CHAPTER

What Is 5G?

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Over the last 40 years, the world has witnessed four generations of mobile communication (see Fig. 1.1).

The first generation of mobile communication, emerging around 1980, was based on analog transmission with the main technologies being AMPS (Advanced Mobile Phone System) developed within North America, NMT (Nordic Mobile Telephony) jointly developed by the, at that time, government-controlled public-telephone-network operators of the Nordic countries, and TACS (Total Access Communication System) used in, for example, the United Kingdom. The mobile-communication systems based on first-generation technology were limited to voice services and, for the first time, made mobile telephony accessible to ordinary people.

The second generation of mobile communication, emerging in the early 1990s, saw the introduction of digital transmission on the radio link. Although the target service was still voice, the use of digital transmission allowed for second-generation mobile-communication systems to also provide limited data services. There were initially several different second-generation technologies, including GSM (Global System for Mobile communication) jointly developed by a large number of European countries, D-AMPS (Digital AMPS), PDC (Personal Digital Cellular) developed and solely used in Japan, and, developed at a somewhat later stage, the CDMA-based IS-95 technology. As time went by, GSM spread from Europe to other parts of the world and eventually came to completely dominate among the second-generation technologies. Primarily due to the success of GSM, the second-generation systems also turned mobile telephony from something still being used by only a relatively small fraction of people to a communication tool being a necessary part of life for a large majority of the world's population. Even today there are many places in the world where GSM is the dominating, and in some cases even the only available, technology for mobile communication, despite the later introduction of both third- and fourth-generation technologies.

The third generation of mobile communication, often just referred to as 3G, was introduced in the early 2000. With 3G the true step to high-quality mobile broadband was taken, enabling fast wireless internet access. This was especially enabled by the 3G evolution known as HSPA (High Speed Packet Access) [21]. In addition, while earlier mobile-communication technologies had all been designed for operation in paired spectrum (separate spectrum for network-to-device and device-to-network links) based on the Frequency-Division Duplex

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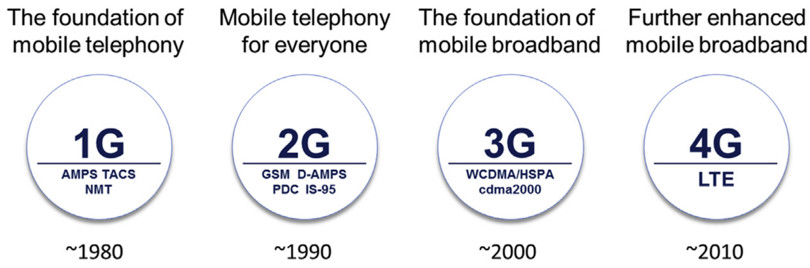

FIGURE 1.1

The different generations of mobile communication.

(FDD), see Chapter 7, 3G also saw the first introduction of mobile communication in unpaired spectrum based on the china-developed TD-SCDMA technology based on Time Division Duplex (TDD).

We are now, and have been for several years, in the fourth-generation (4G) era of mobile communication, represented by the LTE technology [28] LTE has followed in the steps of HSPA, providing higher efficiency and further enhanced mobile-broadband experience in terms of higher achievable end-user data rates. This is provided by means of OFDM-based transmission enabling wider transmission bandwidths and more advanced multi-antenna technologies. Furthermore, while 3G allowed for mobile communication in unpaired spectrum by means of a specific radio-access technology (TD-SCDMA), LTE supports both FDD and TDD operation, that is, operation in both paired and unpaired spectra, within one common radio-access technology. By means of LTE the world has thus converged into a single global technology for mobile communication, used by essentially all mobile-network operators and applicable to both paired and unpaired spectra. As discussed in somewhat more detail in Chapter 4, the later evolution of LTE has also extended the operation of mobile-communication networks into unlicensed spectra.

