LEARNING MADE EASY

2nd Qorvo Special Edition

5G RF for dummies

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5G New Radio demystified

Examine 5G from an RF perspective

The path to 5G

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5G RF

2nd Qorvo Special Edition

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for dummies
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Introduction

In 2017, Qorvo published its first *5G RF For Dummies* book. The book helped many within our industry grasp the complex ideas around 5G technology in an easy-to-understand manner.

We outlined some key concepts in that book that have all come to fruition since then, including the following:

- The development of base station active antenna systems
- The increased usage of carrier aggregation
- Re-farming and opening of additional frequency spectrum

Back in 2017, small cell densification was just rolling out and 5G millimeter fixed wireless access was in its testing phase, but technology advancements have resulted in massive rollouts of both these technologies. In this book, we explore how these and other 5G technology advancements are reshaping the mobile network, our mobile devices, industries, use cases, and businesses.

About This Book

5G RF For Dummies, Qorvo 2nd Special Edition, consists of five short chapters that explore the following:

- The vision of 5G and the technologies enabling it (Chapter 1)
- The discovery of the 5G use cases and the early adopters of the technology (Chapter 2)
- 5G frequency spectrum and how it's being managed, re-farmed, allocated, and shared (Chapter 3)
- A deep dive into 5G New Radio and the RF Front-End technologies enabling it (Chapter 4)
- Important 5G milestones that you can look forward to (Chapter 5)

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 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. 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 will know enough about 5G to be dangerous!

Icons Used in This Book

To make it easy to navigate to the most useful information, these icons highlight key text:

TIP

Follow the target for tips that can save you time and effort.

REMEMBER

Take careful note of these key takeaway points.

TECHNICAL STUFF

Read these optional passages if you crave a more technical explanation.

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` or to `www.qorvo.com/design-hub`.

IN THIS CHAPTER

» **Understanding what's happening**

» **Learning about the 5G vision**

» **Looking at technologies that enable 5G**

Chapter 1 Introducing 5G

Connectivity has become so prevalent in our society that people have come to think of it like electricity — always on and available everywhere.

Consumers and businesses alike are looking to a fifth-Generation (5G) wireless connection to enable

- Faster downlink (DL) and uplink (UL) speeds
- Video and gaming everywhere, all the time
- High quality of service (QoS) — service that's secure and reliable
- Manufacturing/industrial efficiencies
- On-demand anything and everything

Simultaneously, the wireless carrier providers are seeking

- The ability to meet explosive mobile data demand
- Reduction of cost per data bit
- Alternative business models and revenue streams

All the above can be achieved by leveraging the 5G New Radio (NR) architecture, but some highly technical things need to happen to take us there.

In this chapter, you learn about the past, present, and future of 5G cellular networks, so you can better understand the importance of 5G in today's (and tomorrow's) wireless communications.

Understanding What's Happening

As many have anticipated, 5G will be disruptive and life changing. We're already seeing wireless innovation occurring in Internet of Things (IoT), automotive, manufacturing, and retail, providing glimpses into what the future of 5G connectivity will hold.

According to the research group IDTechEx, the rollout of 5G is forecast to contribute $700 billion to the global economy by 2030. The Global System for Mobile Communications Association (GSMA) shows 5G on track to reach 1.4 billion global mobile connections by 2025.

Make no mistake, the 5G revolution has begun. Technology build-outs are happening faster than previously predicted, much faster than the 3G to 4G transition.

Here are a few examples of what's already been happening in the last few years:

- The first operational 5G network was demonstrated at the 2018 Winter Olympics in Pyeongchang, South Korea.
- As of October 2019, mobile network operators' reports suggest that South Korea already has more than 2 million 5G subscribers.
- AT&T's 5G network is the first in the United States to surpass 2 Gigabit wireless speeds.
- Verizon has launched 5G at National Football League (NFL) stadiums across the United States.

As for the future? Here are some predictions:

- By 2021, it's estimated that more people will have mobile phones (5.5 billion) than running water (5.3 billion).
- 5G will add an estimated $4.8 trillion to the global gross domestic product (GDP) by 2023.

- It is projected that there will be 25 billion IoT devices globally by 2025 — 11.4 billion consumer and 13.7 industrial.
- A study by a leading 5G chipmaker estimates the 5G value chain alone could generate $3.5 trillion in revenue, in turn supporting up to 22 million jobs globally.

REMEMBER

5G will form a major part of the worldwide move toward intelligent always-on connectivity. Countries and carriers all over the world are clamoring to be the first with 5G, in whatever category they can. However, as with any technology evolution, the main driving force will be what produces economic, business, and consumer value.

Understanding the 5G Vision

Since the inception of 5G, talk has centered on three main types of use cases:

- Enhanced Mobile Broadband (eMBB)
- Ultra-reliable low latency
- Massive connectivity

Those deploying 5G are first and foremost focused on delivering enhanced mobile broadband services to consumers' smartphones and other mobile devices — in other words, enhanced mobile broadband everywhere. This is the quickest path to realizing a return on a mobile network operator's 5G investment.

The IoT figures heavily into the second and third categories: ultra-low latency and massive connectivity. Services such as fixed wireless access (FWA), smart home, and smart cities have all seen an uptick in focus, driven by the popularity of IoT, narrow band IoT (NB-IoT), cellular vehicle to everything (C-V2X), and industrial IoT 4.0 (see Figure 1-1).

When blazing a new trail, it always helps to have support, and 5G has it. Unlike previous wireless standard transitions from 3G or 4G, 5G has had widespread global support and is accepted as the single global standard for the coming wide area network (WAN) connectivity evolution.

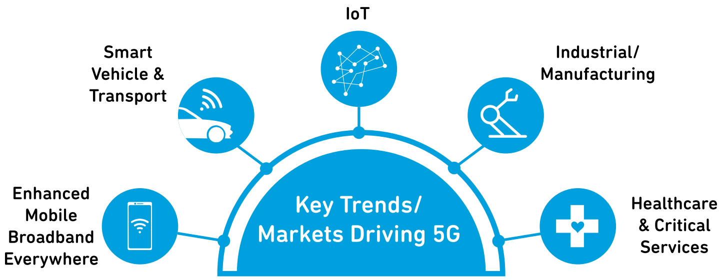

FIGURE 1-1: Top five trends driving 5G.

REMEMBER

With implementation options of either non-standalone (NSA) or standalone (SA), 5G enables global carriers to smoothly implement 5G in their networks. The Third Generation Partnership Project (3GPP), a collective project partnership of mobile system manufacturers, has played a critical role in this smooth evolution and development of the 5G standard.

TECHNICAL STUFF

5G New Radio (NR) uses modulation schemes, waveforms, and access technologies to enable network systems to meet the needs of high data rate services, providing low latency, small data rates, and long battery life.

The ratification of the 3GPP Release 15 NSA 5G NR specification in December 2017 formed the basis of commercial 5G products. The specification covered support for low-, mid-, and high-band spectrum from 600 MHz up to 50 GHz. Release 15 was completely finalized with the late drop in early 2019 (see Figure 1-2).

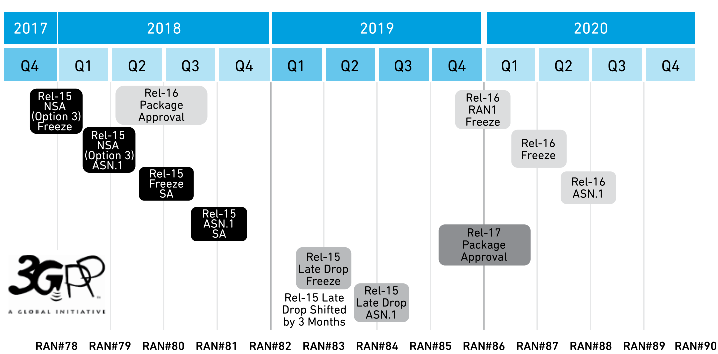

FIGURE 1-2: 3GPP release schedule.

Release 16 will expand 5G in 2020 and will focus on functions for verticals and overall system improvements. It will target advanced use cases beyond Long-Term Evolution (LTE), Vehicle to Everything (V2X) and add enhancements for industrial IoT and Ultra-Reliable Low-Latency Communications (URLLC) to replace factory Ethernet. It will also look to make improvements in signal positioning, multiple-input and multiple-output (MIMO), and lower system power consumption.

TECHNICAL STUFF

Network latency refers to the time required for a packet of data to travel round-trip between two points.

5G Radio Access Network (RAN) is designed to work fully with existing 4G LTE networks. The 3GPP Release 15 standard allowed multiple NR deployment options such as 3x NSA and 2 SA. The option terminology comes from the initial 5G architecture studies used to analyze and establish a final evolution of NSA and SA. NSA uses an LTE anchor band for control, with a 5G NR band to deliver faster data rates. NSA allows carriers to deliver 5G data speeds without requiring a new 5G core buildout. Figure 1-3 shows the transition to 5G from LTE to NSA and SA. The timetable of carrier usage and release will vary by carrier and region.

