CHAPTER

INTRODUCTION

1

Mobile communication has become an everyday commodity. In the last decades, it has evolved from being an expensive technology for a few selected individuals to today's ubiquitous systems used by a majority of the world's population.

The world has witnessed four generations of mobile-communication systems, each associated with a specific set of technologies and a specific set of supported use cases, see Figure 1.1. The generations and the steps taken between them are used here as background to introduce the content of this book. The rest of the book focuses on the latest generations that are deployed and under consideration, which are fourth generation (4G) and fifth generation (5G).

1.1 1G AND 2G—VOICE-CENTRIC TECHNOLOGIES

The first-generation (1G) systems were the analog voice-only mobile-telephony systems of the 1980s, often available on a national basis with limited or no international roaming. 1G systems include NMT, AMPS, and TACS. Mobile communication was available before the 1G systems, but typically on a small scale and targeting a very selected group of people.

The second-generation (2G) systems appeared in the early 1990s. Examples of 2G technologies include the European-originated GSM technology, the American IS-95/CDMA and IS-136/TDMA technologies, and the Japanese PDC technology. The 2G systems were

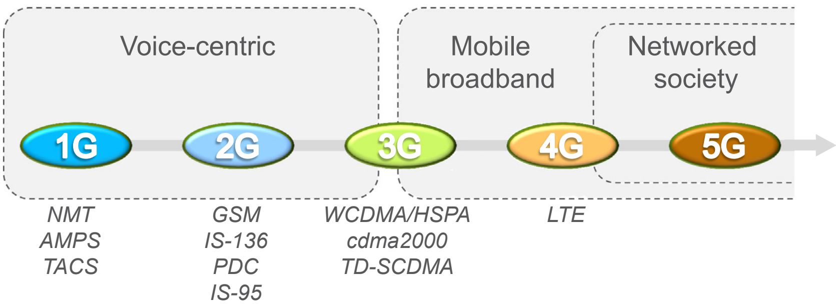

FIGURE 1.1

Cellular generations.

4G, LTE-Advanced Pro and The Road to 5G. http://dx.doi.org/10.1016/B978-0-12-804575-6.00001-7

still voice centric, but thanks to being all-digital provided a significantly higher capacity than the previous 1G systems. Over the years, some of these early technologies have been extended to also support (primitive) packet data services. These extensions are sometimes referred to as 2.5G to indicate that they have their roots in the 2G technologies but have a significantly wider range of capabilities than the original technologies. EDGE is a well-known example of a 2.5G technology. GSM/EDGE is still in widespread use in smartphones but is also frequently used for some types of machine-type communication such as alarms, payment systems, and real-estate monitoring.

1.2 3G AND 4G—MOBILE BROADBAND

During the 1990s, the need to support not only voice but also data services had started to emerge, driving the need for a new generation of cellular technologies going beyond voice-only services. At this time in the late 1990s, 2G GSM, despite being developed within Europe, had already become a de facto global standard. To ensure global reach also for 3G technologies it was realized that the 3G development had to be carried out on a global basis. To facilitate this, the *Third-Generation Partnership Project* (3GPP) was formed to develop the 3G WCDMA and TD-SCDMA technologies, see Chapter 2 for further details. Shortly afterward, the parallel organization 3GPP2 was formed to develop the competing 3G cdma2000 technology, an evolution of the 2G IS-95 technology.

The first release of WCDMA (release 99[1]) was finalized in 1999. It included circuit-switched voice and video services, and data services over both packet-switched and circuit-switched bearers.

The first major enhancements to WCDMA came with the introduction of *High Speed Downlink Packet Access* (HSDPA) in release 5 followed by *Enhanced Uplink in release 6,* collectively known as *High Speed Packet Access (HSPA)* [61]. HSPA, sometimes referred to as 3.5G, allowed for a “true” mobile-broadband experience with data rates of several Mbit/s while maintaining the compatibility with the original 3G specifications. With the support for mobile broadband, the foundation for the rapid uptake of smart phones such as the iPhone and the wide range of Android devices were in place. Without the wide availability of mobile broadband for the mass market, the uptake of smart phone usage would have been significantly slower and their usability severely limited. At the same time, the massive use of smart phones and a wide range of packet-data-based services such as social networking, video, gaming, and online shopping translates into requirements on increased capacity and improved spectral efficiency. Users getting more and more used to mobile services also raise their expectations in terms of experiencing increased data rates and reduced latency. These needs

[1]For historical reasons, the first 3GPP release is named after the year it was frozen (1999), while the following releases are numbered 4, 5, 6, and so on.

were partly handled by a continuous, and still ongoing, evolution of HSPA, but it also triggered the discussions on 4G technology in the mid-2000s.

