CA) increases available bandwidth and data throughput.

Eeny, Meeny, Miny, MIMO

One of the techniques for fattening the data pipe defined from day one in 4G LTE networks is multiple input multiple output (MIMO) — using multiple antennas on the transmit and receive side in the wireless network. Using a technique called *spatial multiplexing*, it's possible to send a different data stream on each antenna, thereby increasing the throughput to the cell tower and to the user device.

While 2x2 MIMO deployments (two antennas in, two antennas out) are common today, 4x4 MIMO (four antennas in, four antennas out) is becoming more practical. 4x4 MIMO effectively enables four independent data streams, thereby increasing the throughput by four times. Thus, the 2CA deployment example (described in the previous section) with two 20 MHz channels and a 2x2 MIMO configuration would increase the data throughput from 150 Mbps to 300 Mbps. The same scenario with a 4x4 MIMO configuration would theoretically increase data throughput to 600 Mbps.

LTE Advanced specifications for MIMO accommodate 8-, 16-, and 32-antenna configurations. LTE Advanced Pro specifications increase MIMO configurations to 64 antenna elements. Realistically, using 64 antenna streams to increase the throughput of a single UE isn't practical. However, using a technique called *beamforming,* the eNodeB can focus energy (that is, steer beams of data) to a particular UE, thereby increasing the throughput of that UE while simultaneously handling other UEs through a different set of beams. Massive MIMO will utilize massive antenna arrays — comprised of hundreds of antennas — to provide efficient signal coverage and higher data rates with lower latency in 5G networks.

No Qualms About QAM

Quadrature amplitude modulation (QAM) is a technique widely used to vary data signals on a carrier used for radio communication. When used for digital transmission of radio communication applications, QAM can carry higher data rates than ordinary amplitude modulated and phase modulated schemes. In QAM, the constellation points are normally arranged in a square grid with equal vertical and horizontal spacing. As a result, the most common forms of QAM use a constellation with the number of points equal to a power of 2 (such as 4, 16, and 64). Thus, 16-QAM uses a 16-point constellation while 256-QAM uses a 256-point constellation.

By using higher order modulation formats (that is, more points on the constellation), it is possible to transmit more bits per symbol. So, 64-QAM has six bits per symbol (more data transmitted), whereas 16-QAM uses only four bits per symbol (less data transmitted). However, the points for a higher QAM are closer together and are therefore more susceptible to noise and data errors. 256-QAM has been used for data in digital cable communications and is now starting to be used for radio communications. 256-QAM is included as part of the LTE Advanced Release 12 standard from the Third Generation Partnership Project (3GPP) because it is likely to work with small cell towers. T-Mobile has achieved 400Mbps downlink speeds in trials through a combination of 4x4 MIMO and 256-QAM.

REMEMBER

5CA and beyond, massive MIMO, and higher-order QAM are all techniques defined as part of the LTE Advanced and LTE Advance Pro standards. With LTE Advanced deployments in full swing, 1 Gbps download speeds are getting closer to becoming a reality in operational networks. 5G will use all these techniques to achieve 20 Gbps data speeds. For example, these are a few of the developments on the 5G horizon:

- CA on very large bandwidths, leading to aggregate totals of 800 MHz (and even 1 GHz) carrier bandwidth
- Massive MIMO antenna arrays of 128 elements or more
- 1024-QAM, and even 4096-QAM

IN THIS CHAPTER

» **Expanding cellular traffic to unlicensed spectrum**

» **Getting LTE-U and LAA to coexist with Wi-Fi in unlicensed spectrum**

» **Going it alone in unlicensed spectrum with MulteFire**

Chapter 3
Tapping into Unlicensed Spectrum

Unlicensed spectrum is used by low-power devices to transmit and receive wireless signals over short distances — typically a few meters. Although specific devices are permitted to operate only in specific bands, the process of getting certifications is not time-consuming or costly, compared to getting a cellular operator license. Some common devices in this category include garage door openers, nursery monitors, home security systems, cordless phones, and Bluetooth speakers/headsets. In this chapter, you learn about the role of unlicensed spectrum in the 5G future.

Giving a "High 5(G)" to Wi-Fi Advancements

Wi-Fi operates in the unlicensed 2.4 gigahertz (GHz) and 5 GHz spectrums. There are fewer rules on who can access these bands and more available spectrum compared to licensed frequency bands. Wi-Fi devices must therefore compete to use the same spectrum as other devices.

Over the past few years, improvements in speed and the advancement of new capabilities have made Wi-Fi viable (and lucrative) for many mobile network operators (MNOs).

MNOs now regularly use Wi-Fi to offload their cellular networks wherever possible. Newer Wi-Fi standards enable massive speed increases. The standards utilize many of the latest multiple input multiple output (MIMO) beamforming techniques and higher quadrature amplitude modulation (QAM) schemes as those used in the licensed spectrum (discussed in Chapter 2).

For example, 802.11ac delivers Wi-Fi speeds of up to several gigabits per second (Gbps) operating in the 5 GHz band, using 80 or 160 megahertz (MHz) wide channels, advanced beamforming techniques, eight spatial streams (MIMO), multi-user MIMO (MU-MIMO), and 256-QAM (which produces four times the spectral efficiency of the previous 802.11n Wi-Fi standard).

The next wave in Wi-Fi is 802.11ax. 802.11ax will use orthogonal frequency-division multiple access (OFDMA) — the same technique used in Long Term Evolution (LTE) networks — in which different subcarriers within a carrier can be used to transport data for different users. As a result, more than one user equipment (UE) device can access the same medium at a given instant without having to back off or concede the medium to another UE device.

TIP

In case you're wondering, other standards exist between 802.11ac and 802.11ax, but they define Wi-Fi standards in unlicensed spectrum other than 2.4 GHz and 5 GHz — and they don't sound as cool as "A-X"!

LTE in Unlicensed Spectrum

LTE in Unlicensed spectrum (LTE-U) is a proposal that was originally developed by Qualcomm for LTE to co-exist with Wi-Fi in shared unlicensed spectrum. In LTE-U, calls are initially set up using licensed LTE spectrum. Additional carriers (for data) can then be aggregated from the unlicensed spectrum. This method will allow the operators to use unlicensed spectrum to "fatten the data pipe."