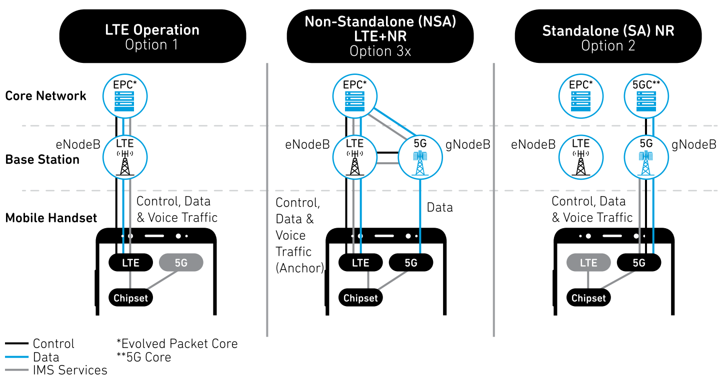

FIGURE 1-3: Progressive transition of 5G deployment.

TECHNICAL STUFF

Recent 5G deployments around the world have leveraged this NSA option to significantly accelerate 5G deployment. The next step in their connectivity evolution will be to the full-blown SA 5G with a dedicated core and radio access network.

TIP

Regardless of NSA or SA implementation, the spectrum for 5G operation is evolving fast. In this book, we reference the more familiar "Sub-6 GHz" terminology for FR1 as "Sub-7 GHz" to support potential frequency allocations up to 7 GHz. In 5G NR Release 15, the operating frequency bands are divided in two frequency ranges: frequency range 1 (FR1) and frequency range 2 (FR2). FR1 is usually called sub-7 GHz and FR2 is the 5G millimeter wave (mmWave) frequency range (see Figure 1-4).

The physical-layer and higher-layer designs are frequency agnostic, but separate radio performance requirements are specified for each. Also, different testing methodologies are used in FR1 and FR2. In FR1, both conducted and over-the-air (OTA) testing methods are utilized, while in FR2 only OTA methodology is required.

Perameter	Frequency Range 1 (FR1)	Frequency Range 2 (FR2)
Also Known As	5G Sub-7 GHz	5G mmWave
Frequency Range	410-7,125 MHz (*includes n77, n78, n79) (reference: 3GPP: 38.101 v16.1.0)	24.25-52.6 GHz (**includes n257, n258, n259, n260, n261) (reference: 3GPP: 38.101 v16.1.0)
Transmission Bandwidths (CC)	5-100 MHz	50-400 MHz
Sub Carrier Spacing	15 kHz, 30 kHz, 60 kHz	60 kHz, 120 kHz, 240 kHz
Carrier Aggregation	Up to 16 carriers	Up to 16 carriers
Waveform & Modulation	CP-OFDM (UL/DL), DFT-s-OFDM (UL): QPSK, 16 QAM, 64 QAM, 256 QAM)	CP-OFDM (UL/DL), DFT-s-OFDM (UL): π/2-BPSK, QPSK, 16 QAM, 64 QAM, 256 QAM
MIMO	Up to 8 layers in DL, up to 4 layers in UL	Up to 8 layers in DL, up to 4 layers in UL
Deployment Applications	Macro cells/many mobile users/ long-range	Small cells/less users/Increased content/short-range
Challenges	Spatial multiplexing - delivers multiple parallel streams of data in same resource block	Beam steering for each mobile user
Spectral Efficiency	High, because of spatial multiplexing	Low spectral efficiency - less users and higher pathloss
Channel Characterization	Rich multi-path propagation	Few propagation pathways
Number of Simultaneous Users	Tens of users, large coverage area	Few users, small coverage area

*FR1

Band	Downlink/Uplink (GHz)
n77	3.30-4.20
n78	3.30-3.80
n79	4.40-5.00

**FR2

Band	Downlink/Uplink (GHz)
n257	26.50-29.50
n258	24.25-27.50
n259	39.50-43.50
n260	37.00-40.00
n261	27.50-28.35

FIGURE 1-4: Frequency ranges FR1 and FR2.

As shown in Figure 1-4, the naming scheme for 5G bands has changed, replacing an *n* to reflect new radio (NR) compared to 4G LTE designations of *B* for Band. LTE bands used for 5G NR will use the same band number with the *n* identifier. Additionally, FR1 and FR2 have several differences beyond testing methodologies. These differences are seen in carrier aggregation, MIMO, and subcarrier spacing.

Looking at Technologies That Enable 5G

In this section, we look deeper at some key technologies that contribute to 5G's performance:

- Spectrum sharing
- Carrier aggregation
- Massive MIMO and antenna array systems
- Fixed Wireless Access (FWA) and mmWave technology

Spectrum sharing

In wireless communications, spectrum is the number one resource needed by mobile network operators (MNO). This precious spectrum must be used effectively and efficiently among all MNOs across different technologies. 5G was built with this in mind, and it's structured to meet the challenges for a next-generation mobile experience by unifying services, spectrum, and networks into a cohesive framework.

To transition to a full 5G implementation, MNOs manage their spectrum allocations dynamically via Dynamic Spectrum Sharing (DSS). DSS is an intelligent way to allocate spectrum between air interface standards (such as 3G, LTE, or 5G) in order to reduce spectrum waste and optimize end-user experience.

Spectrum sharing can unlock spectrum that is lightly used by other adjacent signal carriers. DSS can increase spectrum use while utilizing shared or unlicensed spectrum in the FR2 mmWave bands.

REMEMBER

The ultimate aim of 5G NR is to natively support licensed, shared, and unlicensed spectrum simultaneously, providing more efficient use of the limited spectrum we have available. For example, sharing spectrum allocations across FR1 and FR2 can double the coverage area of new 5G mid- and high-band base stations while delivering hundreds of megabits per second (MB/s) of data indoors and all the way to the cell edge.

Carrier aggregation

Carrier aggregation (CA) combines multiple MNOs into one data channel to increase data rates in the system with optimized usage of available bandwidth. CA has been fundamental to LTE's ability to gradually increase the downlink/receive data rate many mobile handset consumers have enjoyed. 5G NR expands this trend, utilizing CA in both FR1 and FR2, supporting up to 16 component carriers. Using CA of LTE and 5G NR is known as *dual connectivity.* In dual connectivity, carrier aggregation mode, both LTE carriers and 5G NR carriers are simultaneously utilized.

REMEMBER

CA brings about many advantages for 5G NR, such as:

- Increased data rates and throughputs for both UL and DL
- Flexibility for network operators to deploy their licensed spectrum by using any of the CA types (such as intra-band contiguous, intra-band noncontiguous or inter-band noncontiguous)

Massive MIMO

Massive MIMO is said to be the backbone of 5G. Leveraging all the past work under LTE-Advanced, Massive MIMO technology helps carriers achieve an increase in network capacity and data rates, while minimizing expense. For example, massive MIMO reduces energy consumption by targeting signals to individuals by using *beamforming* — a technique that focuses the signal from multiple antennas into a single strong beam. This focused signal technique also helps reduce interference between users in the network. To a consumer, massive MIMO has the potential to deliver a wireless data rate equal to that of a wired connection.

TECHNICAL STUFF

To bring these advantages, massive MIMO technology uses large antenna array systems (AAS), which combine the RF transmit and receive chains into each array unit and typically are composed of 16, 32, 64, or more array elements. The idea of using such large antenna arrays is to exploit the concept of spatial multiplexing. Spatial multiplexing delivers multiple parallel streams of data within the same resource block of spectrum. By essentially expanding the total number of virtual channels, massive MIMO increases capacity and data rates without additional towers and spectrum.

Fixed wireless access with mmWave technology

One of the 5G services that operators are introducing to consumers and businesses is Fixed Wireless Access (FWA) based on 5G's FR2, mmWave spectrum. This technology allows wireless operators to expand into the home Internet market and challenge wired broadband providers with high data rate service.

FWA is one of the earliest 5G service technologies to be rolled out. It delivers gigabit Internet speeds to homes and businesses in a fraction of the time and cost of traditional cable and fiber installations. FWA offers service providers a "last mile" solution to compete with DSL, fiber, and cable. To do this, FWA uses the FR2 mmWave frequency spectrum while leveraging AASs such as those used in massive MIMO that use all-digital or hybrid beamforming (see Figure 1-5).

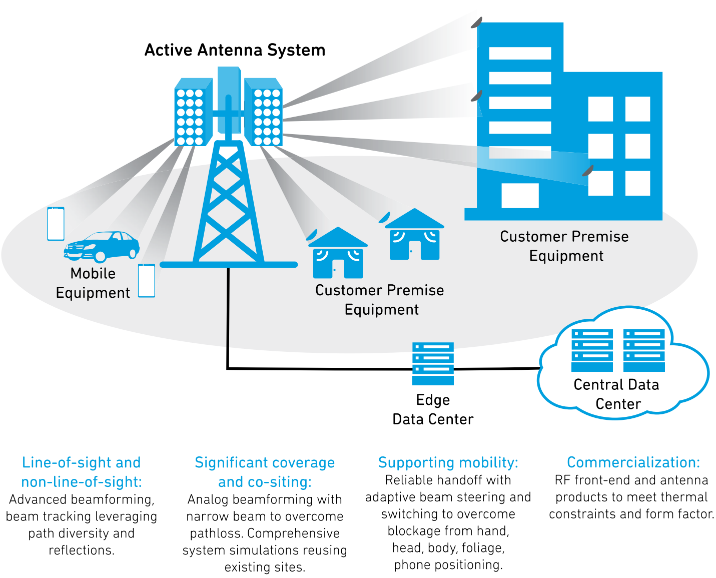

FIGURE 1-5: End-to-end FWA network and benefits.

