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5G Mobile Networks: Requirements, Enabling Technologies, and Research Activities

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2.1 Introduction

In the previous chapter, we have seen the history and evolution of the four generations of mobile cellular systems. After more than three decades of evolution, mobile cellular systems have significantly changed from analog or circuit-based to packet-based communication systems, with also big changes in the speed and bandwidth improvement as well as the number of connected devices. According to the forecast by Ericsson [1], the number of connected devices is growing rapidly and will reach to close to 28 billion by 2021, with around 16 billion Internet of Things (IoT) related devices.

This big change in the demand from users and the emergence of new services, and the increase of the communication needs from vertical industrial sectors such as automotive, agriculture, health, and transport, impose a huge challenge on the current generation of mobile cellular system (i.e. 4G). As a consequence, it requires the development of the next generation mobile system or fifth generation (5G), which is expected to be an ecosystem for every Internet-enabled device. In the following, we will explore more about the vision of the 5G system and its typical use cases, to see how it differs from today's 4G mobile networks.

2.1.1 What is 5G?

Since 5G is still in its infancy and the progress on standardizing is still ongoing, there exist many different definitions of what 5G is and what it will be supporting. In 2015, the Next Generation Mobile Network (NGMN) Alliance, an association of more than 80 partners from the mobile telecommunications industry and research, published a white paper [2], where 5G is defined as "an end-to-end ecosystem to enable a full mobile and connected society. It empowers value creation towards customers and partners, through existing and emerging use cases delivered with consistent experiences, and enabled by sustainable business models". It should be recognized that 5G is not just a one-step evolution from today's 4G network (i.e. LTE 4G and IMT-Advanced), but instead it is a big paradigm shift. According to the 3rd Generation Partnership Project

Comprehensive Guide to 5G Security, Edited by Madhusanka Liyanage, Ijaz Ahmad, Ahmed Bux Abro, Andrei Gurtov, and Mika Ylianttila.

(3GPP) [3], the 5G system will support most of the existing Evolved Packet System (EPS) services (i.e. 4G related services), in addition to many new services.

2.1.1.1 From a System Architecture Perspective

5G will be a mix of multiple access technologies, which include both current and existing access radio technologies such as LTE, and the New Radio (NR) for 5G [4], as well as the evolution of Wireless Local Area Network (WLAN) technologies. In addition, 5G will integrate most of the current emerging network paradigms such as cloud computing, Software Defined Networking (SDN) [5], and Network Function Virtualization (NFV) [6], into a unified, programmable software-centric system and infrastructure.

2.1.1.2 From the Spectrum Perspective

5G will be allocated with a significant amount of new spectrum to cope with massively connected devices, highly dense networks, and to support a variety of use cases, in which the traditional cellular frequency bands (typically < 6 GHz) might not provide sufficient bandwidth for all 5G applications. Particularly, during the World Radiocommunication Conference in November 2015 (WRC-15), an agenda item was approved for studying and investigating additional spectrum above 6 GHz (from 24 GHz up to 86 GHz) for 5G mobile services, and the results of those studies will be considered at the next WRC in 2019. In addition, WRC-15 also identified a range of new spectrum bands below 6 GHz or sub-6 GHz that can be used for 5G mobile services.

2.1.1.3 From a User and Customer Perspective

This is when 5G realized that subscribers can, on demand, have access from their devices from anywhere, at any time with high data rates (e.g. 1G bps), very low latency (e.g. at around 1 ms), much improved quality of service and quality of experience. With 5G, they can experience many newly defined service types such as virtual reality, augmented reality for gaming or other purposes, ultra-high definition and 3-dimension videos, and autonomous driving, etc. In the following, some typical 5G use cases will be described in detail.

2.1.2 Typical Use Cases

So far, there are a large number of use cases, which are considered as main drivers for the upcoming 5G ecosystem. These use cases come from different projects, organizations, and industrial vertical sectors, based up on their visions and their needs. However, in general, there are primarily three main categories of use cases, which have been agreed by most of the standardization groups, including the International Telecommunication Union (ITU) and 3GPP. These include enhanced mobile broadband (eMBB), massive machine type communications (mMTC), and ultra-reliable and low latency communications (URLLC), as shown in Figure 2.1:

- *Enhanced mobile broadband*: This usage scenario refers to the improvement of the current mobile broadband services, which are typically human-centric, in terms of user experienced data rates, traffic volume, coverage, and seamless mobility compared to services delivered in today's system. This scenario covers both wide and dense (e.g. hotspot) area coverages, which have different requirements. Some typical examples

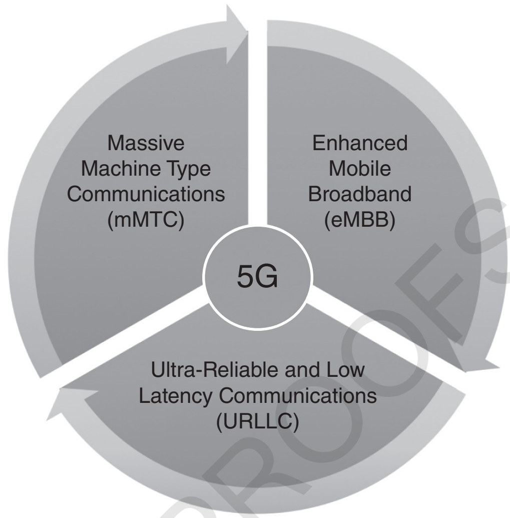

Figure 2.1 Three main use case categories as defined by ITU in [7] and 3GPP in [8].

of 5G services in this category are ultra-high definition video (e.g. 4 K/8 K), virtual reality, augmented reality, virtual presence, etc.

- *Massive machine type communications*: This usage scenario relates to deployments of a large number of connected devices, which typically transmit relatively small amount of data such as sensors and utility meters. These devices are required to be low-cost and have a long battery life. Some typical examples of 5G services in this category are inventory control, smart city, smart metering, video surveillance, etc.
- *Ultra-reliable and low latency communications*: This usage scenario is about the capability to provide a given service with stringent requirements in terms of ultra-low latency, ultra-high reliability and high availability, as well as high throughput. Some typical examples of 5G services in this category are autonomous driving cars, smart grids, eHealth, Tactile Internet, remote surgery, industrial automation and control, etc.

The rest of the chapter will be organized into two main parts. In the first half, typical technical requirements that need to be met when 5G is realized are identified, followed by a description of technologies, which are considered as key enablers for 5G. The second part summarizes ongoing 5G activities, which are recently developing from global, regional standardization organizations to open research forums and research communities worldwide.

2.2 5G Requirements

A huge number of requirements for 5G have been identified by different organizations, companies, and research communities. The requirements emanate from end user's experience, system performance, services, and operation and management. For example, ITU-R has identified some key requirements for 5G such as peak data rate, mobility, connection density, network and spectrum efficiency, etc. [7]. Figure 2.2 summarizes key requirements of 5G and some example values for each requirement. In principle, 5G requirements can be seen from user performance perspective such as data rate,

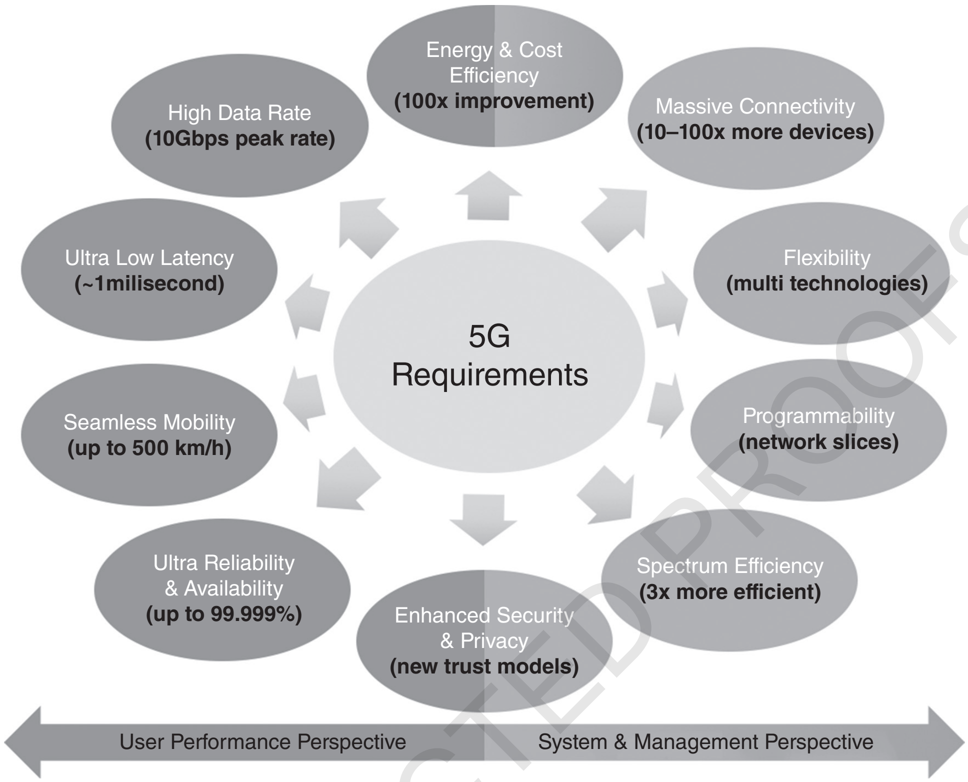

Figure 2.2 5G key requirements and some example values.

latency, mobility, reliability, etc. and from networking and system management perspective such as connection density, network flexibility, energy and cost efficiency, etc. In the following, these key perspectives will be discussed in detail.