The Wi-Fi Alliance developed a Wi-Fi co-existence test plan to ensure that Wi-Fi and LTE could peacefully co-exist, and MNOs (including T-Mobile, AT&T, and Verizon) began experimenting with unlicensed spectrum in addition to their licensed spectrum.

LTE-U has also generated a lot of interest from a small cell perspective because this approach potentially makes small cells a viable alternative to Wi-Fi hot spots.

As you might imagine, strong reservations about LTE-U exist, because of concerns that it will unfairly use the unlicensed spectrum and potentially interfere with other Wi-Fi users. Cable companies, such as Comcast, Charter Communications, and Time Warner Cable (TWC), as well as Google and Microsoft, are opposed to LTE-U. As of February 2017, the U.S. Federal Communications Commission (FCC) has approved Ericsson and Nokia equipment as LTE-U certified.

License Assisted Access

Unlike LTE-U, License Assisted Access (LAA) is a standard defined in the Release 13 specification from the Third Generation Partnership Project (3GPP). LAA attempts to resolve contention issues with Wi-Fi in unlicensed spectrum using a protocol many of us learned as children — Listen Before Talk (LBT). The LBT contention protocol requires LAA to listen to the unlicensed channel first, and then, if there is no other active Wi-Fi user (the channel is silent), the LTE user can use the channel.

TIP

A recent report by Strategy Analytics states that only 16 percent of operators can achieve gigabit LTE without using unlicensed spectrum. Using LTE-U and LAA, 64 percent of operators can achieve gigabit LTE.

Qualcomm's over-the-air trials with Deutsche Telecom in Germany showed that LAA had increased coverage and capacity compared to Wi-Fi on the same spectrum. By respecting the LBT maxim (uh, protocol), the behavior of LAA is more closely modeled to the principle "love thy neighbor" and is a better neighbor to Wi-Fi than Wi-Fi is to LTE. Wi-Fi was more of an imp during its formative years and ignores LBT, trying to access the same medium at the same time as others.

Enhanced LAA (eLAA), which aggregates the uplink on unlicensed spectrum, is the next step in the evolution of LAA. eLAA will be defined in the 3GPP Release 14 specification.

REMEMBER

Both LAA and eLAA require the initial call to be set up on LTE licensed spectrum as the primary channel. Unlicensed spectrum is only used to "fatten" the data pipes.

MulteFire

MulteFire goes beyond LTE-U and LAA by enabling the LTE primary channel on unlicensed spectrum. In fact, MulteFire uses unlicensed spectrum exclusively. This means MulteFire can be deployed for LTE by anyone — without owning licensed spectrum — such as Internet service providers (ISPs) and commercial enterprises. MulteFire also benefits MNOs by providing new deployment opportunities for offloading and augmenting their cellular networks.

In January 2017, the MulteFire Alliance released version 1.0, defining an LTE-like network that can run entirely on unlicensed spectrum and, in some cases, may be an alternative to Wi-Fi with more capacity, better security, and easier handoffs across carrier networks.

REMEMBER

Today's 4G spectrum has around 500 MHz of unlicensed spectrum available to deploy LTE-U, LAA, and MulteFire. In July 2016, the FCC opened up 5G spectrum in the U.S., which has 10.85 GHz of total spectrum (3.85 GHz of licensed spectrum and 7 GHz of unlicensed spectrum). The techniques that are now evolving in LTE Advanced Pro (Releases 13 and 14) — LTE-U, LAA (and eLAA), MulteFire, and others (see Figure 3-1) — will be vital as even more unlicensed spectrum becomes available in 5G. The key goal will be to provide users with a seamless experience, irrespective of whether they are operating on a licensed or unlicensed band.

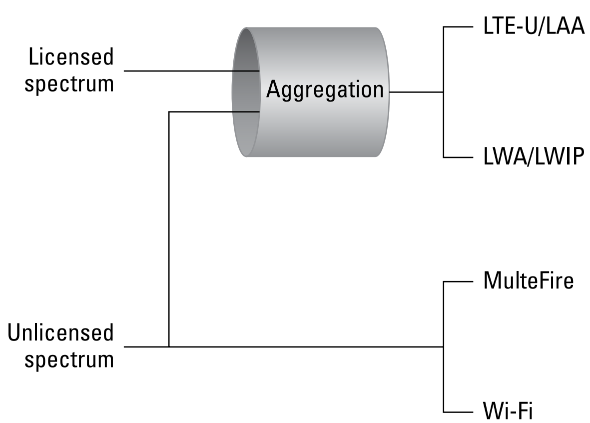


FIGURE 3-1: Leveraging licensed and unlicensed spectrum.

IN THIS CHAPTER

» Defining IoT connectivity requirements

» Handling massive scale with NB-IoT

» Slicing up spectrum for the rise of the machines

» Exploring LoRaWAN and Sigfox for low-power networks

Chapter 4
Enabling Massive IoT

When 4G networks were introduced in 2008, there were close to 700 million mobile subscribers worldwide. Today, there are more than 7 billion mobile subscribers worldwide. By 2020, according to the most conservative estimates, there will be approximately 20 billion Internet of Things (IoT) devices, in addition to the 9 billion mobile subscribers that are expected worldwide.

Thus, 5G networks must not only deliver extreme speeds and feeds, they must provide massive scale, predictability, and reliability to eventually support as many as a trillion connected devices, including mission-critical and potentially lifesaving applications and scenarios. In this chapter, you learn about the key requirements for IoT device connectivity and the innovations that are being developed to support IoT.

Key Connectivity Requirements for IoT Devices

Unlike smartphones and other cellular devices, IoT device communications can be sporadic in nature. Many of these devices "sleep" (to extend battery life for ten or more years in some cases) for long periods of time — hours, days, or weeks — before transmitting a few bytes of data, and thus needn't always be connected to the network. 5G networks must be designed to handle infrequent, but important communications from these types of IoT devices. Although the amount of data these devices send may be significantly lower, they may still be of a time-critical nature. For example, a sensor that detects a hazardous condition may instruct an Evolved Node B (eNodeB) element to shut down equipment in an industrial plant or building. These types of communication, though extremely rare, must be handled with the utmost responsiveness and reliability.