FWA is suitable for several mobile environments — dense urban and suburban, as well as indoor or outdoor hot spots. It can provide high-speed, low-latency connectivity in densely packed or less crowded usage scenarios.

REMEMBER

Using mmWave spectrum, MNOs will be able to support channel bandwidths up to 400 MHz and enable gigabit data rates. There are some non-line-of-sight challenges, but they're mitigated by using massive MIMO AASs that utilize multiple antennas to focus the transmit and receive signals into smaller regions of space, bringing huge improvements in throughput and energy efficiency. The more data streams, the greater the data rate and the more efficient use of radiated power.

MmWave technology has also been rolled out in mobile phone releases. This high-frequency technology will provide us with low-latency devices in our hands that will not only change the future of our homes and businesses but our daily lives.

IN THIS CHAPTER

» Discovering how 5G is different

» Reviewing early adopter use cases

» Learning about network slicing

Chapter 2 Examining Some Use Cases

This chapter explains some of the key differences between 5G and previous generations of cellular connectivity. It also looks at some use cases for 5G early adopters in several business categories and explains how network slicing fits into the 5G picture.

Discovering How 5G Is Different

All previous generations of cellular connectivity standards focused almost solely on consumer communication services advancements such as upgrading web browsing, creating higher data speeds, adding video streaming, and adding improved wireless connections. With 5G, the audience goes far beyond just consumers; 5G also addresses the needs of businesses, cities, utilities, and more.

5G wireless connections will mean faster download and upload speeds, lower latency, and increased capacity. There will be a major shift toward seamless connectivity, with data downloads moving from 4G's 2 Gbps peak data rate to a 10 Gbps peak data rate for 5G. All this translates to shorter delays, better connectivity, higher mobility, and faster speeds for every business, consumer, and entertainment entity.

Although each application has a unique blend of attributes, the majority of 5G use cases can be grouped around one of three categories: Enhanced Mobile Broadband (eMBB), massive Machine-Type Communication (MTC), and Ultra-Reliable Low-Latency Communication (URLLC), summarized in Figure 2-1. In the following sections, we look at these categories in more detail.

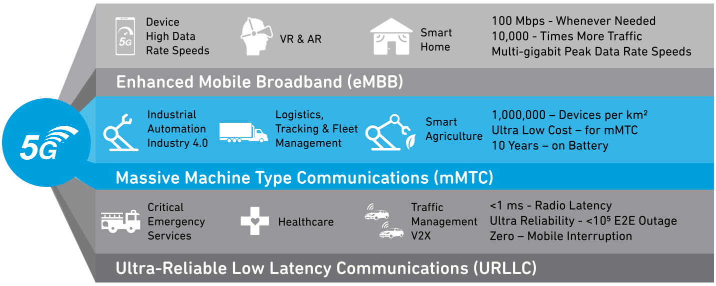

FIGURE 2-1: The promise of 5G.

Enhanced Mobile Broadband

Leveraging both FR1 and FR2 spectrum, 5G will propel mobile computing performance, enabling high-speed, cloud-connection experiences and real-time responsiveness. eMBB will provide extremely high throughput for dense urban, high-mobility, and indoor environments. Users will be able to download several gigabytes of data for applications such as 3D video, augmented reality (AR), and virtual reality (VR) in seconds rather than minutes.

Massive machine-type communication

True to its name, massive MTC will be primarily for machine-to-machine (M2M) communications, connecting anything everywhere, and will require little or no human interaction. The applications are typically low-cost, low-power sensors and devices that provide a good end-to-end coverage and transmit data back to the cloud.

Ultra-reliable low-latency communication

The URLLC use cases require the ability to process, correlate, and orchestrate multifaceted inputs for a fast response. Use cases include self-driving autonomous vehicles, healthcare, utilities, first responders, and security. These services will enable real-time intelligent and autonomous decisions, which require robust coverage, reliable connection, security, and sustainability.

TECHNICAL STUFF

These two categories hold true for the most part, but there are some exceptions. For example, there are IoT MTC applications that can fall under either the massive MTC or critical MTC buckets, depending on their latency needs.

TIP

For more information on IoT refer to *Internet of Things For Dummies*, Qorvo Special Edition, at `www.qorvo.com/design-hub/ebooks/internet-of-things-for-dummies`.

A Look at Some 5G Markets

Since the approval of 3GPPs Release 15 5G specifications, the telecommunications manufacturing industry has begun creating devices. Some industries will be affected by 5G technology out of the gate. For example, more than 18 5G smartphones were released to market in 2019. In the United States, the NFL has aligned with a major carrier to install 5G into NFL stadiums. Additionally, South Korea is on track to enable 6 percent of all subscribers (approximately 4 million people) with 5G phones by the end of the year. Even Europe has jumped on the 5G train, implementing a 5G network at a much faster pace than the prior 4G rollout.

The next several sections explore some uses in different industries, to give you a better sense of how 5G is being deployed.

Automotive

5G communications and connectivity are key to developing the autonomous vehicle, a new frontier in the automotive industry. 5G technologies will be essential to transforming the entire mobile ecosystem and vehicle-to-everything communications.

With 5G the transportation industry will have less traffic congestion, higher-level safety features, reduced emissions, and an overall smoother driving experience. The accident-avoidance features enabled by 5G communications will save not only lives, but also billions of dollars in repair costs, insurance costs, and legal fees.

The automotive industry will be able to entice new vehicle buyers with the features of a fully connected driving experience. Users will have access to real-time traffic information to optimize driving, with features like helping them finding the closest free parking space or enabling predictive maintenance to save time and money.

Drivers and vehicle owners won't be the only ones who see a benefit. Passengers will reap the benefits of next-generation infotainment services. Watching a movie as a passenger, taking important phone calls, or live-streaming the latest news will all be more possible with 5G connectivity.

Manufacturing

Manufacturing industries are under constant pressure to increase factory efficiencies, stay competitive, improve quality, improve safety, enhance security, and maintain profitability. These needs have driven companies to implement Lean practices and automation. However with 5G, much more can be done to alleviate the multitude of business pressures. Enter Industry 4.0.

Industry 3.0 was the introduction of computers into the manufacturing world. In Industry 4.0, computers are connected and communicate with each other independently of human interaction.

REMEMBER

Industries will realize huge gains when they cut the Ethernet cord and go completely wireless. Wireless connectivity in manufacturing can enable flexible production by allowing smart factories to rapidly switch production lines to shorten lead times. But the transition to Industry 4.0 will depend on many new 5G technologies, as shown in Figure 2-2.

For example, at the 2018 Mobile World Congress Americas, Nokia and Verizon demonstrated the difference in productivity between an automated guided vehicle (AGV) controlled using Wi-Fi and an AGV guided by 5G. As both AGVs were transporting pallets, cartons, and products throughout a facility, the 5G-connected AGV was able to quickly react to an obstruction in its path, thanks to 5G's speed and low latency.

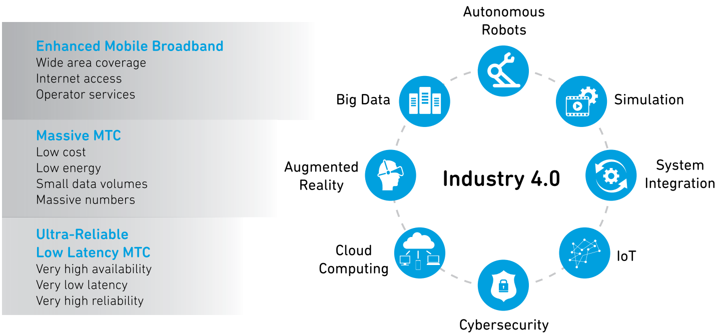

FIGURE 2-2: Industry 4.0.

Control over security is prompting industrial companies to explore private 5G wireless networks. In-house 5G will enable industries to define their own security implementations instead of relying on mobile network operators (MNOs). It also keeps proprietary sensitive data in-house.

Private networks will be a strong part of 5G. Port authorities, hospitals and manufacturing campuses all have interest in using a private network. Today, MNOs and network equipment manufacturers are already working with businesses to set up LTE private networks using the CBRS band in the United States. For 4G and 5G, some of these private networks may be constructed and run by the MNO entirely, as a service to the private business customer, using the MNOs licensed spectrum.

Alternatively, business owners may use a third-party vendor to set up a private network using unlicensed spectrum — as seen already in the LTE CBRS band.