2.2.1 High Data Rate and Ultra Low Latency

Data rate and latency are two major evaluation metrics to assess the user quality of experience in wireless communication systems. When it comes to the development of the next generation system (i.e. 5G), these two metrics are key to satisfy the user quality of experience.

The requirements on the data rate are expressed in terms of the peak data rate, which is the maximum achievable data rate for a user under ideal conditions, and the user experienced data rate, which is the achievable data rate for a user in the real network environment. Currently, 4G networks are offering users the maximum peak data rate of 1G bps, while the maximum data rate experienced by the user is around 10 Mbps [7]. However, the introduction of new bandwidth-hungry applications and services such as virtual reality, ultra-high definition video streaming (e.g. 4 K and 8 K), demands an extreme improvement of 5G networks compared to current 4G networks. According to [7], the peak data rate is expected to be enhanced by up to 20 Gbps, while the user experienced data rate will give 100 times improvement over 4G networks and reach up to 1 Gbps.

Another fundamental requirement is latency, which is typically expressed as end-to-end latency perceived by the end user. With the advent of newly defined services such as Tactile Internet, self-driving car, and automatic traffic control, which require real-time responses and interactions, minimizing the latency is becoming more crucial. More specifically, the 5G system is expected to reduce the latency ten times in the user plane, down to 1 millisecond, and half in the control plane, down to 50 milliseconds, compared to the 4G system [9].

2.2.2 Massive Connectivity and Seamless Mobility

Massive connectivity refers to the requirement of supporting a large number of connected devices and consequently a large or massive number of connections in an area unit (e.g. connection per square kilometer). In the 5G era, the increased number of devices in the network is not only coming from the emergence of new types of services and new types of devices such as sensors, meters, wearable devices, and vehicles, but it also from the exponential increase in the number of existing device types such as smart phones and tablets. Due to the proliferation of these smart things, the 5G system is expected to support a connection density of up to 1 billion connected devices per square kilometer, or put differently, 100 times more devices compared to the 4G system. In addition to the number of connected devices, the network densification can also be reflected by the traffic density, which is measured by the total amount of traffic exchanged by all devices over the considered area [2]. The expected value for this metric in the 5G era is tens of Gbps per square kilometer.

Besides the requirement to support a massive number of connected devices, the 5G system is also expected to provide seamless service experience to mobile users. However, not all devices and users in the 5G era are mobile, thus seamless mobility is not necessary. Therefore, on-demand mobility solutions should be supported, depending on the types of devices and services [2]. For example, it is expected to enable an acceptable service experience for mobile devices moving at speeds up to 500 km/h.

2.2.3 Reliability and High Availability

Reliability and high availability are two other important requirements that need to be guaranteed in the 5G system. In general, the reliability of a system refers to its capability of guaranteeing the success rate of data transmission under stated conditions (e.g. a latency budget) over a certain period of time. Depending on different use cases and services, the reliability rate will vary. As described previously, there are a number of services and applications in the third usage scenario (i.e., ultra-reliable and low latency communications), such as public safety, eHealth, automatic traffic control, and mission critical services, which require extremely high reliability for the communication. In order to support these kinds of services, the 5G system is expected to guarantee a reliability rate of up to 99.999%.

In order to provide services to end users anywhere, at any time, the 5G system must ensure its availability, which refers to the ability to endure against possible outage scenarios. The availability is usually expressed as a percentage of uptime in a given period of time (e.g. a year) and assessed based on the number of nines in the digits (e.g. 99.99%). The 5G system should guarantee the availability rate with as many nines as possible, for example, five nines or 99.999%.

2.2.4 Flexibility and Programmability

Flexibility and programmability are two network-driven requirements. Since the 5G system will be the integration of multiple technologies to support a large number of devices and services, its network architecture should be flexible in order to satisfy a range of different requirements in connection to properties, and attributes exposed by those devices and services. The flexibility of the network can be expressed in terms of the ability to support various types of radio access technologies, the capability of scaling the network resources on demand and independently between the radio access network and the core network, as well as between the control plane and the data/user plane, the capability of installing new services and applications in a very short time, and the capability of re-shaping the network infrastructure in real time to adapt to a change in the user or customer demands.

In addition, the network infrastructure in 5G should be programmable and reconfigurable. Indeed, the 5G network infrastructure will be constructed as a set of different logical virtualized networks or "slices" over the same physical infrastructure. The programmability of the network allows on-demand and autonomic networking, where mobile operators can define, program and configure their own network "slices" according to their policies and their defined use cases.

2.2.5 Energy, Cost and Spectrum Efficiency

Along with the enhancement of the network capacity and the improvement of user experience, energy and cost efficiency must be taken into account in the design of 5G. In particular, the 5G system is expected to have a 100-fold improvement on energy efficiency compared to today's 4G system. Meanwhile, the cost efficiency, which represents the economical aspect of the 5G system, must be increased in order to guarantee mobile operator's revenue.

In addition, as described previously, 5G will be fueled by not only the human-centric devices such as smartphones, but also the massive number of "things", such as sensors, smart meters, etc. These things are required to have much longer battery life in order to operate in the field, without any further power supply, for example at least 10-year battery lifetime.

Last but not least, spectrum efficiency should also be significantly improved compared to today's 4G system. For example, it should be three times higher for enhanced mobile broadband [7].

2.2.6 Security and Privacy

Apart from the aforementioned requirements, security is another important aspect that needs to be taken into account in the development of 5G. Indeed, the introduction of diversified services and devices will pose many challenges for guaranteeing the security in the 5G era. More specifically, the security for 5G will need to be guaranteed in different levels, including access level, infrastructure level, and service level. For example, at the infrastructure level, being enabled by a variety of technologies such as SDN, NFV, network slicing, etc., 5G network infrastructure will be more open and programmable, thus driving new security requirements such as how to securely guarantee the communication channel between the control and data planes as SDN is adopted, and how to isolate and manage network slices securely as network slicing is enabled, etc. At the service level, there will be many kinds of newly defined 5G services, which will require different security levels. For example, some critical services, such as public safety and eHealth, require more security than other services, such as virtual reality, augmented reality, etc. In addition, the involvement of new actors, and the introduction of new business models, will derive new service delivery models and new trust models. For example, in the current system, the trust model is mostly formed between users and mobile operators. However, more actors such as vertical service providers will play an important role in defining new trust models in 5G. The careful design of these models, together with guaranteeing the aforementioned requirements, is necessary to provide an end-to-end secured communication channel for users in the 5G ecosystem.

Last but not least, privacy concerns also need to be considered in the development of 5G. Indeed, 5G networks will accommodate massive numbers of user devices, meaning that a great amount of user privacy information such as user identifiers will be carried over the 5G network. In addition, new types of device identities such as identifiers for IoT devices will also be introduced in 5G. Therefore, it requires an efficient way to manage this massive amount of information as well as to protect and prevent the leakage of user personal information. Research activities and proposals on 5G related security and privacy will be discussed in detail in other chapters.

2.3 5G Enabling Technologies

In order to meet the strict requirements discussed previously, a number of technology candidates have been considered and widely discussed. Table 2.1 provides the mapping between the 5G requirements and corresponding potential technology enablers. The development in technology will happen both in the radio access network (RAN), the core network, and the end-to-end system. In the following, these developments will be described in detail.

Table 2.1 5G key requirements and corresponding technology candidates.