Additionally, eNodeB elements will require massive capacity to scale to support tens of thousands of IoT devices — all with different communications requirements and characteristics — in a single cell.

Finally, a wide variety of security threats and new attack vectors will be surfaced in IoT devices. Unlike many of today's threats — identity theft and credit card fraud, for example — many IoT security threats will be potentially life threatening. Future threats may include hacked control systems in autonomous vehicles and smart grids, or compromised medical devices such as insulin pumps and pacemakers. Thus, 5G technologies will need to provide secure end-to-end communications throughout the network.

NarrowBand IoT (NB-IoT)

The Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) Advanced Pro Release 13 specification defines a new standard — NarrowBand IoT (NB-IoT) — for handling low volumes of data (similar to 2G) from tens of thousands of devices in a single cell (tower, not amoeba).

NB-IoT extends LTE to even narrower bandwidths optimized for low data rate, latency-tolerant IoT applications. NB-IoT reduces device complexity, enables multiyear battery life, and provides deeper coverage to reach sensors in challenging locations, such as remote rural areas or inside buildings.

Perhaps one of the most attractive features of NB-IoT is its ability to leverage already ubiquitous LTE networks, in addition to providing high quality of service (QoS) and comprehensive security.

NB-IoT can be deployed in three different modes:

- **Standalone as a dedicated carrier:** Can use GSM frequencies in a bandwidth of 200 kHz. This does not require LTE.
- **Guard band:** Uses a free resource block within the LTE guard band. This allows the IoT devices to not compete with other LTE devices for the resource blocks within the carrier.
- **LTE in-band:** Uses a resource block within the LTE frequency band. The rest of the blocks are used by the regular LTE devices.

Long Term Evolution for Machines (LTE-M)

Like NB-IoT, Long Term Evolution for Machines (LTE-M or LTE Category M1) leverages a narrow slice of existing LTE spectrum to send and receive data for IoT devices. LTE-M has the same benefits as NB-IoT, but uses a larger network slice than NB-IoT (1.4 MHz compared to 180 KHz in NB-IoT) and leverages the LTE protocol more than the NB-IoT in terms of reusing the same control, data, and transport channels.

TIP

Verizon launched the first LTE-M network in the U.S. on March 31, 2017, and ATT Wireless was expected to follow shortly after.

LoRaWAN and Sigfox

Long Range Wide Area Network (LoRaWAN) is a Low Power Wide Area Network (LPWAN) specification for wireless, battery-operated IoT devices. LoRaWAN operates in the sub-1 GHz unlicensed spectrum band. This limits the volume and frequency of traffic, as well as the ability of the base station to control the network and send traffic down. However, LoRaWAN has great advantages in terms of battery life and cost, and communication is bi-directional.

Sigfox is a French company that created a technology similar to LoRaWAN for IoT device communication. Sigfox technology uses very low bandwidth connections. It is not bi-directional and is only used for sending sparse uplink data with very limited downlink. Like LoRaWAN, Sigfox operates in the sub-1 GHz space and thus uses very low power.

LoRaWAN and Sigfox will be used with certain types of sensors, smart meters, and other low data IoT devices. A disadvantage for these technologies is that, unlike NB-IoT, which is built on top of existing LTE infrastructure, LoRaWAN and Sigfox are not integrated with LTE. However, the cost of deploying a LoRaWAN or Sigfox based IoT device is far less than for an NB-IoT or LTE-M device — by an order of magnitude, since NB-IoT and LTE-M devices must integrate LTE modules into their devices.

REMEMBER

As countries and mobile network operators (MNOs) make IoT technology decisions, it is likely that many standards, protocols, and technologies will need to co-exist. Factors such as cost, coverage, battery life, and integration with older 4G networks will determine which standards, protocols, and technologies are best for each use case.

The 3GPP specifications for IoT technologies are just starting to come out as part of the LTE-A Pro standards. Many IoT devices will need to operate at very low power, ideally suited for sub-1 GHz spectrum rather than the millimeter wave (mmWave) spectrum (discussed in Chapter 6). That said, there are some compelling 5G techniques, like resource spread multiple access (RSMA) waveforms that allow grant-free transmissions for “things” to send their data without prior scheduling by the eNodeB. As a result, the scheduling algorithm becomes less complex. 5G will also enable multi-hop mesh for these low-power devices, allowing out-of-coverage devices to relay to other connected devices in order to send data to the eNodeB.

IN THIS CHAPTER

» Virtualizing the network for 5G and IoT

» Knowing which network elements to virtualize

Chapter 5 Getting Real About the Need to Virtualize

Virtualization has been a hot topic in the technology industry for many years and its advantages transcend the cellular industry. In this chapter, you learn about the network elements that can be virtualized and the essential role of virtualization in 5G.

Driving 5G and IoT with Virtualization

Telecommunications companies and mobile network operators (MNOs) have invested heavily in their 4G and Long Term Evolution (LTE) networks. These organizations have embraced virtualization to enable faster, more agile, and scalable deployments that can keep pace with the explosion in subscriber data traffic and consumption, all while keeping control of their overall capital and operating costs. Even though these investments have already given users mobile connectivity of unprecedented speed and pervasiveness, they have only laid the foundation of what's to come, as 5G and smart, connected devices start to roll out.

A recent study by a division of Nokia Bell Labs provides a glimpse of what's coming. The study found that the number of Internet of Things (IoT) connected devices is expected to expand from 1.6 billion in 2014 to well over 20 billion by 2020. Also, by 2020, global consumption demand for digital content and services on portable devices will see an average increase of 30 to 45 times the levels seen in 2014. Thus, MNOs will need to further accelerate their technology investments to meet ever-increasing consumer and business connectivity demands.

Recognizing the IoT explosion

Although MNOs in the U.S. are starting to embrace "pre-standard" 5G, vying for the first mover's advantage, the standards are not expected until 2018. This has echoes of the early days of 3G in the late 1990s and early 2000s, before proprietary implementations were standardized. It isn't surprising that some operators in the U.S. have already announced their plans to deploy 5G later this year, and some of the early adopters in Korea, Japan, and China are also ready to roll out 5G. Because of the rapid deployment, many 5G concepts are being solidified quickly.