Healthcare

Just as 5G will save lives in vehicle transportation, it will also save lives and transform the healthcare industry. Ultra-reliable low-latency MTC will be an important part in 5G healthcare use cases. With the growing popularity of wearable sensors, video conferencing, and virtual patient care visits, healthcare is at the start of a new era.

5G will help the healthcare industry meet the growing demands of digital transformation. Adding a high-speed 5G network will help transport huge data files such as MRI imagery quickly and reliably.

Telemedicine (which refers to consulting a healthcare professional remotely) requires a network that can support real-time high-quality video, and that has traditionally meant less mobility and wired connection lines. With 5G, however, the healthcare system can use mobile networks, increasing mobility and reach a wider audience.

By using 5G IoT devices, real-time remote monitoring can assist healthcare providers in monitoring patients and can gather data used to improve personalized and preventative care. These devices also increase patients' engagement in their own healthcare.

Network Slicing

So, how do we take all the use cases referenced in this chapter and make them all work together?

The 5G mobile network has a lot of moving parts, and network slicing helps organize them. 5G will need to serve many customers with different needs and use cases. Network slicing will be a key enabler of a new type of virtual networking architecture that delivers several sets of resources tailored to specific use cases.

REMEMBER

Network slicing is the ability to create many virtual networks that are customized and optimized for the specific service and traffic. In a public or private 5G network, this means the network can be optimized to meet the needs of the user and support different use cases within the network.

Each slice will be optimized to provide the resources and network topology required for the specific service and traffic. Functions such as speed, capacity, connectivity, and coverage will be allocated to meet the demands of each use case, but functional components may also be shared across different network slices.

Over time, network slicing will enable operators to introduce a greater degree of programmability and will be used to handle large usage scenarios such as massive IoT.

IN THIS CHAPTER

» Introducing the 5G 3GPP global frequency spectrum

» Understanding frequency spectrum

Chapter 3
Bandwidth Matters: The 5G Frequency Spectrum

A *frequency spectrum* is a range of radio frequencies at which a particular type of wireless communication operates. Different wireless technologies use different spectrums, so they don't interfere with one another. Because the spectrum for any given technology is limited, there is a lot of competition for space, and new ways to share and use spectrum more efficiently are constantly being developed and enhanced.

This chapter takes a look at the 5G Third Generation Partnership Project (3GPP) global frequency spectrum, which is the spectrum used in 5G communication.

Introducing the 5G 3GPP Global Frequency Spectrum

More frequency bandwidth means you can receive more data, faster. The greater the bandwidth, the less time it takes to download large files. Mobile network operators (MNOs) and regulators are, therefore, doing all they can to re-farm, acquire, or share frequency spectrum.

Re-farming is a method to convert the use of spectrum from one existing application to a new one (when MNOs converted spectrum used for 2G directly to 4G LTE around the 2010 timeframe).

Regulators have made significant strides to free up spectrum, but further action is required. Spectrum must be made available in all frequency ranges to accommodate the many use cases and performance requirements of 5G. Additionally, for carriers to increase capacity needed to support 5G, they must obtain more bandwidth, because bandwidth is the key to faster data rates.

3GPP allocates International Mobile Telecommunications (IMT) bands for each global region. As explained in Chapter 1, 3GPP is a collective project partnership between mobile system manufacturers. 3GPP has been steadily adding new time-division duplexing (TDD) and frequency-division duplexing (FDD) 3G and 4G bands over the last few years through a combination of re-farming and clearing existing services such as digital TV.

Even before the advent of 5G, 4G LTE provided many improvements in spectral efficiency. The introduction of higher-order advancements in modulation, such as 64 quadrature amplitude modulation (QAM) and 256 QAM, as well as multiple-input and multiple-output (MIMO) and beamforming, are pushing the limits of peak data rates up to 2 gigabits per second. LTE's addition of carrier aggregation (CA) has also provided MNOs with an option to increase bandwidth, combining several frequency carriers each up to 20 MHz wide — to provide as much as 140 MHz of usable spectrum. In the United States, when using unlicensed LAA and CBRS spectrum along with 7 Component Carrier (CC) CA, 140 MHz of aggregated bandwidth is achievable. 5G takes this one step further, allowing for larger CC bandwidths. In FR1 below 7 GHz, 100 MHz can be achieved, and for FR2 mmWave, up to 400 MHz can be attained. 5G in FR2 can aggregate up to 800 MHz if the individual MNO owns enough spectrum licenses.

5G spectrum is being allocated in two main frequency ranges:

- Sub-7 GHz (FR1)
- Millimeter Wave (mmWave) (FR2)

Figure 3-1, shows global allocated sub-7 GHz spectrum by country.

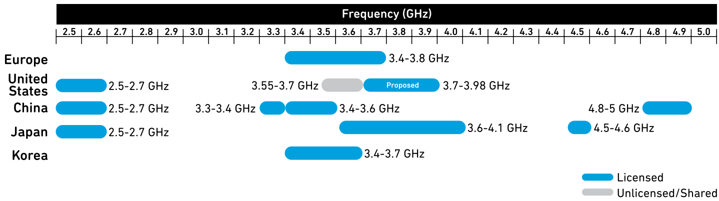

FIGURE 3-1: Global 5G Sub-7 GHz band usage.

Above 6 GHz, it's easier to find 100 MHz or more of contiguous bandwidth in the mmWave bands. This bandwidth is typically centered around 24 GHz, 28 GHz, 39 GHz, and onward to 80 GHz, and 5G allows channel bandwidths as high as 400 MHz in FR2.

Figure 3-2 shows the availability of the worldwide mmWave bands. Although more spectrum is available above 6 GHz, propagation conditions at these frequencies are more complex and often require line-of-sight (LOS) conditions between the base station and device. MmWave also requires highly directional beam forming and massive MIMO antennas to track users in real time.

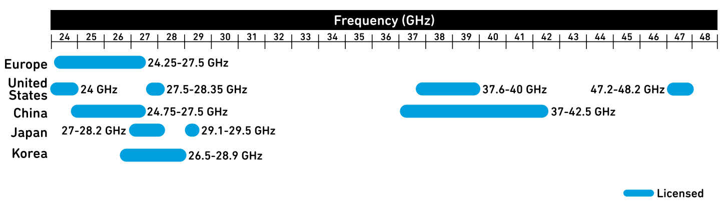

FIGURE 3-2: Global 5G mmWave band usage.

Understanding Frequency Spectrum

The deployments of 5G will be an evolution that builds on today's spectrum assets. Technology will perform differently depending on frequency band. Some bands will be better suited for certain use cases than others.

You can think about 5G spectrum in two main ways: the frequency bands that are allocated, and how each band is licensed (whether it is unlicensed, licensed, or shared).

5G Frequency bands

5G Frequency bands fall into three distinct ranges:

- **Low band:** 410 MHz to 1 GHz.
  - Limited capacity with large area coverage and indoor penetration.
  - Peak data rate tops out at approximately 200 Mbps.
- **Mid-band:** 1 GHz to 7 GHz.
  - Good for urban deployment with increased capacity.
  - Peak data rate tops out at approximately 2 Gbps.
- **High band:** 24 GHz to 100 GHz (mmWave).
  - Limited coverage with potential for very high capacity.
  - Peak data rate tops out at approximately 10 Gbps.

While operators and original equipment manufacturers (OEMs) continue working to finalize mmWave technology, sub-7 GHz will be the go-to 5G network technology in the near term. Sub-7 GHz frequencies are suited for both rural and urban areas, since the technology can deliver high data rates over long distances (Figure 3-3).

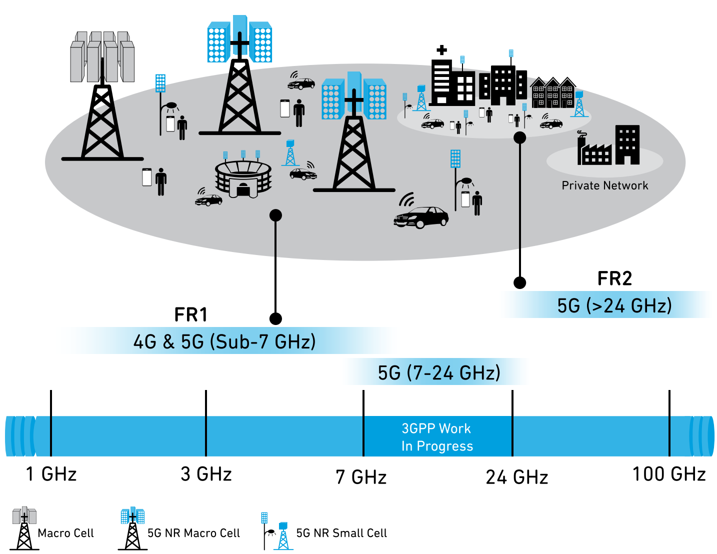

FIGURE 3-3: LTE-Advanced Pro and 5G NR ecosystem.

Higher-frequency bands, such as mmWave, are optimal for short-range, low-latency, and very high-capacity transmission for Enhanced Mobile Broadband (eMBB). However, as alluded to before, these higher-frequency bands have a shorter transmission range and are more susceptible to signal loss due to weather or objects and have limited indoor penetration. These mmWave cell site network designs are like 4G small cells, because they provide similar range and coverage.