Requirements	**Technology Candidates**
High Data Rate	mmWave, Massive MIMO, Small Cell
Ultra-Low Latency	Mobile Edge/Fog Computing, D2D
Massive Connectivity	Massive MIMO, D2D, M2M, Small Cell
Reliability and High Availability	Cloud-RAN, SDN, NFV, MANO, Cloud Computing
Flexibility and Programmability	Cloud-RAN, SDN, NFV, Network Slicing, MANO
Energy and Cost Efficiency	Cloud-RAN, SDN, NFV, Network Slicing, MANO
Spectrum Efficiency	Massive MIMO, Small Cell, D2D
Security and Privacy	See Chapters 5–7

2.3.1 5G Radio Access Network

The enabling technologies for 5G RAN include mmWave communication, massive Multiple Input Multiple Output (MIMO), ultra-dense small cell, Machine-to-Machine (M2M) and Device-to-Device (D2D) communications, cloud-RAN, and mobile edge and fog computing. These technologies will be described in the following.

2.3.1.1 mmWave Communication

As mentioned previously, one of the key features of the 5G system is to have higher capacity in terms of data rate, for example, up to tens of Gbps at peak data rate. In order to achieve those targets, more spectrum availability is required. However, current wireless systems are typically operating in a spectrum band, ranging from hundreds of MHz (e.g. 700 MHz) to below 3 GHz (e.g. 2.6 GHz). These spectrum usages are not sufficient enough for 5G. One of the most effective solutions for expanding the bandwidth range is to exploit the very high spectrum bands, which have not been occupied yet (e.g. > 10 Ghz). In particular, during the meeting at the WRC-15 conference hosted by ITU, several proposed frequency bands above 10 GHz for 5G have been approved to be studied ahead of the next WRC conference in 2019 [10], for example, 24.25–27.5 GHz, 50.4–52.6 GHz, 81–86 GHz, etc. In this sense, millimeter wave communication (mmWave) [12] is the best technology candidate.

The mmWave research was first conducted by Jagadis Chandra Bose in 1897, which refers to the use of frequencies in the range of 30 to 300 GHz, with the corresponding wavelengths in between 10 mm and 1 mm, as shown in Figure 2.3. Due to some reasons, such as high propagation loss, the mmWave communication was commonly used for indoor environments or backhaul links. However, many research initiatives have illustrated the feasibility of mmWave technology for 5G mobile networks by adopting many recent advances in propagation modeling [11] or channel modeling [12], to create a larger amount of bandwidth. Apart from the benefits of allowing larger bandwidth, higher data rate that makes the mmWave a promising technology for 5G, there are still a number of challenges and open issues that need to be solved in the future, such as interference and heterogeneity [13].

2.3.1.2 Massive MIMO

In order to meet the 5G requirements in terms of network density and capacity enhancement, one of the most prominent solutions is to densify the number of deployed antennas, which refers to a technical solution called massive MIMO. Fundamentally,

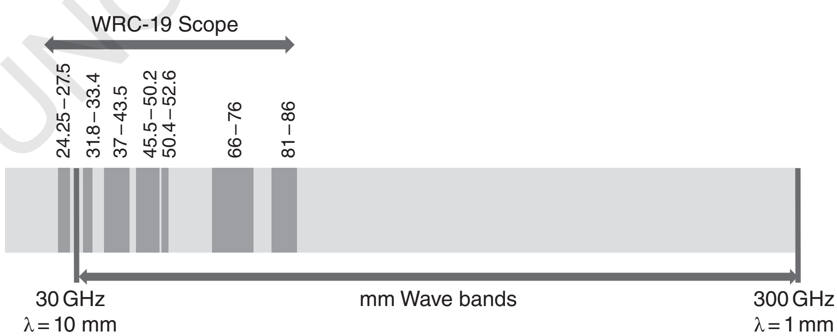

Figure 2.3 Millimeter-wave bands and potential 5G bands to be studied ahead of WRC-19.

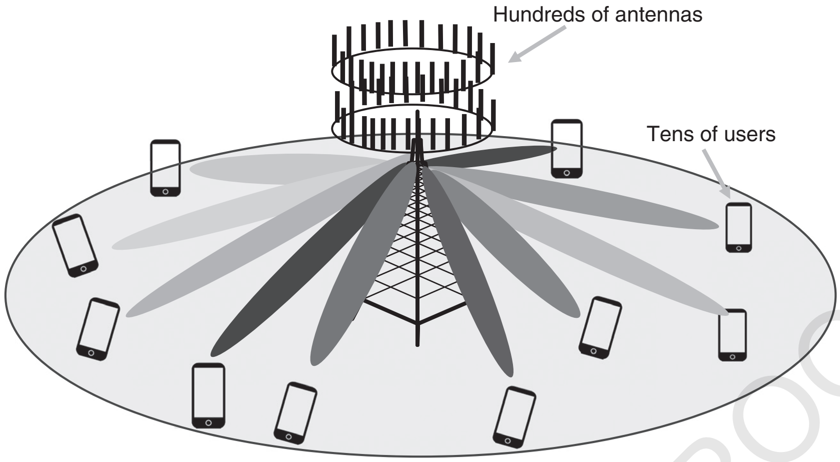

Figure 2.4 An illustration of massive MIMO concept.

MIMO is an antenna technology for wireless communications in which multiple antennas are used to transmit and receive data. In fact, the MIMO concept has been commonly utilized in current 4G networks, which refers to multi-user MIMO communication [14], where several users are simultaneously served by a multiple-antenna base station; whereas, massive MIMO is defined as a multi-user MIMO system, where the number of base station's antennas and the number of users are large [15]. Such a feature as having more antennas at the base station promises to increase the network capacity and density. More importantly, massive MIMO is said to significantly enhance spectral and energy efficiency [15]. These reasons make massive MIMO an essential technology for 5G [16]. Figure 2.4 depicts the concept of massive MIMO. Apart from the benefits of massive MIMO, there are still several research questions that need to be addressed, such as mitigation of plot contamination, channel estimation, implementation-aware algorithmic design, etc.

2.3.1.3 Ultra-Dense Small Cells

Another way of increasing the network density and improving the throughput is to densify the number of wireless nodes, which have a smaller coverage range than the macro-cell base stations used in the 3G and 4G legacy systems. The technical solution behind this idea is denoted as the small cell technology. As defined by the Small Cell Forum, the "small cells" is an umbrella term for operator-controlled, low-powered radio access nodes with a coverage range in between ten to several hundreds of meters, including those that operate in licensed spectrum and unlicensed carrier-grade WiFi. An example of small cell deployment is shown in Figure 2.5.

With small cells, the size of the cell is reduced, meaning they bring the network much closer to the user, thus better serving high traffic areas such as indoor and hotspot areas. In addition, the higher number of low-powered transmission points on the small cell network enables better use of available frequency resource, thus improving the spectral efficiency. Furthermore, the 5G system will be constructed in a heterogeneous fashion, where macro and small cells are co-located and maybe connected to each other

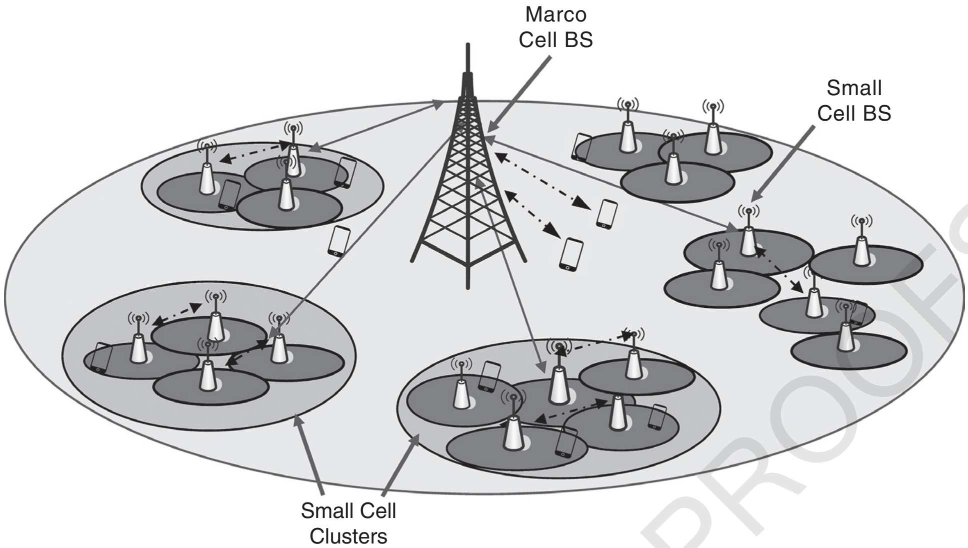

Figure 2.5 An illustration of small cells deployment.

via wireless backhaul links, thus providing increased levels of network capacity through traffic offloading. However, the heterogeneity of small cells in the network will pose challenges in terms of interference and mobility management, thus affecting system performance as a whole. These issues will need to be addressed in future research. Some other ongoing research on small cells for 5G would include load balancing, wireless backhauling, mmWave and massive MIMO in small cells, etc. [17].