The 4G LTE technology was from the beginning developed for packet-data support and has no support for circuit-switched voice, unlike the 3G where HSPA was an “add-on” to provide high-performance packet data on top of an existing technology. Mobile broadband services were the focus, with tough requirements on high data rates, low latency, and high capacity. Spectrum flexibility and maximum commonality between FDD and TDD solutions were other important requirements. A new core network architecture was also developed, known as *Enhanced Packet Core* (EPC), to replace the architecture used by GSM and WCDMA/HSPA. The first version of LTE was part of release 8 of the 3GPP specifications and the first commercial deployment took place in late 2009, followed by a rapid and worldwide deployment of LTE networks.

One significant aspect of LTE is the worldwide acceptance of a single technology, unlike previous generations for which there has been several competing technologies, see Figure 1.2. Having a single, universally accepted technology accelerates development of new services and reduces the cost for both users and network operators.

Since its commercial introduction in 2009, LTE has evolved considerably in terms of data rates, capacity, spectrum and deployment flexibility, and application range. From macro-centric deployments with peak data rates of 300 Mbit/s in 20 MHz of contiguous, licensed spectrum, the evolution of LTE can in release 13 support multi-Gbit/s peak data rates through improvements in terms of antenna technologies, multisite coordination, exploitation of fragmented as well as unlicensed spectrum and densified deployments just to mention a few areas. The evolution of LTE has also considerably widened the use cases beyond mobile broadband by, for example, improving support for massive machine-type communication and introducing direct device-to-device communication.

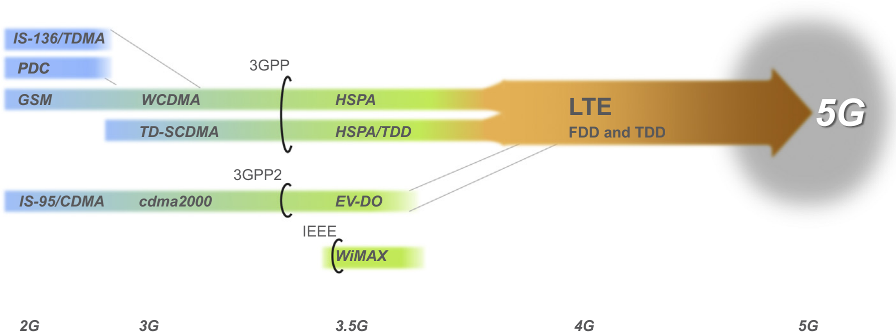

FIGURE 1.2

Convergence of wireless technologies.

1.3 5G—BEYOND MOBILE BROADBAND—NETWORKED SOCIETY

Although LTE is still at a relatively early stage of deployment, the industry is already well on the road towards the next generation of mobile communication, commonly referred to as fifth generation or 5G.

Mobile broadband is, and will continue to be, an important part of future cellular communication, but future wireless networks are to a large extent also about a significantly wider range of use cases. In essence, 5G should be seen as a platform enabling wireless connectivity to all kinds of services, existing as well as future not-yet-known services and thereby taking wireless networks beyond mobile broadband. Connectivity will be provided essentially anywhere, anytime to anyone and anything. The term *networked society* is sometimes used when referring to such a scenario where connectivity goes beyond mobile smartphones, having a profound impact on the society.

Massive machine-type communication, exemplified by sensor networks in agriculture, traffic monitoring, and remote management of utility equipment in buildings, is one type of non-mobile-broadband applications. These applications primarily put requirements on very low device power consumption while the data rates and amounts of data per device are modest. Many of these applications can already be supported by the LTE evolution.