Mid-band spectrum offers a balance of capabilities and is complementary to mmWave in urban and suburban settings. Mid-band provides availability of 5G beyond densely populated areas, due to its greater range and better propagation characteristics. An additional advantage with mid-band deployments is that carriers can add these to existing 4G cell site areas, mitigating additional expense of purchasing or leasing spaces on or around buildings.

The lower bands, below 2 GHz, provide excellent coverage and mobility. Carrier aggregation can be used to provide greater bandwidth to users in this band. These bands are great for interactive communications and massive machine type communications (mMTC). This spectrum is well suited for indoor penetration.

Spectrum licensing

Next, let's look at the three ways that spectrum is allocated for use:

- **Unlicensed spectrum:** LTE-U, LAA, eLAA, Wi-Fi, Bluetooth, C-V2X, DSRC, CBRS
- **Licensed spectrum:** Auctioned and cleared spectrum
- **Shared spectrum:** Authorized shared access required

There is a significant amount of unlicensed spectrum available — much more than licensed spectrum. To date this has been used mostly for Wi-Fi, point-to-point, transport or backhaul, meter reading, and automation. In addition, unlicensed spectrum is reserved internationally for industrial, scientific, and medical (ISM) applications. Licensed spectrum throughout the world is managed and regulated by the country of origin; for example, the Federal Communications Commission (FCC) manages spectrum for the United States.

Unlicensed spectrum bands are generally shared. But there are limitations on unlicensed spectrum usage to ensure orderly sharing. All users of unlicensed spectrum must abide by regulations that limit the allowable transmit power, radiation patterns, duty cycles, and access procedures to ensure all users can be served while mitigating interference. An example of this would be LAA and Wi-Fi sharing the 5 GHz unlicensed band.

Dynamic spectrum sharing

Spectrum sharing is an important part of the migration to 5G SA. Dynamic spectrum sharing (DSS) is the catalyst for enabling mobile network operators to quickly launch 5G. Using DSS, carriers can launch 5G in bands currently used for 4G LTE. DSS enables an existing LTE carrier to operate 5G NR and LTE simultaneously. Using DSS, an operator doesn't have to split spectrum for either 4G LTE or 5G; instead, the operator can share that spectrum between the two technologies. This enables carriers to intelligently, flexibly, and quickly introduce and add 5G within existing 4G networks. DSS is a game changer because it also allows 5G and LTE to operate in the same band, at the same time.

IN THIS CHAPTER

» Diving deeper into 5G NR

» Exploring RFFE technologies that make the difference

Chapter 4 Exploring 5G RF Technology

5G New Radio (NR) is an entirely new radio interface and radio access network, with strong roots coming from the 4G LTE (long-term evolution) and Wi-Fi standards. (*NR* stands for *new radio.*) It will be the key to enabling the 5G mobile communications system. 5G NR uses the best available technologies and techniques to meet the 5G requirements outlined by the standards bodies.

This chapter explains some of the technical aspects of 5G NR, so you can understand what's behind the scenes. It also looks at some of the features and technologies behind RF Front End (RFFE), a key part of a 5G network.

Diving Deeper into 5G NR

You probably have a basic understanding of 5G at this point, but let's go a bit deeper and take a look at the technology that underpins it. The foundation of 5G lies in these technical pillars:

- Spectrum (covered in Chapter 3)
- Dynamic spectrum sharing (also covered in Chapter 3)

- Extension of orthogonal frequency-division multiplexing (OFDM), which is a method of encoding more digital data onto multiple carrier frequencies
- Multiple-input and multiple-output (MIMO), which involves using many antennas simultaneously to increase data speeds and reduce errors
- Beamforming, which combines RF signals from multiple antennas to produce a stronger signal that's focused toward a specific device or receiver
- Small cell or network densification, which places many cell sites close together to increase the available capacity

These technologies will also provide significant enhancements to existing 4G LTE networks to increase flexibility, scalability, and efficiency. Some of these, like dynamic spectrum sharing, we cover in previous chapters. Others may be brand new to you here. We'll look at each one in the following sections.

Spectrum and dynamic spectrum sharing

As mentioned in Chapter 3, spectrum and dynamic spectrum sharing go hand-in-hand to implement enhanced mobile broadband (eMBB) requirements such as 1 Gbps or greater data rate speeds and the desired rate of user equipment (UE) adoption.

5G provides significant data rate gains when compared to 4G LTE. However, most of that benefit comes from the increased bandwidth available with new 5G bands, as shown in Figure 4-1. Only a small part of the increase in data throughput is due to the implementation of 5G NR. As you can see, downlink (DL) data rate scenarios increase exponentially by adding spectrum as opposed to only a 19 percent gain with carrier aggregation and 5G NR upgrades.

OFDM

In the development of 5G NR, the first step was its physical layer design, of which waveform is a core technology component. After a review of several proposals, 3GPP chose to extend the use of OFDM by adding a cyclic prefix OFDM (CP-OFDM) waveform for 5G in both Uplink (UL) and Down Link (DL).

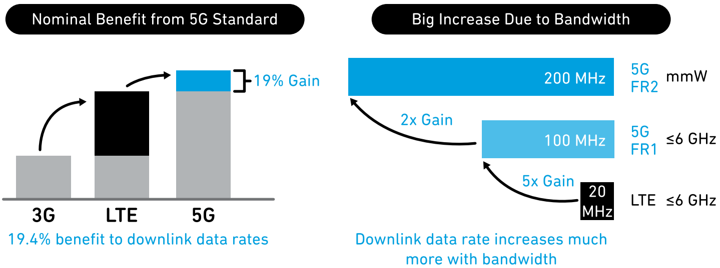

FIGURE 4-1: Comparing 4G LTE and 5G NR DL data improvements.

CP-OFDM uses many parallel narrow-band subcarriers instead of a single wide-band carrier to transport information. It's well defined and it has been successfully implemented in the 4G LTE DL and Wi-Fi communication standards, making it an appropriate selection for 5G NR designs.

However, 5G NR UL also makes available a different waveform format, similar to the one used in 4G LTE UL — Discrete Fourier Transform Spread OFDM (DFT-S-OFDM). DFT-S-OFDM is a waveform adopted in 4G that combines merits of Cyclic Prefix (CP) OFDM with a low Peak-to-Average-Power ratio (PAPR). DFT-S-OFDM aids in UL range and is likely the waveform of choice for opportunities like high-power, Power Class 2 applications or in situations where a user equipment (UE) operates far from the tower at the base stations cell's edge.

Furthering flexibility, 5G NR provides subcarrier spacing options beyond LTE's fixed 15 kHz. 5G NR spacing includes FR2 and has a maximum spacing of 240 kHz. The flexible carrier spacing is used to properly support the diverse spectrum bands, spectrum types, and deployment models needed for 5G NR.

DFT-S-OFDM is very similar to LTE's single-frequency division multiple access (SCFDMA) used for UL, and CP-OFDM is very similar to LTE's orthogonal frequency-division multiple access (OFDMA) used for DL. 3GPP chose CP-OFDM because it is

- Scalable with lower-complexity receivers.
- Ranked best on the 5G performance indicators that matter most, such as compatibility with multi-antenna technologies.
- Well controlled in the time domain, which is important for low-latency critical applications and time-division duplex (TDD) deployments.

- More robust to phase noise and Doppler effect (a change in frequency and wavelength of a wave) than other waveforms.
- More efficient for MIMO spatial multiplexing, which equals higher spectral efficiency.
- Well suited for UL transmissions in macro deployments.

5G MIMO and massive MIMO

Massive MIMO is an extension of MIMO technology. MIMO effectively reuses the same bandwidth multiple times in order to transmit more data, which allows for a more efficient use of spectrum.

Many of today's LTE MIMO base stations consist of up to eight antennas and one or two antennas on the receiver. This enables the base station to simultaneously transmit eight streams to eight individual users, or to double down and send two streams to four users.

The move to massive MIMO with 4G exponentially increases the number of antennas — up to 16, 32, 64, 128, or even more. These collections of antennas are called antenna array systems (AASs). They help focus energy into smaller regions of space through beamforming (see the next section) to bring tremendous improvements in throughput and radiated energy efficiency.

Massive MIMO helps to

- Prevent transmission in undesired directions, which alleviates interference
- Decrease latency, which allows for faster speeds and higher reliability
- Reduce fading and drops of calls and connections
- Simultaneously serve a large group of users
- Introduce two-dimensional beamforming

In addition to increasing cellular capacity and efficiency, massive MIMO uses sharp antenna beam patterns consisting of many antenna elements to transmit and receive RF signals in parallel. In massive MIMO base stations, data streams don't interfere between each other because each of them has a distinct radiation pattern. Each data stream signal strength is transmitted in the direction of the target UE, and in the directions of the other UEs the signal strength is minimized to reduce interference.