2.3.1.4 M2M and D2D Communications

a) *M2M Communication*
As mentioned previously, two-thirds of the use case categories of 5G will be related to the IoT and Machine Type Communication (MTC), including massive and critical communications. Therefore, although the concept of M2M or MTC communication was introduced in 4G LTE systems by 3GPP some time ago [18], it is still considered as one of the key enablers for 5G [19]. Fundamentally, M2M communication refers to the automated data communications among devices and the underlying data transport infrastructure [20]. The data communications may occur between an MTC device and a server, or directly between two MTC devices. There are a number of services and applications enabled by M2M communication, such as monitoring and metering, home and industry automation, health care, and automotive, as shown in Figure 2.6 (a). Several open issues and challenges need to be resolved in future M2M related research. such as scalability, security and privacy, energy efficiency, etc.
b) *D2D Communication*
D2D communication [21] refers to direct communication between two mobile users/devices, without traversing through a network infrastructure. It has been specified by 3GPP in LTE Release 12. Exploiting direct communication between devices, D2D communication can help improve spectrum efficiency, user data rate gain, and reduce latency as well as energy consumption, thus being considered as

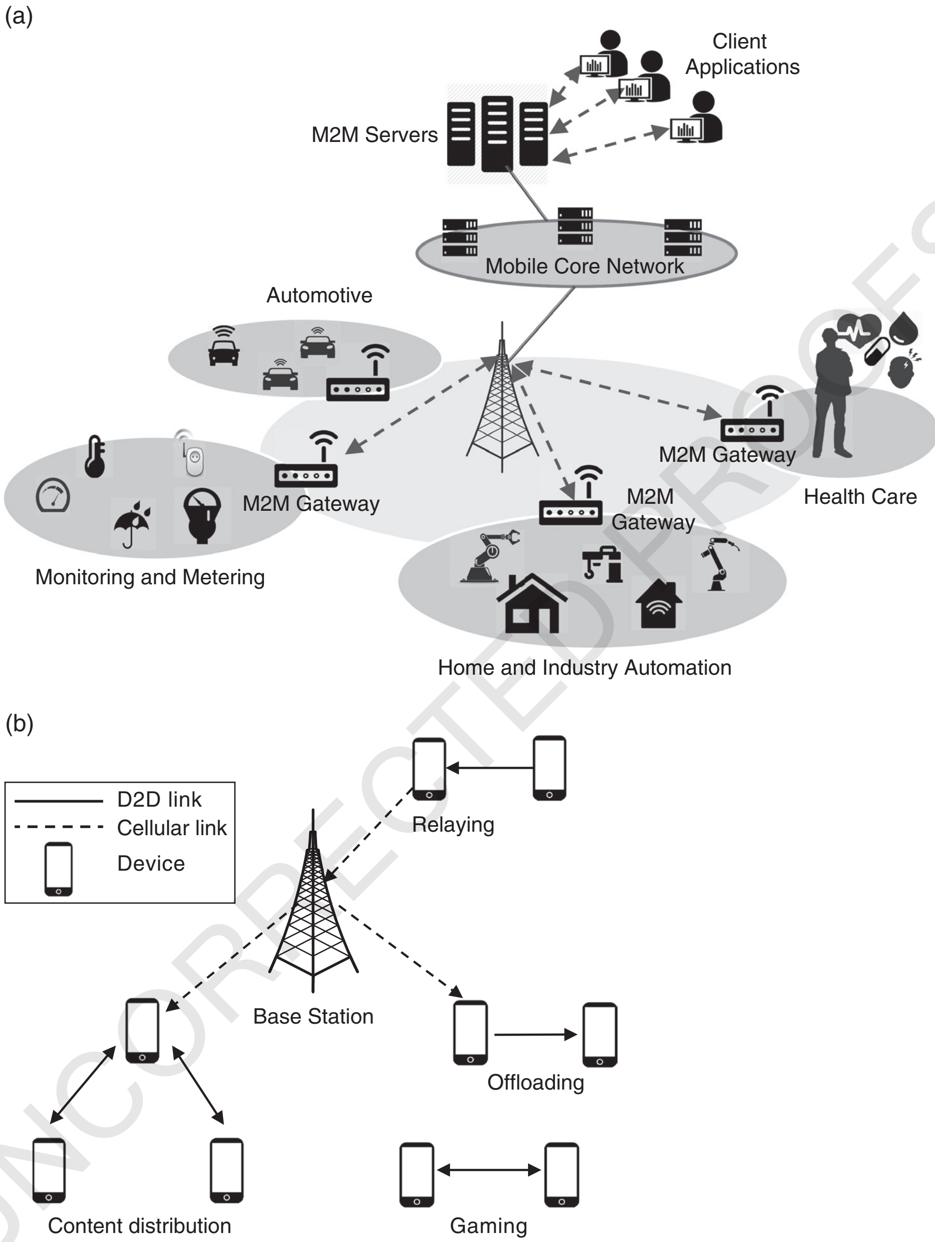

Figure 2.6 (a) M2M communications and use case examples; and (b) D2D communications and use case examples.

one of the key components of the 5G system [22]. In general, the operation of D2D communication can be in-band D2D on licensed cellular spectrum (e.g. LTE) and out-of-band D2D on unlicensed spectrum (e.g. WiFi). There are a number of use cases and application scenarios for D2D, such as proximity-based services, gaming, public safety, vehicular communications, and offloading, as shown in Figure 2.6(b). However, there are a number of open issues that need to be solved in the future, such as interference management, resource management services and device discovery, security and privacy. Some other directions for future research would be the integration of D2D communication with mmWave and massive MIMO technologies.

2.3.1.5 Cloud-based Radio Access Network

Cloud-based Radio Access Network (Cloud-RAN) is an ideal solution to design the radio access part of 5G networks, since it enables energy efficiency, cost savings on baseband resources, as well as improvements on network capacity, increased throughput, etc. [23]. The Cloud-RAN is essentially the decoupling of the Remote Radio Head (RRH) from the Baseband Unit (BU) of a base station, and the implementation of BU in a centralized cloud computing environment. RRHs are connected to a BBU pool by using high speed fiber or microwave-link fronthaul networks. In fact, there are several options to split the functionality of the base station, which refers to the RAN-as-a-Service (RANaaS) [24]. These two concepts are shown in Figures 2.7(a) and (b). This simplified base station architecture is paving the way for dense 5G deployment, by making it affordable, flexible and efficient [25].

Apart from the benefits that Cloud-RAN offers to the design of the 5G system, there are various challenges that need to be overcome before fully exploiting its benefits; such as fronthaul constraints and performance optimization, placement optimization of RRHs, efficient scheduling and elastic scaling of BBUs in the BBU pool. Some other research directions in the future could be the incorporation of C-RAN and distributed RAN (D-RAN) or research on heterogeneous CRAN (H-CRAN).

2.3.1.6 Mobile Edge and Fog Computing

As we move to 5G, many of its services and applications will require very stringent latency in magnitude of milliseconds. One of the most prominent solutions is to bring the IT services and processing capabilities down to the edge of the mobile network, within the RAN and in close proximity to mobile users. This refers to the concept of Mobile Edge Computing (MEC) technology and its similarity, Fog Computing. Figure 2.8 illustrates the concept of MEC and its architecture. As specified in the ETSI white paper [26] published 2015, the aim of MEC is to reduce latency, ensure highly efficient network operation and service delivery, and offer an improved user experience. With this capability, MEC will open new frontiers for network operators, application service providers, and content providers, by enabling them to introduce innovative services and applications. Some typical examples of services enabled by MEC are augmented reality, RAN-aware video optimization, connected cars, and IoT, etc. [26].