5G is sometimes narrowly classified as a higher bandwidth radio access technology. But it is much more than that. It will also be the network for low-power devices and sensors that are classified as IoT devices, as well as low-latency applications. One example is the low latency required for some mission-critical devices, such as autonomous vehicles. The need for low latency will dictate that key LTE base station functions are distributed, with some moving closer to the edge and others being pooled in the cloud.

Another example is that vertical sectors will require different types of services from the 5G network. Some will need high bandwidth, while others will need low power. Some will need very low latency, and others will need very high availability. The vast volume of IoT devices will range from those that send multiple gigabits of data per second to those that will only send a few bits every month. This flexibility and elasticity can be supported only by advanced network virtualization.

Focusing on service

To support such varying 5G use cases across multiple verticals, MNOs need to shift from being network-centric to being more service-oriented.

To understand this shift, consider the concept of network slicing (see Figure 5-1). Here are a few typical cases:

- Mobile broadband with higher bandwidth video requiring high availability everywhere

- Low-power sensors that can operate on a pair of AA batteries for 10 years
- Autonomous vehicles that can zip through crowded city streets but brake within microseconds when they sense potential obstructions in their paths

TECHNICAL STUFF

Each of these scenarios requires a different configuration of the requirements and parameters in the network, potentially including:

- Home Subscriber Server (HSS)
- Mobility Management Entity (MME)
- User equipment (UE)
- Enhanced Node B (ENB or eNodeB)
- Serving Gateway (SGW)
- Packet Data Network Gateway (PGW)
- Policy and Charging Rules Function (PCRF)
- LTE Evolved Packet Core (EPC) interfaces (S1-MME, S11, S1-U, SGi)

In essence, each use case requires its own network slice. Networks must be built in a manner that allows speed, availability, capacity, and coverage to be allocated in logical slices to meet the demands of each use case.

The best way to implement network slices will be via virtualization — to use service provider software-defined networking (SDN), network functions virtualization (NFV), and network orchestration (see Figure 5-2). In each of these cases, the SDN controller will configure and build network slices that include service chains such as deep packet inspection (DPI), emails, and security scans per user or per service. The network services — including the Centralized Radio Access Network (C-RAN), Virtual Evolved Packet Core (vEPC), and Virtual IP Multimedia Subsystem (vIMS) — are virtualized as virtual network functions (VNFs) that allow MNOs to set up services rapidly, and scale them in response to network and service demands.

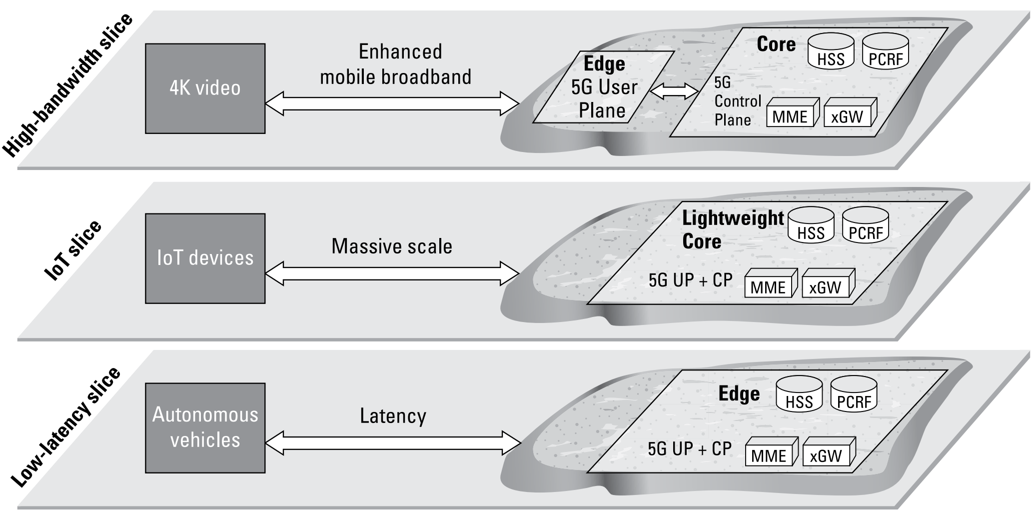


FIGURE 5-1: 5G network slices.

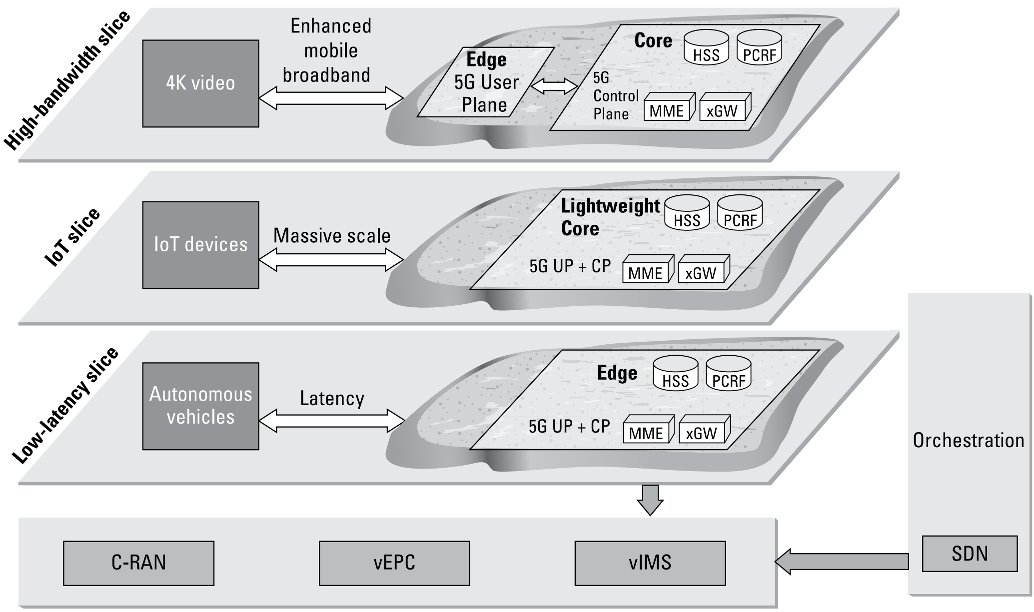


FIGURE 5-2: Network slices, VNFs, and management and orchestration in a 5G architecture.