1.1 3GPP AND THE STANDARDIZATION OF MOBILE COMMUNICATION

Agreeing on multi-national technology specifications and standards has been key to the success of mobile communication. This has allowed for the deployment and interoperability of devices and infrastructure of different vendors and enabled devices and subscriptions to operate on a global basis.

As already mentioned, already the first-generation NMT technology was created on a multinational basis, allowing for devices and subscription to operate over the national borders between the Nordic countries. The next step in multinational specification/standardization of mobile-communication technology took place when GSM was jointly developed between a large number of European countries within CEPT, later renamed ETSI (European Telecommunications Standards Institute). As a consequence of this, GSM devices and subscriptions were already from the beginning able to operate over a large number of countries, covering a very large number of potential users. This large common market had a profound impact on device availability, leading to an unprecedented number of different device types and substantial reduction in device cost.

However, the final step to true global standardization of mobile communication came with the specification of the 3G technologies, especially WCDMA. Work on 3G technology was initially also carried out on a regional basis, that is, separately within Europe (ETSI), North America (TIA, T1P1), Japan (ARIB), etc. However, the success of GSM had shown the importance of a large technology footprint, especially in terms of device availability and cost. It also become clear that although work was carried out separately within the different regional standard organizations, there were many similarities in the underlying technology being pursued. This was especially true for Europe and Japan which were both developing different but very similar flavors of *wideband CDMA* (WCDMA) technology.

As a consequence, in 1998, the different regional standardization organizations came together and jointly created the *Third-Generation Partnership Project* (3GPP) with the task of finalizing the development of 3G technology based on WCDMA. A parallel organization (3GPP2) was somewhat later created with the task of developing an alternative 3G technology, cdma2000, as an evolution of second-generation IS-95. For a number of years, the two organizations (3GPP and 3GPP2) with their respective 3G technologies (WCDMA and cdma2000) existed in parallel. However, over time 3GPP came to completely dominate and has, despite its name, continued into the development of 4G (LTE, and 5G) technologies. Today, 3GPP is the only significant organization developing technical specifications for mobile communication.

1.2 THE NEXT GENERATION—5G/NR

Discussions on *fifth*-generation (5G) mobile communication began around 2012. In many discussions, the term 5G is used to refer to specific new 5G radio-access technology. However, 5G is also often used in a much wider context, not just referring to a specific radio-access technology but rather to a wide range of new services envisioned to be enabled by future mobile communication.

1.2.1 THE 5G USE CASES

In the context of 5G, one is often talking about three distinctive classes of use cases: *enhanced mobile broadband* (eMBB), *massive machine-type* *communication* (mMTC), and *ultra-reliable and low-latency communication* (URLLC) (see also Fig. 1.2).

- eMBB corresponds to a more or less straightforward evolution of the mobile-broadband services of today, enabling even larger data volumes and further enhanced user experience, for example, by supporting even higher end-user data rates.
- mMTC corresponds to services that are characterized by a massive number of devices, for example, remote sensors, actuators, and monitoring of various equipment. Key requirements for such services include very low device cost and very low device energy consumption, allowing for very long device battery life of up to at least several years. Typically, each device consumes and generates only a relatively small amount of data, that is, support for high data rates is of less importance.
- URLLC type-of-services are envisioned to require very low latency and extremely high reliability. Examples hereof are traffic safety, automatic control, and factory automation.

It is important to understand that the classification of 5G use cases into these three distinctive classes is somewhat artificial, primarily aiming to simplify the definition of requirements for the technology specification. There will be many use cases that do not fit exactly into one of these classes. Just as an example, there may be services that require very high reliability but for which the latency requirements are not that critical. Similarly, there may be use cases requiring devices of very low cost but where the possibility for very long device battery life may be less important.