A similar concept to MEC is Fog Computing (FC) [27] defined by Cisco in 2012, a paradigm in which cloud computing resources are extended to the edge of the network, to create a highly virtualized platform that provides compute, storage, and networking services between end-devices and traditional data centers. Some of the prominent features of FC, which are suitable for 5G communications, are low latency, location

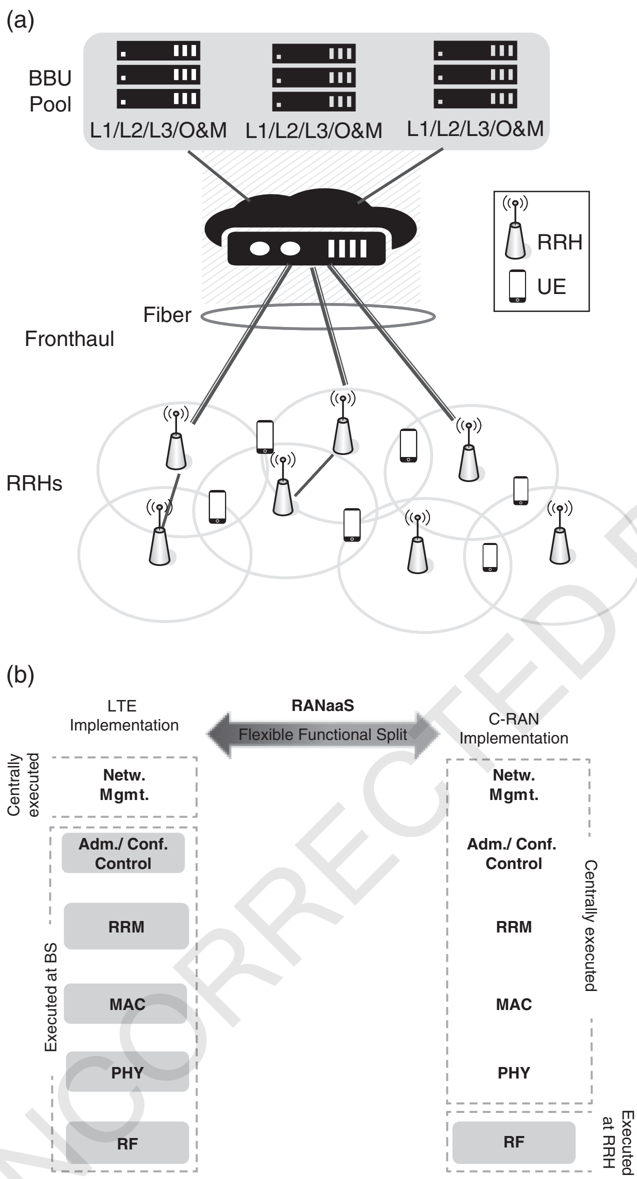

Figure 2.7 (a) Cloud-RAN concept, adapted from [23]; and (b) RANaaS concept, adapted from [24].

awareness, real-time interactions, mobility support, geographical distribution, and the predominance of wireless access [27].

Although both MEC and FC are extremely fit for the development of the 5G system, there are several research issues that need to be further explored, such as the interworking between edge clouds, between edge clouds and centralized clouds, mobility management to allow users to seamlessly access edge applications, and other open challenges such as security and performance.

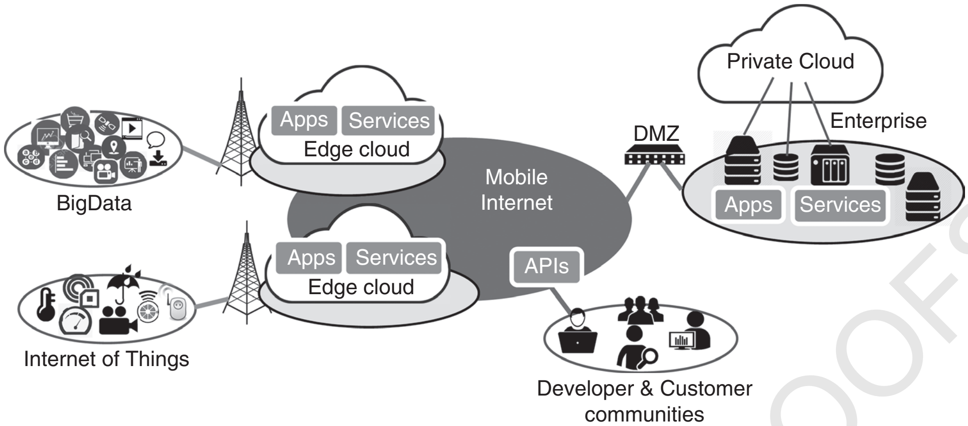

Figure 2.8 Mobile Edge Computing architecture (adapted from [26]).

2.3.2 5G Mobile Core Network

SDN, NFV, and cloud computing are considered as key technologies to design the core part of 5G networks. These technologies are described as follows:

2.3.2.1 Software Defined Networking

In terms of network flexibility and programmability, SDN [5] is widely recognized as the best technology candidate for the development of 5G networks. The concept of SDN was first proposed in the campus and data center network areas. It features the separation of the data plane from the control plane, and facilitates the network management through the abstraction of network control functionalities, as shown in Figure 2.9 (a). Being adopted into 5G, SDN will enable a more agile and flexible core network architecture. In addition, programmability and openness characteristics of SDN will help mobile operators shorten the life cycle of introducing their new services and innovation into markets. By separating the control and data planes, the network infrastructure can be constructed on demand on the basis of service requirements (network-as-a-service), thus improving the resource efficiency. It is worth to note that the SDN concept can also be used in the RAN domain, where the SDN controller could control and schedule the radio resources for base stations, thus improving the spectrum efficiency as well as mobility management.

However, there are still many challenges and issues with SDN that need to be addressed, such as the scalability problem due to the centralization of network intelligence, extra latency between devices and the SDN controller, security problem of the communication channel between the control and data planes, the lack of standardization on designing the protocol communicating between the control and data planes, policy and charging enforcement. Other aspects related to the adoption of SDN into mobile networks, such as placement problem of SDN controller, mobility management, load balancing, etc., have been detailed in [28].

2.3.2.2 Network Function Virtualization

As described previously, the 5G system is not just about high data rate, low latency, and flexibility. It is also about cost efficiency, which will have impact on the revenue of mobile operators. 5G mobile operators will expect the cost for the deployment, which refers to

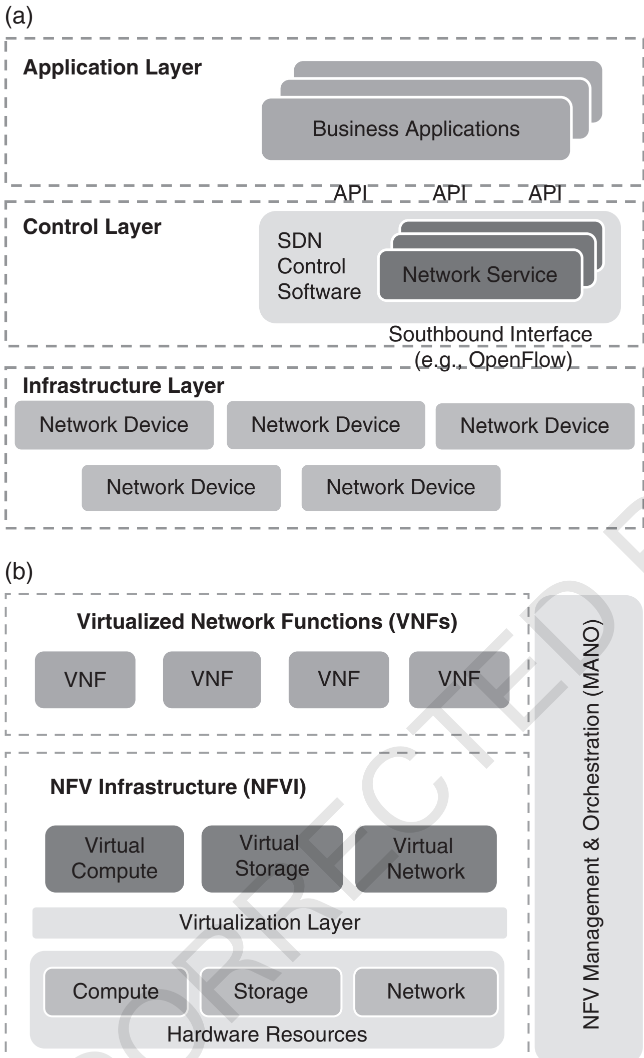

Figure 2.9 (a) SDN architecture, adapted from [5]; and (b) NFV architecture adapted from [6].

capital expense or CAPEX, and the cost for operation and management, which refers to operational expense or OPEX, to be as low as possible. NFV [6] is the foundation for these capabilities and is identified as the cornerstone of 5G core network solutions. Figure 2.9(b) shows the reference architectural framework of NFV. Essentially, NFV refers to the relocation of network functions, which are traditionally implemented on dedicated costly hardware platforms to software appliances running in the cloud environment or on general-purpose commodity servers. By operating the network function as software, it is easier for mobile operators to dynamically scale the resources (computing, storage, and networking) according to changes in traffic demands, and to faster time-to-market of new services. In addition, the combination of SDN and NFV has encouraged the development of new networking paradigms, such as network service chaining, and network slicing.