Beamforming

Beamforming uses multiple antennas to control the direction of a wave form by appropriately weighting the magnitude and phase of individual antenna signals in an array of multiple antennas, providing significant advantages to 5G. Because beamforming is a technique used in massive MIMO systems, the two terms are sometimes used interchangeably.

Beamforming is used in mmWave spectrum, roughly above 24 GHz. This spectrum provides ultra-fast data speeds because it uses wide channel bandwidth of 200 to 400 MHz. Carriers will use this technology to deploy 5G for Fixed Wireless Access (FWA), as a "last-mile" connectivity solution providing a high-speed connection to homes and businesses.

One drawback of using FWA mmWave is that it's subject to signal attenuation (loss of signal strength) due to rain, foliage, or buildings. Maintaining line-of-sight with the UE is sometimes difficult in these scenarios, and the result can be signal delays, attenuation, and arrival signal variations. However, using beamforming can help reduce the negative effects, as shown in Figure 4-2. By taking advantage of the multiple paths of massive MIMO and beamforming, the spatial channel between the antenna elements and the UE can be characterized and digitally encoded and decoded to help mitigate signal loss, even when there is limited line-of-sight.

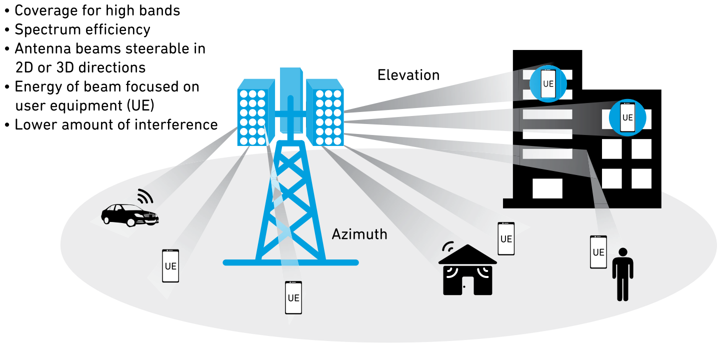

FIGURE 4-2: Massive MIMO with beamforming.

The massive MIMO beamforming base station technology illustrated in Figure 4-2 is deployed in densely populated areas such as cities.

Network densification

Today the wireless infrastructure network includes many elements, including macro cell base stations, metro cells, outdoor and indoor distributed antenna systems (DASs), and small cells. These all work together in a heterogeneous network (HetNet), as shown in Figure 4-3.

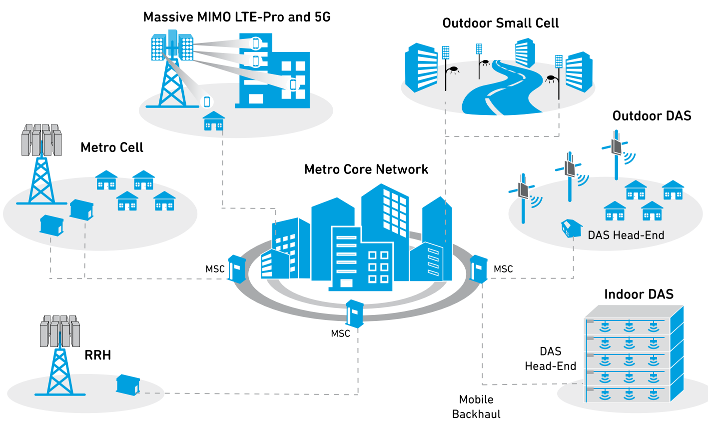

FIGURE 4-3: Wireless infrastructure heterogeneous network with small cell integration.

Densification is the process of adding more cell sites to increase the amount of available cellular capacity. These cell types can be micro or small cell to address capacity-strained areas in the network. They also offload traffic from surrounding macro and micro sites.

Small cell base stations are miniature base stations that break up a cell site into smaller groupings. A *pico cell*, *micro cell*, or *femtocell* is used depending on the coverage area, and can be an indoor or outdoor unit (see Table 4-1).

TABLE 4-1 Base Station Types

Cell Type	Output Power (W)	Cell Radius (km)	Users	Locations
Femtocell	0.001 to 0.25	0.01 to 0.1	1 to 30	Indoor
Pico cell	0.25 to 1	0.1 to 0.2	30 to 100	Indoor/outdoor
Micro cell	1 to 10	0.2 to 2.0	100 to 2,000	Indoor/outdoor
Macro cell	10 to more than 50	8 to 30	More than 2,000	Outdoor

There are important differences between a micro base station, which has one large "data pipe" going into the network, and a small cell. With a small cell, the pipe is broken up into many smaller pipes to cover a certain area. The main goal of a small cell is to increase the macro cell's edge data capacity or to cover areas that are blocked from the macro cell (poor coverage), the ultimate aim being improved data, speed, and network efficiency. Figure 4-4 illustrates a small cell integration network.

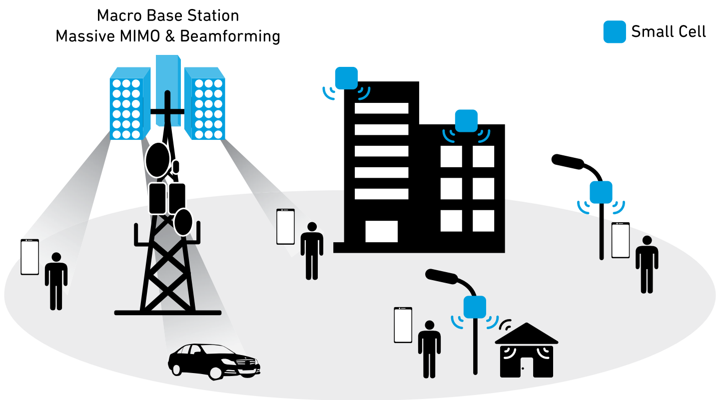

FIGURE 4-4: Small cell integration network.

Small cells:

» Increase data capacity, especially in highly dense areas such as a high shopping area or downtown city area.

- Eliminate expensive rooftop systems and installations or rental costs.
- Improve mobile handset performance.

When discussing densification and small cells, we need to consider the Internet of Things (IoT), where devices are connected using many wireless technologies. The implementation of small cells and the many connected devices will be a critical aspect to allowing massive and ultra-reliable low-latency machine type communications (MTC). These IoT categories fall roughly into four transmission classes:

- Wired
- Short-range to midrange wireless (Bluetooth to mesh networking Wi-Fi, ZigBee)
- Long-range wireless (4G LTE and 5G cellular), low-power wide area networking (LPWAN)
- Satellite

5G will enable *Massive IoT*, supporting up to tens of billions of devices, objects and machines that require ubiquitous connection. These devices could be mobile, nomadic, or stationary.

5G NR spectral carrier aggregation

Carrier aggregation (CA) is a technology that combines two or more carriers into one data channel to enhance the data capacity. Using existing network spectrum, CA enhances network performance and ensures a high-quality user experience by enabling operators to provide increased UL and DL data rates. CA was a key contributor to increasing user data throughput in 4G, and it will be just as important in 5G. Global carriers are actively adding CA bands and features such as MIMO to increase capacity, as shown in Table 4-2.

As we mention in Chapter 1, the naming conventions have changed for the 5G bands. An *n* (that is, n77 or n78) has been replaced to reflect new radio (NR), whereas 4G LTE names used *B* for Band. LTE bands used for 5G NR will use the same band number with the *n* identifier.

TABLE 4-2 **Global Carrier Aggregation Bands and Features**

Region	Bands	CA Type and Features
Europe	B1, B3, B7, B8, B20, B28, B32, B38, B40	5CC_CA, UL 2CC_CA, 4x4 MIMO
China	B1, B3, B5, B8, B34, B39, B40, B41	5CC_CA, UL 2CC_CA, 4x4 MIMO
South Korea	B1, B3, B5, B7, B8	5CC_CA, UL 2CC_CA, 4x4 MIMO
Japan	B1, B3, B11, B18, B19, B21, B26, B28, B41, B42	5CC_CA, UL 2CC_CA, 4x4 MIMO
Australia	B1, B3, B5, B7, B8, B28, B40	5CC_CA, UL 2CC_CA, 4x4 MIMO
United States	B2/25, B4/66, B5, B7/B12, B13, B14, B26, B30, B41, B46, B48, B70, B71	5CC+_CA, UL 2CC_CA, 4x4 MIMO, LAA, HPUE

5G CA will provide multi-connectivity with asymmetric upload and download, providing up to 700 MHz of channel bandwidth at mmWave frequencies. In the sub-7-GHz band, up to 400 MHz of instantaneous bandwidth can be achieved using four 100 MHz channels.

Each component carrier (CC) in frequency-division duplex (FDD) or time-division duplex (TDD) can have a bandwidth of 1.4, 3, 5, 10, 15, or 20 MHz. Thus, with five CCs at 20 MHz, a maximum bandwidth of 100 MHz can be achieved with CA. In TDD, the bandwidth and number of CCs must be the same for both the UL and the DL. 4G LTE-Advanced Pro provides a maximum bandwidth of 100 MHz, supporting 32 CCs, so up to 640 MHz can be reached. In 5G NR, there is another CA option called *dual connectivity* (DC), where 4G LTE and 5G NR bands can be aggregated.