Managing the migration

Thus, virtualization will be a vital piece of the puzzle as 5G is rolled out and the IoT grows. But the speed and agility that virtualization enables must be balanced against the need for network visibility, resilience, manageability and security, throughout the development, roll-out, and mass usage of each service.

MNOs and service providers must weigh the trade-offs between

- Quality and cost.
- Flexibility and control.
- Moving too quickly and not moving fast enough.

REMEMBER

As a result, the demand for simple, end-to-end solutions that can efficiently test and validate the effectiveness and benefits of virtualization at every stage is only going to increase. Network virtualization will be a key driver of the IoT ecosystem as it develops — and full-lifecycle reliability and performance testing will be a key element of this shift.

Virtualizing Network Components

When LTE networks were conceptualized, one notable difference from earlier 3G architectures was the idea of a central "brain" — the evolved Node B (eNodeB). From the eNodeB — the point at which the cellular network wirelessly connects directly to user equipment (UE) — to the Internet, the connectivity would all be Internet Protocol (IP) based.

When data centers and other wired network components (such as routers, switches, and firewalls) started being virtualized on standard off-the-shelf servers, it was only natural for the wireless, IP-based 4G evolved packet core (EPC) to follow.

Virtual EPC (vEPC)

Because packet gateways, policy servers, and subscriber databases are all IP-based in the LTE network, the EPC is an excellent candidate for replacing proprietary hardware with virtualized functions hosted on standard, off-the-shelf servers. The benefit for MNOs is the elasticity this model enables — no more dedicated hardware and no need to oversubscribe every part of the network. Servers can be quickly and easily provisioned or de-provisioned based on real-time subscriber capacity needs. With SDN controllers and EPC functions migrated to NFV, and orchestration schemes added to manage it all, the wireless core could be fully virtualized and cloud ready!

Centralized Radio Access Network (C-RAN)

Virtualization in the radio access network (RAN) requires separating out latency-sensitive elements and the radio itself, then pooling the rest of the baseband functions into centralized baseband units (BBUs). Which functions should stay with the remote radio head (RRH) and which ones should move to centralized BBUs has been extensively studied, and a few options exist.

The C-RAN model, which requires a fiber connection between the RRH and the BBUs, is popular in some regions of the world, such as China and Korea. This front-haul interface is challenging because it has distance limitations and is bandwidth limited. It uses a protocol known as the Common Public Radio Interface (CPRI). China Mobile has been in the forefront of the C-RAN architecture. Other countries such as Japan and Korea have also adopted C-RAN. In the U.S., Verizon is looking at implementing C-RAN for small cells.

Mobile Edge Computing (MEC)

Mobile Edge Computing (MEC) offers an important balance as cellular networks move to a central model. MEC allows certain latency-sensitive components to be moved to the network edge. For example, even though it may make business sense for MNOs to centralize several functions into VNFs running on standard off-the-shelf servers, some critical functions may need to be closer to the edge of the network to ensure high availability, low latency, and higher levels of security.

TIP

The network edge is also a good place to host application servers that require local context. For example, if you are driving around and you receive restaurant ads on your mobile device based on your current location, you need the application service to be close to the edge to avoid a lengthy delay in the app that could render the information obsolete.

IN THIS CHAPTER

» **Tuning in to the basic functions of 5G New Radio**

» **Catching the millimeter wave**

Chapter 6

Creating a New 5G World Order with New Radio (NR)

In this chapter, you learn about a completely new technology that creates the foundation for 5G — the 5G New Radio (NR) physical air interface.

5G NR Basics

Unlike the other 5G elements (covered in previous chapters), that advance the industry toward the goals of 5G networks, 5G New Radio (NR) is not an evolution of 4G Long Term Evolution (LTE) innovations. 5G NR is a completely new technology specification — a physical air interface — that is required to achieve the extreme bandwidth, low latency, and massive scalability requirements of 5G.

REMEMBER

The other four areas of 4G LTE innovation that are being further developed for 5G include:

» **Speeds and feeds:** Discussed in Chapter 2, innovations such as carrier aggregation (CA), massive multiple input multiple output (MIMO), and quadrature amplitude modulation (QAM), among others, enables carriers to "fatten" the data pipe.

- **Unlicensed spectrum:** Discussed in Chapter 3, LTE in unlicensed spectrum (LTE-U), License Assisted Access (LAA and enhanced LAA, or eLAA), and MulteFire enable carriers to leverage unlicensed spectrum as additional data pipes.
- **Internet of Things (IoT):** Discussed in Chapter 4, IoT developments include NarrowBand IoT (NB-IoT), LTE for Machines (LTE-M or LTE Category M1), and Low Power Wide Area Network (LPWAN) specifications such as Long Range WAN (LoRaWAN) and Sigfox. These developments enable wireless communication with a diverse array of billions of IoT devices.
- **Virtualization:** Discussed in Chapter 5, software-defined networking (SDN) and network functions virtualization (NFV) enable mobile network operators (MNOs) to achieve cost-effective scalability and elasticity in their core networks with innovations that include network slicing, virtual evolved packet core (vEPC), centralized radio access network (C-RAN), and mobile edge computing (MEC).

The 5G NR specification enables the following goals of 5G:

- **Extreme bandwidths:** 5G NR aggregates eight component carriers (CCs). The carrier width specifications are still in development, but will likely be 100 megahertz (MHz) or greater, providing a total of approximately one gigahertz (GHz) of aggregated bandwidth — wide enough to carry 20 gigabits of data per second.
- **Low latency:** In LTE Advanced, each subframe (there are 10 subframes) is handled in one millisecond (ms). 5G will be five to ten times faster — each subframe is handled in 100 to 200 microseconds (µs). 5G NR will use new channel coding techniques, such as low density parity check (LDPC), that are more efficient than existing techniques, resulting in shorter transmission time intervals (TTIs).

  TECHNICAL STUFF

  A technique called *scalable orthogonal frequency-division multiplexing (OFDM) numerology* will be used to support different use cases and scenarios within the same frame. Effectively, shorter TTIs will be used for low latency, high reliability use cases, and longer TTIs for higher spectral efficiency, higher bandwidth use cases. 5G NR can also effectively multiplex between short and long TTIs, thereby allowing a diverse set of users to simultaneously use the system.