Although NFV has been proven as the key enabler for the development of 5G, especially the core part, there are many challenges that need to be further studied in future work, such as optimization of network functions placement, resource allocation, management and orchestration, and network performance [29].

2.3.2.3 Cloud Computing

As described in the previous section, cloud computing has been considered as an ideal solution for re-designing the current RAN architecture. With its anticipated benefits. such as on-demand and elastic provisioning of services and resources over the Internet, cloud computing has made it as one of the key enablers for designing 5G core networks. In this case, 5G core network functions will be realized as virtual machines or containers controlled by the cloud manager. The capability of providing resources in a multi-tenant model of cloud computing allows mobile operators to implement the concept of mobile virtual network operators (MVNO) much more easily than in the past. In addition, a pay-as-you-use business model and the ability to move and consolidate the resources offered by cloud computing. can help the mobile operators reduce their capital and optimize operational expenses. Compared to NFV, cloud computing was born to virtualize the commodity IT hardware. while NFV refers to the inspiration of cloud computing to virtualize network functions. In fact, in the recent development of NFV, many cloud technologies such as OpenStack[1] or VMware[2] are serving as the resource backend for virtual network functions.

Centralizing all resources will ease the management and provisioning process. but it will result in the long delay for end-to-end communication, which may not be suitable for some of the newly defined 5G services. Therefore, combining cloud computing and other computing paradigms, such as mobile cloud computing, fog and edge computing, will be a promising direction to investigate in future research.

2.3.3 G End-to-End System

The key technology enablers for constructing a 5G end-to-end system include network slicing, and management and orchestration.

2.3.3.1 Network Slicing

Today's 4G system have been optimized mostly for serving human-to-human communication, where mobile phones are the main players. However, in the future, the 5G system is expected to support diverse services and applications with various characteristics and requirements, where IoT devices will become dominant. Such IoT-related services will require different types of features and network capabilities in terms of latency, data rate, mobility, reliability, security, etc. Therefore, in order to guarantee these requirements and improve the network performance and resource utilization, each service type should be provided as an end-to-end isolated infrastructural environment to operate on. In this sense, the network slicing concept will become the foundation of capabilities.

1 OpenStack. https://www.openstack.org/
2 VMware. http://www.vmware.com/

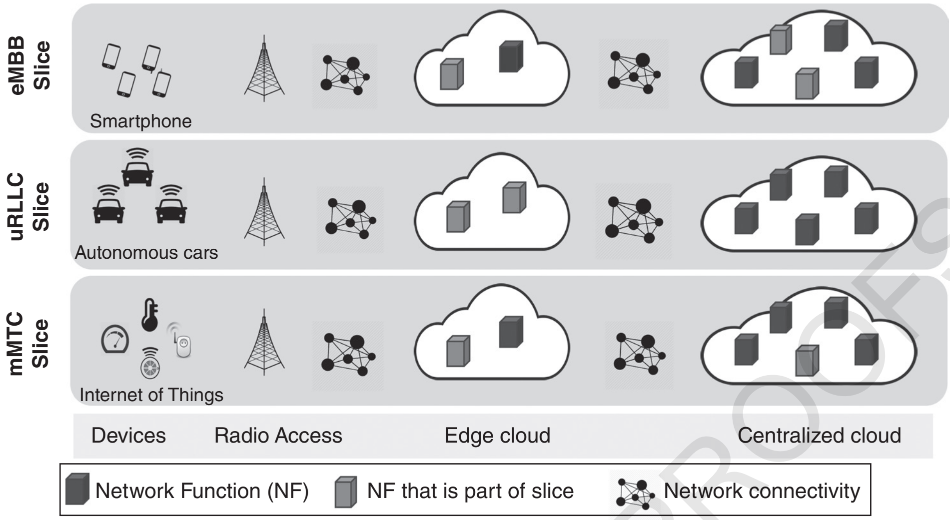

Figure 2.10 An example of network slicing.

Although network slicing has been widely recognized as the key characteristic of 5G by many network operators and vendors, it has not yet been standardized, thus there are variants of defining what slicing is. According to ITU-T in [30], slicing is the basic concept of the Network Softwarization. It allows logically isolated network partitions (LINP), with a slice being considered as a unit of programmable resources such as network, computation and storage. As NGMN defined in its white paper [2], a network slice, namely "5G slice", is composed of a collection of 5G network functions and specific radio access technology settings that are combined together for the specific use a case or business model. Figure 2.10 illustrates an example of the network slicing concept, with three different slices corresponding to the three main 5G use cases categories discussed in Section 2.1. To this end, the implementation of the network slicing concept is on an end-to-end basis. The 5G system will be composed of multiple end-to-end slices, where dedicated resources and quality of service (QoS) are guaranteed.

However, network slicing still presents many challenges and gaps that must be fulfilled in the future study, such as slice definition, lifecycle management of a slice, resiliency of slice control, resource allocation and optimization within a slice and between slices, strongly guaranteeing security within a slice and between slices, end-to-end QoS management, integrating with other technologies (e.g. information centric networking (ICN), D2D), etc.

2.3.3.2 Management and Orchestration

When the 5G mobile networking era arrives in the next few years, due to the diversity of use cases, services, and the number of network slices created with different resource requirements, the management and orchestration (MANO) of the network becomes more and more crucial. The role of MANO will be managing the whole network infrastructure in terms of fault management, configuration, accounting, performance, and security. More importantly, MANO will be in charge of lifecycle management and

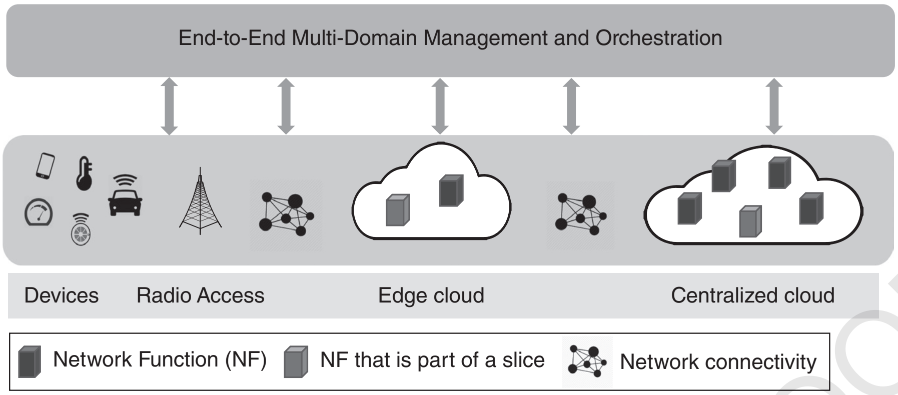

Figure 2.11 The illustration of the end-to-end multi-domain management and orchestration.

provisioning the network resources for the end-to-end connectivity of network slices in a dynamic, automated, and efficient manner. As illustrated in Figure 2.11, the role of the end-to-end management and orchestration will be multi-domain, multi-operators, and multi-technology spanning from the infrastructure layer to the application (service) layer, and spanning from the RAN to the core of the network.

In 2014, the NFV MANO working group in the European Telecommunications Standards Institute (ETSI) has specified in its technical specification [31], an architectural framework showing main components and their functionalities, as well as the operations within the framework. In the meantime, there are several efforts that have implemented the NFV MANO concept as open source platforms, such as OpenStack Tacker, OpenBaton, OSM, Open-O, etc. [30]. These open source platforms are being applied to today's 4G core network and will be integrated into the deployment of the 5G network architecture.

However, due to the diversity of network resources from RAN to the core, the current NFV MANO framework should be extended in order to manage not only virtualized network functions and resources, but also physical nodes. In addition, dynamically managing and orchestrating the network services and slices would also be challenging.

2.4 5G Standardization Activities

A number of research activities are currently being carried out within standardization organizations, such as International Telecommunication Union (ITU), 3GPP, ETSI, the Institute of Electrical and Electronic Engineers (IEEE), and the Internet Engineering Task Force (IETF). In the following, the status of ongoing activates within these organizations will be summarized.