TIP

For more information on CA, refer to *Carrier Aggregation For Dummies*, Qorvo Special Edition, at www.qorvo.com/design-hub/ebooks/carrier-aggregation-for-dummies.

Exploring RFFE Technologies That Make the Difference

To truly enable the vision of 5G, more innovation is needed. Network base stations and user equipment such as handsets are becoming sleeker and smaller, and consuming less energy. Printed circuit board (PCB) size in many RF applications is decreasing to fit into these smaller devices. Thus, RF suppliers must exploit new packaging technologies to minimize the RF component footprint. Taking this one step further, some suppliers are creating a *System in a Package* (SiP) approach to reduce the number of RF components in spite of the additional increased cost of the package for these type solutions.

This approach is being applied to the RF Front-End, which comprises all the components between the base band and the antenna.

A typical RFFE consists of switches, filters, amplifiers, and tuning components. These technologies are decreasing in size and increasingly being integrated with each other. As a result, in handsets, small cells, antenna array systems, and Wi-Fi, as well as other 5G applications, the RFFE is turning into a complex, highly integrated SiP.

All in all, it will take disruptive RF technological and packaging innovations to deliver on the 5G promise.

Gallium Nitride technology

Gallium Nitride (GaN) is a binary III/V direct bandgap semiconductor that is well suited for high power transistors capable of operating at high temperatures. The potential of GaN power amplifier (PA) technology in 5G communications is only beginning to be realized. High RF power, low DC power consumption, small form factor, and high reliability of GaN will enable equipment manufacturers to reduce the size of their base stations. This, in turn, will facilitate weight reductions for 5G base station tower-mounted antenna array systems, allowing for lower-cost installations. Additionally, GaN easily supports high throughput and wide bandwidth across the high mmWave frequencies.

GaN is the most suitable technology for enabling high *effective isotropic radiated base station power* (EIRP), as shown in Figure 4-5. In the United States, the Federal Communications Commission (FCC) has defined very high EIRP limits at 75dBm per 100MHz for the 28GHz and 39GHz bands. The challenge? Building equipment that meets these targets while staying within the cost, size, weight, and power budgets expected by mobile network operators (MNOs). GaN is the key to allowing MNOs to attain these high EIRP values with fewer elements and higher output power than other technologies.

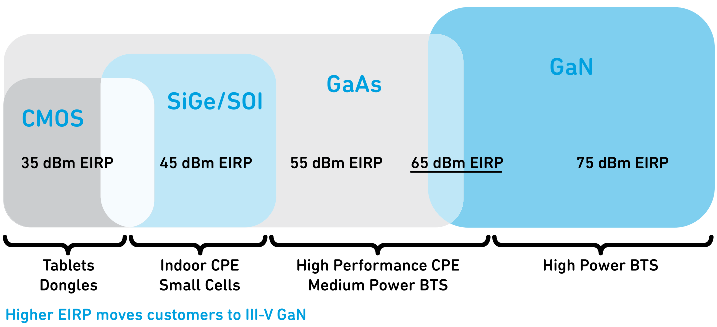

FIGURE 4-5: Suitability of semiconductor technology versus EIRP requirement.

For high power base station applications, compared to other power amplifier technologies like silicon-germanium (SiGe) or silicon (Si), GaN has lower total power dissipation to attain the same EIRP targets, as shown in Figure 4-6. This is better for tower-mounted system design, because it reduces the weight of the overall system, complexity and still offers lower power consumption.

Some key attributes of GaN include the following:

» **Reliability and ruggedness:** The higher power efficiency of GaN reduces heat output. Wide-bandgap GaN tolerates much higher operating temperatures, so cooling requirements in compact areas can be relaxed. Because GaN can reliably operate at high temperatures in tower-top applications, like antenna array systems, cooling fans may not be required and/or heatsinks can be reduced in size. Cooling fans have historically been the number-one cause of field failures due to their mechanical nature. Large heatsinks create significant cost for the hardware itself, as well as potentially adding labor costs for installation due to the weight. Using GaN eliminates these expensive heat dissipation approaches.

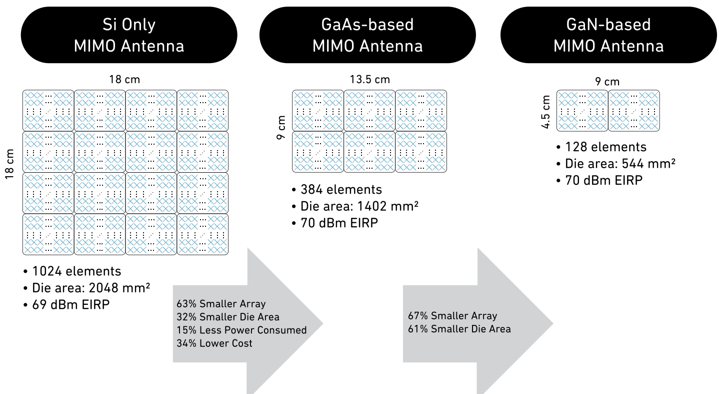

FIGURE 4-6: GaN simplifies base station complexity and reduces cost.

- **Low current consumption:** GaN lowers operating costs and creates less heat. Lower currents also help reduce system power consumption and demands placed on power supplies. Low power consumption also reduces the operational expenditures for service providers.
- **Power capability:** GaN devices offer much higher output power than other semiconductor technologies. The market trend and need for higher power from base stations plays into the strengh for GaN technology.
- **Frequency bandwidth:** The high device impedence of GaN and lower gate capacitance enables greater operational bandwidth and higher data speeds. GaN technology also has good RF performance above 3 GHz, whereas other technologies such as Silicon do not perform as well. Today's

GaN modules and power amplifiers deliver broadband operation to support the unprecedented bandwidth requirements for 5G.

- **Integration:** 5G demands smaller solutions, prompting suppliers to replace large multi-technology discrete RF front-ends with monolithic, fully integrated solutions. GaN manufacturers are catching this wave and are developing fully integrated solutions that combine the transmit and receive chain in a single package. This further reduces system size, weight, and time to market.

TIP

For more on GaN technology refer to *GaN For Dummies*, Qorvo Special Edition, at `www.qorvo.com/design-hub/ebooks/gan-for-dummies`.

Bulk acoustic wave filter technology

With all the additional bands and CA combinations, along with the fact that cellular communications must coexist with many other wireless standards, interference is more of a challenge than ever before. Filter technology is essential to reduce the interference between bands and standards.

With their small footprint, excellent performance, and affordability, *surface acoustic wave* (SAW) and *bulk acoustic wave* (BAW) filters have dominated the mobile device filter market.

TIP

For more on filter technology refer to *Filters For Dummies*, Qorvo Special Edition, at `www.qorvo.com/design-hub/ebooks/filters-for-dummies`.

BAW filters are well suited for frequency ranges between 1 and 6 GHz, while SAW is well suited for frequencies below 1 GHz. BAW's 5G sweet spot is, therefore, the sub-7-GHz realm.

The use of BAW and SAW can reduce the interferences for LTE, Wi-Fi, and automotive communications as well as the new 5G sub-7-GHz frequencies while meeting manufacturer stringent size and performance criteria.

For smartphone designers, the introduction of 5G is another assault on battery life and board space. The pressure to integrate and shrink continues to increase with each product generation. Operating at the higher frequencies means power amplifiers are less efficient while antennas and lines have higher loss. 5G phones also require more RF switches, which adds link budget loss. (*Link budget* is the sum of all the gains and losses from a transmitter through a cable, trace, and so on to the receiver in a telecommunications system.)

Not surprisingly, the number of filters in a phone has increased dramatically from 4G technology to 5G, as shown in Figure 4-7. Carrier aggregation (CA) has been a major contributing factor to the increase. With all the global CA combinations and the number of standards and bands being added to the phones, filter technology is on the rise. Filter complexity has also increased, driven by CA combinations and the desire to optimize phone performance.

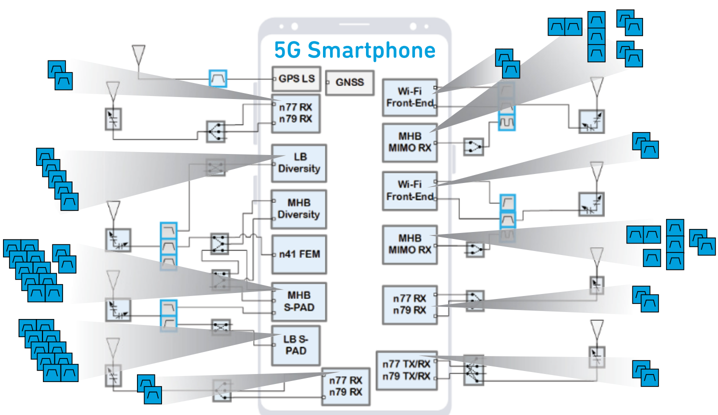

FIGURE 4-7: Handset smartphone with integrated filter technology.