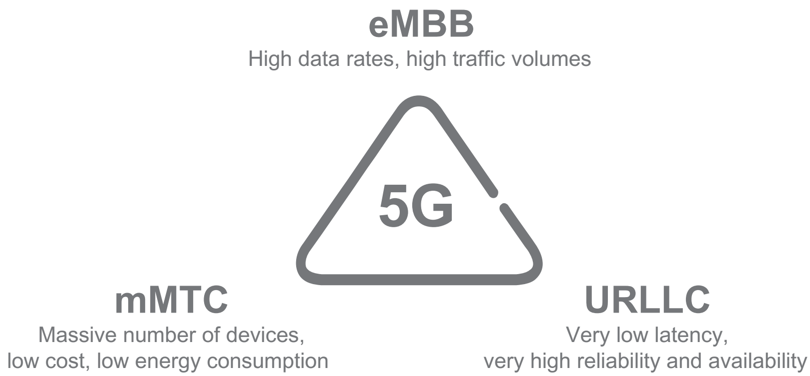

FIGURE 1.2

High-level 5G use-case classification.

1.2.2 EVOLVING LTE TO 5G CAPABILITY

The first release of the LTE technical specifications was introduced in 2009. Since then, LTE has gone through several steps of evolution providing enhanced performance and extended capabilities. This has included features for enhanced mobile broadband, including means for higher achievable end-user data rates as well as higher spectrum efficiency. However, it has also included important steps to extend the set of use cases to which LTE can be applied. Especially, there have been important steps to enable truly low-cost devices with very long battery life, in line with the characteristics of massive MTC applications. There have recently also been some significant steps taken to reduce the LTE air-interface latency.

With these finalized, ongoing, and future evolution steps, the evolution of LTE will be able to support a wide range of the use cases envisioned for 5G. Taking into account the more general view that 5G is not a specific radio-access technology but rather defined by the use cases to be supported, the evolution of LTE should thus be seen as an important part of the overall 5G radio-access solution, see Fig. 1.3. Although not being the main aim of this book, an overview of the current state of the LTE evolution is provided in Chapter 4.

1.2.3 NR—THE NEW 5G RADIO-ACCESS TECHNOLOGY

Despite LTE being a very capable technology, there are requirements not possible to meet with LTE or its evolution. Furthermore, technology development over the more than 10 years that have passed since the work on LTE was initiated allows for more advanced technical solutions. To meet these requirements and to exploit the potential of new technologies, 3GPP initiated the development of a new radio-access technology known as NR (New Radio). A workshop setting the scope was held in the fall of 2015 and technical work began in the spring of 2016. The first version of the NR specifications was available by the end of 2017 to meet commercial requirements on early 5G deployments already in 2018.

NR reuses many of the structures and features of LTE. However, being a new radio-access technology means that NR, unlike the LTE evolution, is not

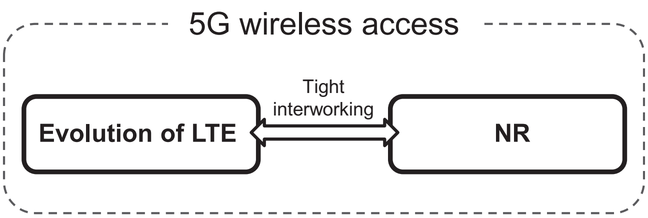

FIGURE 1.3

Evolution of LTE and NR jointly providing the overall 5G radio-access solution.

restricted by a need to retain backwards compatibility. The requirements on NR are also broader than what was the case for LTE, motivating a partly different set of technical solutions.

Chapter 2 discusses the standardization activities related to NR, followed by a spectrum overview in Chapter 3 and a brief summary of LTE and its evolution in Chapter 4. The main part of this book (Chapters 5−19) then provides an in-depth description of the current stage of the NR technical specifications, finishing with an outlook of the future development of NR in Chapter 20.

1.2.4 5GCN—THE NEW 5G CORE NETWORK

In parallel to NR, that is, the new 5G radio-access technology, 3GPP is also developing a new 5G core network referred to as 5GCN. The new 5G radio-access technology will connect to the 5GCN. However, 5GCN will also be able to provide connectivity for the evolution of LTE. At the same time, NR may also connect via the legacy core network EPC when operating in so-called *non-standalone mode* together will LTE, as will be further discussed in Chapter 6.