- **Massive MIMO:** 5G NR extends MIMO up to 256 antenna elements and enables massive MIMO. This is a key enabler for higher spectrum bands. The antenna elements in this case are smaller, thereby making it less complex to build a massive array.
- **Massive IoT:** 5G NR will use resource spread multiple access (RSMA) on the uplink to enable grant-free transmission of data on the uplink. A device does not need an enhanced Node B (eNodeB) to give it a grant (or slot) in the pipe to transmit data. This capability eliminates the need for signaling and allows devices to send small packets asynchronously. 5G NR will also address distance and location challenges in low-power IoT devices, using a technique called *multi-hop mesh* to relay uplink data via nearby devices.

5G NR is part of the Release 15 specification from the Third Generation Partnership Project (3GPP). Two versions of 5G NR exist:

- **Non-standalone (NSA) 5G NR:** NSA will use the existing LTE radio and core network as the control plane anchor for mobility management and coverage, while adding a new 5G carrier. Early 2019 deployments of 5G NR will use this configuration. In this mode, the connection is anchored in 4G LTE while 5G NR carriers are used to boost data rates and reduce latency.
- **Standalone (SA) 5G NR:** SA will use the new 5G core network (5GCN) architecture, including the full control and user plane offered by 5G.

An interim release of the 5G NR NSA specification was accelerated to the end of 2017 to enable large-scale trials and deployments for enhanced mobile broadband (eMBB) use cases to begin in 2019. The 5G NR SA specification is expected in mid-2018.

More Spectrum — mmWave Bands

In the U.S., the Federal Communications Commission (FCC) has opened a total of 10.85 GHz of spectrum above 24 GHz to enable 5G use cases. The new spectrum includes 3.85 GHz of licensed spectrum from 27.5 to 28.35 GHz and 37 to 40 GHz, and 7 GHz of unlicensed spectrum from 64 to 71 GHz.

These bands — between 30 GHz and 300 GHz — are known as millimeter wave bands (mmWave). These high frequency bands translate to narrow wavelengths in the range of one to ten millimeters. There are some challenges with mmWave, including:

- Short transmission paths and high propagation losses over long distances and anything that is not line of sight
- Weakened signals in gases and precipitation

However, the short transmission paths and propagation loss characteristics of mmWave enable spectrum reuse, by limiting the interference between adjacent cells. Additionally, because of the extremely short wavelengths of mmWave signals, transmission paths can be extended using small, multi-element dynamic beamforming antennas that can be installed in user equipment (UE) such as smartphones.

TIP

5G NR, operating at very high frequencies with small coverage areas (because of propagation and line-of-sight issues), is ideal for dense urban locations, where cell sizes are generally small (approximately 200 meters).

IN THIS CHAPTER

» Bringing 5G home

» Staying entertained on the move

» Getting a dose of virtual and augmented reality

» Driving 5G for smart cars and autonomous vehicles

» Living in a connected world

» Assimilating humans and machines

Chapter 7
Exploring 5G Use Cases

In this chapter, you learn about some of the key use cases that will be enabled by 5G.

Fixed Wireless Broadband Service

5G will begin its commercial drive with the fixed wireless broadband use case in the U.S. AT&T and Verizon are racing to be the first to deliver fixed wireless broadband service to their customers.

Verizon acquired XO Communications, which included the 28 gigahertz (GHz) spectrum, in 2016. One of the primary drivers for Verizon will be to offer 5G as an alternative to cable/advanced digital subscriber line (ADSL) for high-speed broadband access to residential customers for gigabit speed Internet, 4K content, virtual reality (VR), and more. The goal is to achieve greater than one gigabit per second (Gbps) speeds without digging trenches to get fiber to your home.

AT&T is also pursuing 5G on fixed wireless in both the 28 GHz and 37 GHz spectrum bands. 5G video trials are currently underway for some residential customers, allowing them to stream DIRECTV NOW video service over a fixed wireless 5G connection. In its internal testing, AT&T Wireless claims it can now achieve 13 Gbps over a 5G connection. Like Verizon, AT&T is also looking at 5G to replace home broadband connections delivered by cable companies.

If successful, these use case trials could signal the end of the "cable guy" coming out "sometime between 1 p.m. and 4 p.m." to route a coaxial cable through your home. In areas where there is currently only one option for home broadband or television service, this technology could also lead to more competition, better service, and lower rates for subscribers.

Cable companies, such as Charter Communications, are also exploring 5G technologies. Charter is planning to conduct 28 GHz 5G experiments in the near future with antennas mounted on a mobile trailer and van with hydraulic masts, which will be moved to each of the test locations.

TIP

The motivation for a company like Charter is that 5G will enable a host of new products that take advantage of low-latency, high-capacity networks, including virtual reality (VR) and augmented reality (AR) applications, many of which will be used in a fixed home or office location.

Entertainment Everywhere

The natural progression of the fixed wireless broadband use case (discussed in the previous section) enables mobile broadband at extreme data rates "everywhere" — not only to a fixed home or office location.

Although some of the envisioned mobile broadband experience started in Long Term Evolution (LTE) networks, 5G takes it to a different level with 4K (and subsequently 8K) television, high dynamic range video streaming, 3D videos, and more. All these applications require very high bandwidth, and many require always-on connectivity to push real-time information to the users. The transformation from fixed wireless to wireless everywhere requires several mobility-specific factors to be addressed, such as fast handoffs, seamless connectivity at very high speeds and low latency, high reliability when mobile, and others.

REMEMBER

Cloud storage is also driving the growth of uplink data rates. In the past, content was mostly downloaded and thus required a "fat" pipe in only one direction: the downlink from the base station to the mobile device. However, content is increasingly being uploaded to different cloud storage platforms, requiring robust data pipes in both the downlink and uplink directions. Cloud gaming is another 5G driver that requires fast responsiveness and high broadband capacity.

Virtual Reality (VR) and Augmented Reality (AR)

Virtual reality (VR) technology creates a fully immersive, computer-generated experience that simulates or re-creates real-life situations and environments. In contrast to VR, augmented reality (AR) layers computer-generated images and enhancements onto a real-world situation or environment to provide a more meaningful context for user interaction.