One of the many things BAW technology has in its favor is heat dissipation, as shown in Figure 4-8. As previously discussed, increased PA power results in increased heat. If PA power is increased to compensate for loss in the system or for signal range challenges, the transmit filter will see an increase in heat. This heat negatively affects the filter performance and operating life and causes a frequency shift in both the attenuation areas and pass band. Using BAW technology helps to mitigate this issue because BAW-SMR (solidly mounted resonator) has a vertical heat flux, which improves the movement of heat away from the device. At high frequency, the reflector layers are even thinner, which helps further improve the heat extraction from the BAW resonator.

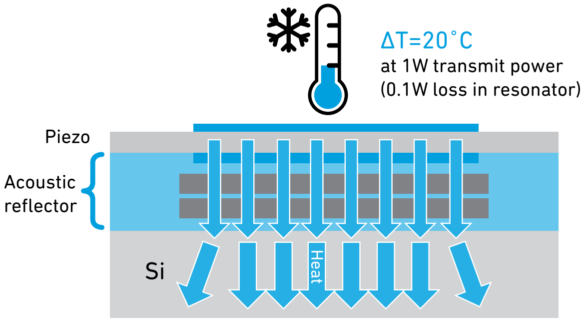

FIGURE 4-8: SMR BAW filter power handling.

RF technology, packaging, and design

Multiple semiconductor technologies make up the RFFE. The many 5G applications demand a variety of process technologies, design techniques, integration, and packaging to meet the needs of each unique use case.

RFFE solutions for 5G sub-7 GHz require packaging innovations such as closer placement of components, shorter lead lengths between components to minimize loss, double-sided mounting, compartmental shielding, and higher "Q" (quality) surface mounted technology (SMT) components.

TIP

For more on 5G related RF technology refer to Qorvo's Design Hub e-books, blogs, white papers, articles, and videos at `www.qorvo.com/design-hub`.

All of the 5G use cases will require RF front-end technology. 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 4-9, there are multiple semiconductor technologies for each RF function and application.

These applications demand a variety of process technologies, design techniques, integration, and packaging to meet the needs of each unique situation.

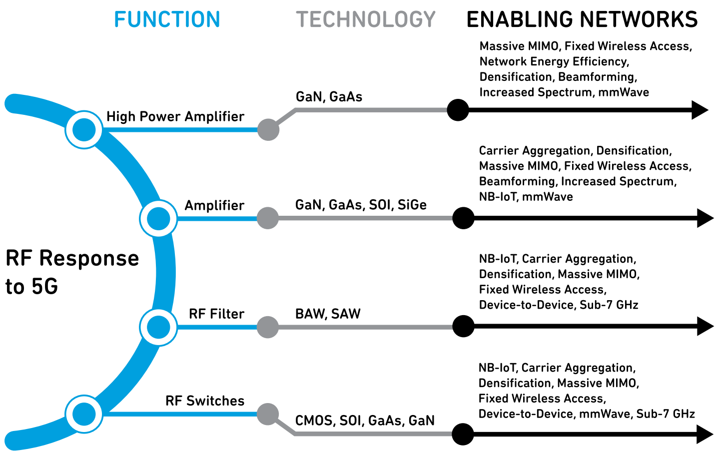

FIGURE 4-9: RF communication technology enabling 5G.

IN THIS CHAPTER

» Anticipating new 5G technologies

» Exploring how changing user needs will affect 5G

Chapter 5
Ten Important Milestones on the Road to the 5G Future

Wondering what's next for 5G? The next several years are going to bring many changes, both because of the technologies that are still improving and the changing ways that people are using the Internet and other networks. Here are ten important 5G milestones that you can look forward to.

FR2 5G mmWave

As you learned earlier in this book, carriers and phone manufacturers are revving up 5G by implementing mmWave technology. The FR2 higher-frequency mmWave bands (above 24 GHz) will expand both network capacity and wireless use cases, with theoretical 5G transfer speeds of up to 10 gigabits per second. Because these mmWave bands have a significantly shorter range than lower-frequency bands, providers will need to roll out more short-range cellular sites to avoid coverage gaps.

Cellular IoT

In 2018, Ericsson reported that there were more Internet of Things (IoT) devices than mobile phone connections. But this is only the tip of the iceberg — Ericsson is forecasting 3.5 billion connections by 2023. This popularity and growth are mainly due to increased industry focus and 3GPP standardization of cellular IoT technologies. Cellular networks offer coverage nearly everywhere, and unparalleled levels of reliability, security, and performance required by the most demanding IoT applications.

Network Densification

Network densification means a network is getting more dense — in other words, supporting more users and devices in a given area. Network usage increases every year, and densification is going to explode with the automated vehicle, networked healthcare, and enhanced mobile broadband initiatives that are beginning to roll out.

To accommodate this surge in use, operators in high-usage areas are migrating down the towers and deploying small cells and other integrated radio antenna units connected to centralized baseband resources. Such configurations help providers meet 5G capacity, data rates, and connectivity requirements as usage increases.

Massive MIMO and Antenna Array Systems

Massive MIMO and antenna array systems (AASs) are crucial for large-scale deployments in 5G mobile networks. Massive MIMO and AAS expand capacity and data rates beyond legacy systems by adding a significantly higher number of antennas on the base station, enhancing uplink and downlink performance. AAS uses MIMO and beamforming techniques to improve end-user experience, capacity, and coverage.

Spectrum Gathering

5G must support significantly faster mobile broadband speeds and lower latency. To accomplish this, more spectrum is required. The additional 5G spectrum within the two FR1 and FR2 frequency ranges will deliver widespread coverage and support all use cases. See Chapter 1 for more FR1 and FR2 details.

Vehicle to Everything Communication

Vehicle to Everything (V2X) communication is a general concept that refers to both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. When implemented, it will enable data exchanges between a vehicle and its surroundings.

V2X will enhance traffic efficiency by providing warnings for traffic congestion, ensuring driver/vehicle safety, reducing CO_2 emissions via adaptive cruise control, and smart transportation management.

TIP

To find out more about V2X refer to *Connected Car For Dummies*, Qorvo Special Edition, at `www.qorvo.com/design-hub/ebooks/connected-car-for-dummies`.

Industry 4.0 and Manufacturing

Businesses and industries are under constant pressure to improve quality, boost factory efficiency, stay competitive, enhance safety, improve security, and cut manufacturing costs, all while remaining profitable. Industry 4.0 will significantly transform the way goods are produced and delivered. (Refer to Chapter 2 for more details on Industry 4.0.) It will move the industry toward smart production and flexible manufacturing.

IoT Everywhere

IoT is becoming more popular every year with both consumers and businesses, in everything from home appliances and security systems to industrial robotics and street lighting. Most recently, cloud computing, artificial intelligence (AI), augmented reality (AR), and security assurance have accelerated the IoT ecosystem even further.

The 3GPP standards for IoT encompass massive IoT and ultra-reliable low latency critical communications. The 5G networks being deployed today will build upon 4G LTE networks including Narrowband-IoT (NB-IoT). IoT will continue to evolve and work seamlessly with 5G, leading to massive IoT enabling a connected world numbering in the billions of IoT devices.

Healthcare and Telemedicine

Cellular carriers have already jumped on the telemedicine train and are actively helping the healthcare industry become more connected to transfer real-time data.

5G will expand possibilities by providing the additional bandwidth and connectivity required for widespread use of technologies such as telehealth and remote home monitoring. For people in rural areas, with doctors located many miles away, traveling while ill is a challenge. With telehealth and remote home monitoring, patients can receive care from the comfort of their homes. Healthcare providers can meet with patients via video calls and provide basic care or submit prescriptions without an in-person visit.

Augmented Reality and Virtual Reality

The future of augmented reality (AR) and virtual reality (VR) depends on 5G. These cutting-edge technologies superimpose digital data onto the physical world and enable computers to generate simulations of 3D images or create 3D environments.

By taking advantage of 5G's speed and bandwidth, AR and VR will enable new functionality for business, cities, education, retail, manufacturing, and healthcare. For example, smart glasses can use AR and mixed reality (a combination of AR and "real life") to provide remote help to a technician repairing a machine.

AR also holds great potential for retail businesses to interact with customers in new ways. For example, AR can enable a customer to see how an item he's considering purchasing, such as a lamp or sofa, will look in his home.

Get ready for a new era of mobile communications

The future of 5G is here. 5G technology is bringing maximum performance, coverage, and reliability and is transforming entire industries. 5G supports new and existing use cases, including enhanced mobile broadband: virtual reality, smart home connectivity and mobile connectivity everywhere; massive machine type communications: industrial automation (industry 4.0) logistics, fleet management, and smart agriculture; ultra-reliable low latency communication: critical emergency services and traffic management (V2X). Learn how 5G New Radio, massive MIMO, network densification and carrier aggregation are helping 5G usher in a new communications era.

Inside…

- See the 5G vision
- Recognize the drivers of 5G
- Look at 5G use cases
- Understand 5G frequency spectrum
- Examine innovative 5G RF technologies
- Identify the path from non-standalone to standalone

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