Another example of non-mobile-broadband applications are *ultra-reliable and low-latency communications* (URLLC), also known as critical machine-type communication. Examples hereof are industrial automation, where latency and reliability requirements are very strict. Vehicle-to-vehicle communication for traffic safety is another example.

Nevertheless, mobile broadband will remain an important use case and the amount of traffic in wireless networks is increasing rapidly, as is the user expectation on data rates, availability, and latency. These enhanced requirements also need to be addressed by 5G wireless networks.

Increasing the capacity can be done in three ways: improved spectral efficiency, densified deployments, and an increased amount of spectrum. The spectral efficiency of LTE is already high and although improvements can be made, it is not sufficient to meet the traffic increase. Network densification is also expected to happen, not only from a capacity perspective, but also from a high-data-rate-availability point of view, and can provide a considerable increase in capacity although at the cost of finding additional antenna sites. Increasing the amount of spectrum will help, but unfortunately, the amount of not-yet-exploited spectrum in typical cellular bands, up to about 3 GHz, is limited and fairly small. Therefore, the attention has increased to somewhat higher frequency bands, both in the 3–6 GHz range but also in the range 6–30 GHz and beyond for which LTE is not designed, as a way to access additional spectrum. However, as the propagation conditions in higher frequency bands are less favorable for wide-area coverage and require more advanced antenna techniques such as beamforming, these bands can mainly serve as a complement to the existing, lower-frequency bands.

As seen from the discussion earlier, the range of requirements for 5G wireless networks are very wide, calling for a high degree of network flexibility. Furthermore, as many future

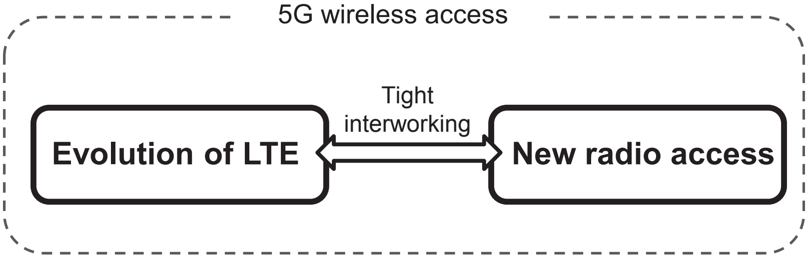

FIGURE 1.3

5G consisting of LTE evolution and a new radio-access technology.

applications cannot be foreseen at the moment, future-proofness is a key requirement. Some of these requirements can be handled by the LTE evolution, but not all, calling for a new radio-access technology to complement LTE evolution as illustrated in Figure 1.3.

1.4 OUTLINE

The remainder of this book describes the technologies for the 4G and 5G wireless networks.

Chapter 2 describes the standardization process and relevant organizations such as the aforementioned 3GPP and ITU. The frequency bands available for mobile communication is also be covered, together with a discussion on the process for finding new frequency bands.

An overview of LTE and its evolution is found in Chapter 3. This chapter can be read on its own to get a high-level understanding of LTE and how the LTE specifications evolved over time. To underline the significant increase in capabilities brought by the LTE evolution, 3GPP introduced the names LTE-Advanced and LTE-Advanced Pro for some of the releases.

Chapters 4–11 cover the basic LTE structure, starting with the overall protocol structure in Chapter 4 and followed by a detailed description of the physical layer in Chapters 5–7. The remaining Chapters 8–11, cover connection setup and various transmission procedures, including multi-antenna support.

Some of the major enhancements to LTE introduced over time is covered in Chapters 12–21, including carrier aggregation, unlicensed spectrum, machine-type communication, and device-to-device communication. Relaying, heterogeneous deployments, broadcast/multicast services, dual connectivity multisite coordination are other examples of enhancements covered in these chapters.

RF requirements, taking into account spectrum flexibility and multi-standard radio equipment, is the topic of Chapter 22.

Chapters 23 and 24 cover the new radio access about to be standardized as part of 5G. A closer look on the requirements and how they are defined is the topic of Chapter 23, while Chapter 24 digs into the technical realization.

Finally, Chapter 25 concludes the book and the discussion on 5G radio access.