Although current 4G networks are sufficient for some early-adopter VR and AR experiences, the introduction of 5G will enable more novel VR and AR experiences and make them available for mass adoption by consumers. Offering much more capacity, lower latency, and a more uniform experience, 5G will not only improve, but will also be a requirement for some of the most exciting AR and VR use cases, including:

- Sharing live streaming content on social media from event venues along with 50,000 other people in a stadium becomes even more challenging with 4K 360-degree video because each user is uploading 25 Mbps at the same time.
- Next-generation VR and AR experiences will have "six degrees of freedom" (6DoF) — the next level of immersion — allowing users to move within and intuitively interact with the environment. 6DoF content is an order of magnitude richer in naturalness and interactivity than current "three degrees of freedom" (3DoF) video. 3DoF experiences, such as 360-degree

video, allow the user to look around rotationally from a fixed position. 6DoF experiences, which are available in video games today, allow the user to move spatially through the environment just by walking or leaning their head forward.

6DoF head-motion tracking is required to enjoy 6DoF content in an intuitive manner. Many industries such as tourism, education, and other forms of immersive video will flourish as 6DoF technologies evolve. Most components of the video delivery pipeline are currently ill-suited for 6DoF video, including capture devices, production software, codecs, compression algorithms, the network, and players. 6DoF video also demands bit rates in the range of 200 Mbps to 1Gbps, depending on the end-to-end latency.

Connected and Autonomous Vehicles

Smart, connected cars are already here — and some security risks have already been notoriously demonstrated — and self-driving autonomous vehicles are beginning to appear on our roads. Other applications that 5G will enable for smart, connected cars include:

- **Traffic safety:** This includes the ability to detect hazardous road conditions, such as inclement weather or nearby accidents, and provide real-time guidance for appropriate courses of action to enable safer driving and reduce the risk of accidents. For example, imagine a situation in which your driverless car gets a real-time message (in microseconds) that a truck is rapidly approaching the intersection that you are about to cross. Your car then automatically slows down to let the truck pass the intersection, thereby avoiding a possible accident.
- **Entertainment (for passengers):** Live video and music streaming (including 4K ultra high-definition movies), interactive video games, cloud connectivity, and data exchange elaborate the need for high capacity and high mobility mobile broadband.
- **Augmented reality (AR):** Displaying key information in near real-time for drivers requires low latency so that the information is timely and relevant. In the earlier truck

example, a live situation is being tracked by the involved IoT devices and infrastructure, and relayed in real-time to the users — vehicle and human.

- **Self-driving, autonomous vehicles:** These will require ultra-reliable, high-speed communication between different driverless cars, and between cars and infrastructure.

The Connected World

Smart homes, smart cities, multiple industries (such as health, retail, smart grids, and remote factories) have a common thread — they are using more and more devices and sensors that communicate with one another and the rest of the world.

Many of these devices are mission critical; others may send high-definition video, requiring high availability and very low latency. Yet another set of devices may send small data packets relatively infrequently (for example, every few hours, days, or weeks). Some examples of common use cases with diverse connectivity requirements include:

- **Logistics and freight:** These devices and sensors typically require lower data rates, but need wide coverage and reliable location information.
- **Smart grid:** A smart grid requires low latency sensors to regulate the use of utilities such as electricity, natural gas, and water. Leveraging digital information, such as the behaviors of suppliers and consumers, allows the smart grid to improve the efficiency, reliability, economics, and sustainability of the production and distribution of these resources.
- **Remote medical:** Collaborating about a medical case with other surgeons located thousands of miles away was a use case scenario discussed as part of the Long Term Evolution (LTE) rollout. It can become a reality with the extreme bandwidth, low latency, and high availability of 5G networks.
- **Hazardous areas:** The ability to remotely explore mining areas or shut down a nuclear power plant during an emergency — in a fraction of the time required for human interaction, and without risk to human life — is possible with 5G.

Augmented Humans

Looking ahead to the more distant future — perhaps 30 years from now — Google futurist Ray Kurzweil predicts humans will be able to upload their entire minds to computers and become "digitally immortal" — an event called *singularity.*

In 2011, IBM's Watson beat former winners on the television game show *Jeopardy!*, proving that computers can outperform the best of humans when it comes to synthesizing information and beating them to the buzzer. Google Home and Amazon Echo are becoming more common in homes — perhaps a bit unnerving at first as they start entering our private lives, and increasingly taking center stage when we want them to tell us more about the weather, play our favorite song, read us our favorite *5G For Dummies* book, or tell a few jokes. As machine learning and artificial intelligence develop further, these intelligent devices will better understand human behavior and evolve beyond databases of information. Eventually, they will also become more mobile and intrinsic in our lives, rather than sitting on a shelf in our living rooms.

REMEMBER

5G — with its extreme bandwidths, very low latency, and massive scale support — will be a critical component in creating these real-time experiences, initially as an assistant to humans, and eventually even "thinking" for humans (in some cases). Shopping for clothes with your kids or selecting your next car will become a more immersive experience. 5G technology might also assist humans as an augmented partner, offloading some of the tasks humans don't want to "expend their own brain cells" on. Although it may sound like science fiction, 5G might be a starting point for the next evolution of humans and machines.