2.4.1 ITU Activities

After success in developing international standards and specifications for the previous International Mobile Telecommunications (IMT) generations, including IMT-2000 (i.e. 3G) and IMT-Advanced (i.e. 4G), ITU continues its leading role to outline the concept and vision for 5G, including identifying key parameters, with a target date set for 2020, thus it is called IMT-2020. Currently, the 5G related activities within ITU are happening in two of its three main sectors: ITU Radiocommunication sector (ITU-R), which focuses on wireless and radio system aspects, and ITU Telecommunication standardization sector (ITU-T), which focuses on wireline and network architecture aspects.

2.4.1.1 ITU-R

In 2012, ITU-R, having the leading role of Working Party (WP) 5D, initiated work to develop the next generation IMT for the year 2020 and beyond, or IMT-2020. As initial results from the work, in September 2015, ITU-R released a recommendation ITU-R M.2083-0 [7], which defines the framework and overall objectives, including the description of key usage scenarios, key capabilities, technology trends, spectrum implications, and timelines for the development of IMT-2020. By June 2017, several deliverables are expected to be completed at the ITU-R WP 5D 27th meeting, including reports on the technical performance requirements, evaluation criteria and evaluation methods, specification submission requirements, and a circular letter.

From the spectrum regulation perspective, ITU-R published a report in July 2015, which provides information on the study of technical feasibility of IMT in the bands above 6 GHz. As already discussed, the WRC-15 hosted by ITU-R has come up with several agenda items for investigating additional spectrum above 24 GHz, which will be finalized in the WRC-19.

2.4.1.2 ITU-T

In May 2015, ITU-T started working on IMT-2020 by establishing a new Focus Group (FG IMT-2020) within the ITU-T Study Group 13, to identify the network standardization requirements for the 5G development of IMT for 2020 and beyond. The main objectives of FG IMT-2020 are to identify the needs for standardization of the "wireline elements" of 5G networks, be a launching point for ITU-T's contribution to IMT-2020 standardization, and to align deliverables with those of ITU-R. As the initial results from the first phase, FG IMT-2020 has completed a report on gap analysis in December 2015 [32]. The report identifies 85 gaps, such as high-level network architecture, network softwarization, etc. In 2016, FG IMT-2020 was restructured into four working groups (WG), including Architecture and Framework WG, Network Softwarization WG, Information Centric Networking WG, and End-to-End Network Management WG. Also, in 2016, several proofs of concepts were demonstrated, such as end-to-end network slicing.

2.4.2 3GPP Activities

Overall, the 5G research activities within the 3GPP can be divided into three phases: Pre-5G phase, 5G phase I, and 5G phase II, happening at both 3GPP RAN and Service and System Aspect (SA) Technical Specification Groups (TSG). The outputs of these phases will appear in technical specifications Release 14, Release 15, and Release 16, respectively. The status of ongoing 5G related activities in 3GPP is summarized below.

2.4.2.1 Pre-5G Phase

The Pre-5G phase is also known as the study phase, which started in early 2015. At that time, the 3GPP Services WG within TSG SA (SA1) initiated a Study Item (SI) on New Services and Markets Technology Enablers (SMARTER), with the objectives of developing high-level use cases and identifying the related high-level potential requirements for 5G. According to [8], use cases within the SMARTER study are grouped into four main building blocks, including Enhanced Mobile Broadband (eMBB), Massive Internet of Things (mIoT), Critical Communications (CriC), and Network Operation (NeO). The System Architecture WG (SA2) also initiated several feasibility studies on the enhancement of the existing architecture. as well as a study item on designing a new system architecture for the next generation mobile networks [33]. In addition, the SA Telecom Management WG (SA5) completed a study item on the NFV concept in the management of mobile networks.

From a RAN perspective, TSG RAN has completed a study on channel model for frequency spectrum above 6GHz. In September 2015, 3GPP organized a workshop on RAN for 5G and established a study item on the requirements and scope of the new radio technology. All results from the study items by SA and RAN TSGs will be inputs for the technical specification Release 14, which will be completed in June 2017.

2.4.2.2 5G Phase I

After finishing the pre-5G phase with a lot of proposed study items, this phase will start the first phase of standardization of 5G related solutions, in which work items are proposed for approval. The 5G phase I will focus on the use case building block of enhancing mobile broadband, as well as low latency and high reliability. The concept of New Radio (NR) will be standardized from this phase, where the frequency range will be below 6GHz and above 6GHz. It will also address the operation of standalone and non-standalone NR. From the SA perspective, the requirements from the SMARTER study and study items on SA2 will be followed in the 5G phase I. This phase will be completed in June 2018, with the release of Release 15.

2.4.2.3 5G Phase II

The 5G phase II will be optimized, not only for enhanced mobile broadband, but for all 5G use cases. The NR will be further studied and standardized with new requirements and features, such as the operation at higher frequency band using mmWave technology. The SA work items will be further enhanced and improved, including security aspects from the SA Security WG (SA3). Although the concrete work item for the second phase has not been decided upon yet, the results from this phase should be ready by December 2019 for the IMT-2020 submission and addressing all identified use cases and requirements.

2.4.3 ETSI Activities

There are several industry specification groups (ISGs) and working groups within ETSI related to the development of 5G, such as NFV ISG[3], MEC ISG[4], mmWave Transmissions (mWT) ISG[5], and Next Generation Protocols (NGP) ISG[6].

ESTI NFV ISG was founded in 2012 with the objective to develop the required standards for NFV. So far, this group has published three white papers providing information, including a reference architectural framework, research activities and progress, scope and

3 ETSI NFV ISG. http://www.etsi.org/technologies-clusters/technologies/nfv
4 ETSI MEC ISG. http://www.etsi.org/technologies-clusters/technologies/mobile-edge-computing
5 ETSI mWT. http://www.etsi.org/technologies-clusters/technologies/millimetre-wave-transmission
6 ETSI NGP. http://www.etsi.org/technologies-clusters/technologies/next-generation-protocols

perspective for the future action. Currently, ETSI NFV ISG has been working on different aspects of NFV, including architectural models, management and orchestration, software architecture, and reliability and availability. In November 2015, they set up a new group, ETSI OSM, for the development of open source software for NFV MANO.

ETSI MEC ISG was founded in 2014 and aims at creating a standardized, open environment to allow the efficient and seamless integration of applications across multi-vendor MEC platforms. Many activities are going on within this ISG, including defining service scenarios, technical requirements, framework and reference architectures, as well as proof of concepts.

ETSI mWT ISG was launched in 2015, with the purpose of studying mmWave technology for higher frequency bands in between 30 and 300 GHz. Currently, the mWT ISG is working to facilitate the use of the V-band (57–66Ghz), the E-band (71–76 and 81-86GHz) and, in the future, higher frequency bands (50 GHz up to 300 GHz) for large volume backhaul and fronthaul applications. The mWT ISG also expects to publish a specification on the channelization of W-band (92–114,5GHz) and D-band (130–174.8GHz) in the near future.

ETSI NGP ISG was created to review the future landscape of Internet protocols, with the goal of creating more efficient Internet protocols for future IP networks including 5G. In October 2016, the first group specification on the next generation protocols was published, which lists example use cases and compares the existing IP suite protocols with next generation ones.

2.4.4 IEEE Activities

Currently, the IEEE has various 5G initiatives[7] taking place in many working groups, such as the IEEE 802 standards group, the IEEE Communication Society (ComSoc), and the IEEE SDN initiative.

The IEEE 802 standards group originally focuses on local and metropolitan networks, including both wired (IEEE 802.3 for Ethernet) and wireless networks (IEEE 802.11 for Wi-Fi, IEEE 802.15 for WPAN, and IEEE 802.16 for WiMaX). Currently, the IEEE 802 standing committee group has been discussing the creation of an IEEE 5G specification and the relationship between IEEE and IMT-2020 [34]. Several potential 5G-related projects have been considered, such as IEEE 802.11ay for mmWave bands operation, and IEEE 802.1ah for IoT.

IEEE ComSoc has, since May 2015, been organizing a series of summits that focus on 5G. Recently, IEEE ComSoc has formed an IEEE GET5G Committee to discuss various issues and challenges related to 5G, and develop special interest groups (SIGs) in various areas such as mmWave, cloud-based mobile core, Tactile Internet, end-to-end latency, network architecture, and gigabit service enablement, which are crucial to 5G.

The IEEE SDN Initiative was launched in 2014 by the IEEE Future Directions Committee, addressing specific issues and challenges raised by the adoption of SDN and NFV that goes beyond technical issues to also encompass skill development and economics. The IEEE SDN initiative has recently published a white paper, which identifies technical challenges, business sustainability and policy issues of 5G software-defined ecosystems [35].

7 IEEE 5G Initiative. http://5g.ieee.org/about

2.4.5 IETF Activities

IETF is a standards body for the development and promotion of standards for the evolution of the Internet. It has many groups working on specific topics related to the development of 5G standards. For example, in the IoT research area, IETF has 6TiSCH and CoRE. There are working groups researching service function chaining (SFC), and distributed mobility management (DMM). In addition, affiliated with IETF, the Internet Research Task Force (IRTF) has several research groups working on new emerging technologies, such as SDNRG, NFVRG, Thing-to-Thing (T2RG), and ICNRG. Recently, several research topics, such as network slicing and IP protocols for 5G, have also been actively discussed at side meetings at the regular IETF 96 and IETF 97 meetings in 2016.

2.5 5G Research Communities

Along with the activities being carried out in the standardization organization, 5G-related research topics are also being discussed globally within research communities in Europe, Asia and America. It should also be noted that they have proven the strong cooperation between each other through the signing of Memorandum of Understanding (MoU) contracts. In the following, the ongoing 5G related activities within these communities will be summarized.

2.5.1 European 5G Related Activities

The following will provide a snapshot of the status of ongoing activities related to the development of 5G that takes place within EU 7th Framework Program (FP7), EU Horizon 2020 (H2020) Program, and Celtic Plus Program.

2.5.1.1 5G Research in EU FP7

The earliest research related to 5G was started under the umbrella of EU FP7. Since 2013, the European Commission has granted 50 million euros to research into developing 5G technology, with the mission of making the EU a leader in 5G research and delivering 5G mobile technology by 2020. The grant was funded to more than ten projects[8], which address the architecture and functionality needs for 5G and beyond 4G networks, such as METIS-I, 5GNOW, iJOIN, Mobile Cloud Networking, etc. Among these projects, the METIS project phase I (METIS-I)[9] is the biggest, with the total cost of around 27 million euros. The METIS-I project has been recognized as a reference for the development of 5G worldwide. So far, these projects have been completed, with their final reports now available.

2.5.1.2 5G Research in EU H2020

The EU H2020 program is the successor of the previous EU FP7 program, which has been funded with nearly 80 million euros available over a 7-year period from 2014 to 2020. In 2013, to continue the research on 5G, the EU Commission, the EU ICT industry,

8 EU FP7. https://5g-ppp.eu/projects/
9 METIS Project. https://www.metis2020.com

and other partners, formed 5G Infrastructure Public Private Partnership (5G-PPP)[10] with the funding of 700 million euros from the H2020 program and 700 million euros committed by the private side, to continue developing 5G technology and to make EU take a global leading position in 5G. So far, the 5G-PPP has published white papers, which identify the vision, architecture, key capabilities, design principles, key enabling technologies, and the time plan for 5G. It has also published a series of white papers investigating use cases and requirements from vertical sectors such as eHealth, Factory, Automotive, and Energy. The 5G research within 5G-PPP will go through three major phases until 2020, with three corresponding proposal calls. The first phase was dedicated to the research and innovation and the first call has resulted in 19 projects being selected. The budget of 128 million euros fund the 19 projects, working with different research topics from 2014 to 2016, including radio network architecture and technologies, convergence beyond last mile, network management, and network virtualization and software networks [36]. With the budget of 148 million euros, the second phase will focus on proofs of concept, experiments, and vertical industry, spanning from 2017 to 2019. The third phase will focus on large-scale trials with vertical industry. The research in this phase will be started by 2018, with the fund of around 425 million euros.

2.5.1.3 5G Research in Celtic-Plus

Celtic-Plus[11] is a telecommunication and ICT cluster under the umbrella of EUREKA, which is an intergovernmental organization formed by several European countries in 1985. The Celtic-Plus mission is to facilitate innovative research projects in the area of telecommunications, new media, future Internet, and applications and services towards a new "Smart Connected World". The current research focus within Celtic-Plus spans two key areas: "Networking and Clouds" and "Services and Applications". Each research area has many research topics, which are closely related to the development of 5G, such as cloud computing, SDN, NFV, IoT, eHealth, smart cities, and smart homes, etc. Some examples of 5G related projects within the Celtic-Plus are UNITED about NFV support of IoT services, WINS@HI about wearable IoT network solution for work safety, SIGMONA about SDN and NFV for mobile network[12], etc. [37].

2.5.2 Asian 5G Related Activities

Ongoing activities related to the development of 5G are also being conducted in some research communities in Asia, including 5G Forum in South Korea, 5G Mobile Communications Promotion Forum (5GMF) in Japan, and IMT-2020 Promotion Group in China.

2.5.2.1 South Korea: 5G Forum

In May 2013, the 5G Forum[13] was formed on the basis of the collaboration between mobile network operators, global manufacturers, research institutes, universities, and the government. Its main mission and objectives are to promote 5G technology research

10 5G-PPP. https://5g-ppp.eu
11 Celtic-Plus. https://www.celticplus.eu
12 SIGMONA Project. http://sigmona.org/
13 5G Forum. http://www.5gforum.org/

and development, as well as international collaboration on 5G technology. During the years 2015 and 2016, the 5G Forum has published several white papers outlining the vision, requirements, enabling technologies, spectrum considerations, and a service roadmap for the development of 5G by 2020 and beyond. As planned, the first world trial of 5G will be deployed by the members of 5G Forum such as ETRI, SKT, KT at the Pyeongchang Winter Olympics in 2018.

2.5.2.2 Japan: 5GMF Forum

The 5GMF Forum[14] was founded on September 30, 2014 with the objectives of promoting 5G research and study in Japan, as well as the global collaboration based on a roadmap on the 5G implementation policy by the government of Japan. In May 2016, the 5GMF Forum published the first white paper entitled "5G Mobile Communications Systems for 2020 and beyond", which identifies its visions, key concepts and key technologies with their release of 5G. In addition, the 5GMF Forum has also been organizing several workshops on 5G related issues and global collaboration with other 5G initiatives. As planned, the world's first 5G implementation will take place at the Olympic and Paralympic Games in Tokyo in 2020.

2.5.2.3 China: IMT-2020 5G Promotion Group

The IMT-2020 5G Promotion Group[15] was jointly established by three Chinese ministries, including the Ministry of Industry and Information Technology, Ministry of Science and Technology, and the National Development and Reform Commission in February 2013, based on the original IMT-Advanced Promotion Group. The main objectives of the group are to promote the development of 5G technologies in China and to facilitate cooperation with other global 5G initiatives. So far, the group has published several white papers presenting their vision, key concepts and key technologies for 5G. The group has also been organizing several 5G Summits every year to open the door for collaboration with foreign companies and organizations.

2.5.3 American 5G Related Activities

The primary coordinated 5G effort in the Americas is in the 5G Americas[16] organization. The 5G Americas is an industry trade organization composed of telecommunication service providers and manufacturers, aiming at leading 5G developments for the Americas. Its mission is to advocate for and foster the advancement and full capabilities of LTE wireless technology and its evolution beyond to 5G. So far, the 5G Americas has published several white papers related to 5G requirements, solutions, spectrum, as well as the evolution of 4G.

14 5GMF Forum. http://www.5gmf.org/
15 IMT-2020 (5G) Promotion Group. http://www.imt-2020.cn/en
16 5G Americas. http://www.4gamericas.org

2.6 Conclusion

The number of ever-increasing number of connected devices, the emergence of new services, and the increase of communication needs from vertical industries require the development of the next generation system, 5G. Although 5G is still under the research and development process, it will most likely be ready for the users by 2020. In the 5G system, there will be a variety of advanced technologies, such as massive MIMO, Cloud-RAN, SDN, NFV, etc., as well as the usage of unoccupied frequency bands above 6 GHz. In addition, the 5G network infrastructure will be constructed as multiple slices by adopting the network slicing technology. These technologies promise to fulfill the requirements, which come from both the user perspective and the networking perspective, in order to serve a large number of use cases in 5G era.

This chapter presents the visions and main use-case classes, key requirements, and enabling technologies for 5G. The chapter also summarizes the status of ongoing activities related to 5G development from all over the world, including standardization organizations as well as regional research communities. In the remaining chapters, potential security related problems in future 5G networks will be analyzed and discussed.

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