IN THIS CHAPTER

» Going beyond speed and latency

» Looking at drivers and timelines

» Overcoming misconceptions about limitations

» Recognizing complementary technologies

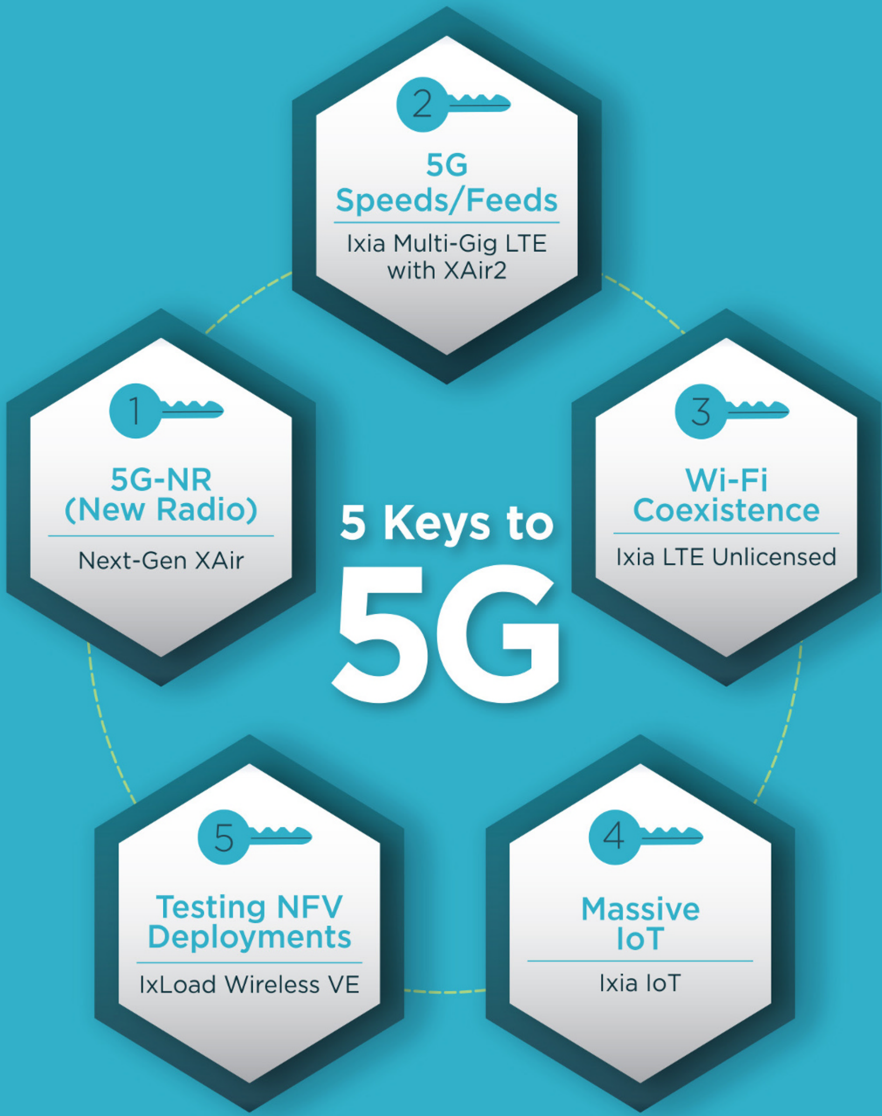
» Transforming entire industries

Chapter 8
Ten Myths About 5G — Debunked

In this chapter, we expose ten common myths about 5G — and we clue you in to the reality behind them. Keep these points in mind:

- **5G is all about higher speeds to the user.** Although one of the key goals of 5G is to provide extreme bandwidth (high-speed data) to users, low latency and massive scale are other key goals of 5G. So, 5G isn't just about speed!
- **5G requires less than one millisecond latency.** Although less than one millisecond of latency is a goal of 5G, 5G networks will be deployed before that target is actually achieved.
- **Smartphones will lead the charge to 5G.** The iPhone and Android were born in the 3G era and virtually exploded (literally, in some cases) during the 4G LTE era. However, 5G will not only enable faster and better smartphones — it will also lead to mass-market consumer VR and AR devices, sensors and applications for smart homes and cars, industrial robots, and billions of other Internet of Things (IoT) devices yet to be conceived.

- **5G will be commercially available in 2017.** Although Verizon plans to roll out 5G fixed mobility in 2017 and Olympic 5G trials will be underway during the 2018 Winter Olympics, 5G standards will not be finalized until the end of 2017. Thus, although some early, pre-standard versions of 5G will be coming soon, the 5G standard is not complete. Standards-compliant 5G will be coming much later.
- **5G is only for short-range, line-of-sight communication.** In addition to other frequency bands, 5G uses mmWave bands, which are ideal for very short ranges. However, plenty of ongoing experiments demonstrate how techniques such as beamforming can achieve greater ranges to users in challenging environments beyond line-of-sight.
- **5G will be used only in very high bands.** Although 5G will be deployed in very high millimeter wave (mmWave) bands, it will also re-use spectrum in lower bands, both licensed and unlicensed.
- **5G will replace 4G LTE.** 5G will coexist with 4G LTE for a long time to come. 4G has plenty to offer for many current applications such as voice, data, and even IoT.
- **5G will be a revolution, not an evolution.** Although 5G brings in a new physical layer (in 5G New Radio, or 5G NR), there is plenty of evolution from LTE-A Pro technologies such as carrier aggregation (CA), massive multiple input/multiple output (MIMO), quadrature amplitude modulation (QAM), unlicensed spectrum (LTE in unlicensed spectrum or LTE-U, License Assisted Access or LAA, and MulteFire, among others), IoT, and virtualization.
- **5G will be required to drive IoT.** IoT will initially be driven by LTE-A Pro where NarrowBand IoT (NB-IoT) is specified. In addition, other low-power technologies, such as Long Range Wide Area Network (LoRaWAN) and Sigfox, have been defined for IoT.
- **The 5G winners will be the operators and vendors.** Mobile network operators (MNOs), network equipment manufacturers (NEMs), and smartphone manufacturers were the primary business beneficiaries of 4G LTE. However, 5G will transform many industries, including car manufacturing, agriculture, health and medicine, transportation and logistics, and many more.


2
5G Speeds/Feeds
Ixia Multi-Gig LTE with XAir2
1
5G-NR (New Radio)
Next-Gen XAir
3
Wi-Fi Coexistence
Ixia LTE Unlicensed
5 Keys to
5G
5
Testing NFV Deployments
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Dream up new opportunities in the 5G future

The next-generation mobile network is on the horizon. 5G, the successor to 4G LTE networks, will enable significantly greater mobile speeds — as much as 20 gigabits per second — with very low latency. 5G will support a massive array of devices, from smart phones to virtual reality devices to small sensors. In this book, you learn about the technological innovations being developed today to enable a 5G future. You also learn about potential use cases that will transform entire industries and create new business models and opportunities.

Inside...

- Where wireless communication is headed
- Why higher speeds are the future
- How the IoT will employ 5G connectivity
- Why the unlicensed spectrum matters
- Why New Radio is a starting point for 5G
- How 5G will enable new business models

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