An Overview of 5G Technologies

Huu Quy Tran, Ca Van Phan and Quoc-Tuan Vien

Abstract Since the development of 4G cellular networks is considered to have ended in 2011, the attention of the research community is now focused on innovations in wireless communications technology with the introduction of the fifth-generation (5G) technology. One cycle for each generation of cellular development is generally thought to be about 10 years; so the 5G networks are promising to be deployed around 2020. This chapter will provide an overview and major research directions for the 5G that have been or are being deployed, presenting new challenges as well as recent research results related to the 5G technologies. Through this chapter, readers will have a full picture of the technologies being deployed toward the 5G networks and vendors of hardware devices with various prototypes of the 5G wireless communications systems.

1 Introduction

Intelligent devices are developing daily from personal and household equipment, such as smartphones, washing machines, fridges, air-conditioners, etc., to bulky items in factories. These devices are keeping changing to accommodate the upcoming fifth-generation (5G) of cellular networks. The 5G networks can therefore be regarded as an infrastructure to accelerate the process of social change and the industry.

The 5G networks are promising to meet the demands of various individual applications with a significant increase in size, content, and rate. It is also a platform for innovation to deal with millions of applications. The 5G networks, however, raise a number of issues that need to be tackled. For instance, how to guarantee that the

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devices are interacting with each other with a latency of less than one millisecond? Although such concern is not a critical requirement in general telecommunication systems with only voice or data services, it is vital in some specific areas with particular services, such as healthcare, military, and disaster communications systems.

The applications of 5G cellular networks will spread across smart city infrastructure with high capacity storage, intelligent transportation, and smart communication systems. The 5G evolution is being fueled by a number of factors such as the explosion of mobile data traffic, the increasing demand for high data rates, and the growth in connected and searchable devices for low-cost, energy-saving, and environmentally friendly wireless communications.

This chapter is devoted to outlining various research directions for the 5G networks that have been or are being studied and examined with new design challenges as well as their relevant works will be provided.

2 Evolution of Mobile Technologies from 1G to 5G

Starting with the first-generation (1G) mobile communications systems launched by Nippon Telegraph and Telephone (NTT) for the first time in 1979, the 1G systems were then employed worldwide in the 1980s. In the 1G systems, analog wireless access with narrowband frequency division multiple access (FDMA) is employed with a channel spacing of around 25–30 kilohertz (kHz). Then, the second-generation (2G) systems, i.e., North American Interim Standards 54 and 136 (IS-54/136), European standards Global System for Mobile (GSM), and Japan standards Personal Digital Cellular (PDC), were deployed in the 1990s, all of which adopted time division multiple access (TDMA) with the channel spacing ranging from 25 to 200 kHz [1].

Along with FDMA and TDMA, a wireless access technique based on code division multiple access (CDMA) was developed and standardized first in the IS-95 by Qualcomm in 1995 with its initial version called cdmaOne. With the CDMA, the channel spacing is 1250 kHz, which is much wider compared to the traditional 2G systems [1]. The data transfer rate in the 2G systems is however only around 9.6 kilobits per second (kbps) and does not meet the requirements of multimedia communications with high resolution. This accordingly motivated the development of the third-generation (3G) systems. The 3G systems were expected to provide advanced services with much higher data rates of megabits per second (Mbps) [2–4]. The first 3G networks were introduced by NTT DoCoMo in Japan in 1998 and were commercially launched in October 2001 also by NTT DoCoMo. The 3G systems were then deployed worldwide; for instance, in South Korea in January 2002 by SK Telecom, in the United States in 2002 by Monet Mobile Networks, and in the United Kingdom in 2003 by Hutchison Telecom.

With higher data rate requirements, the cellular networks kept evolving from the 3G to the fourth-generation (4G) systems. As a candidate standard for the 4G systems, the first-release Long-Term Evolution (LTE) standard was commercially deployed in

Norway and Sweden in 2009. The 4G systems enable a very high data transmission rate of up to 1–1.5 Gigabits per second (Gbps) for low-mobility communication, such as pedestrians, stationary users, nomadic and local wireless access, and up to 100 Mbps for high-mobility communication, such as mobile access from trains and cars. The 4G technologies were regarded as the future standard of wireless devices, allowing users to download and transfer high-quality multimedia. There exist two standard core technology of the 4G networks, including Worldwide Interoperability for Microwave Access (WiMAX) and LTE using different frequency bands (see [5, 6] and references therein). The LTE has switched to LTE-Advanced (LTE-A) since the fall of 2009 with many various LTE services started to launch in South Korea, the United States, and the United Kingdom in 2012.

Beyond the current 4G systems with LTE-A standards, the fifth-generation (5G) wireless systems have been proposed to be the next telecommunications standards aiming at providing a higher capacity, a higher reliability, and a higher density of mobile broadband users [7–9]. In order to address the high traffic growth and increasing demand for high-bandwidth connectivity, the development of 5G networks becomes crucial to support a massive number of connected devices with real-time services and high-reliability communications in critical applications [10–13]. By providing wireless connectivity for a diversity of applications from wearable devices, smartphones, tablets, and laptops to utilities within smart homes, transportation, and industry, the 5G networks are promising to provide ubiquitous connectivity for any kind of devices, enabling and accelerating the development of Internet of Things (IoT).

Further than improving solely the maximum throughput, the 5G systems are expected to provide lower power consumption dealing with battery issues, concurrent data transfer paths, lower outage, and better coverage for cell-edge and high-mobility users. Moreover, the 5G systems are required to be more secure, better cognitive functionality via software-defined radio (SDR), and artificial intelligent (AI) capabilities. With the employment of the SDR, a lower infrastructure cost could be favorably achieved, which might help reduce the traffic fees while the users can experience high-quality multimedia beyond 4G speeds. The evolution of mobile technologies from 1G to 5G is illustrated in Fig. 1.

3 5G Trends, Targets, Requirements, and Challenges

Despite some uncertainties, the 5G wireless systems have drawn attention to publicity, generating a call for innovative designs and philosophies from researchers in academia to mobile operators and communications service providers in industry. Expected to be commercially deployed around 2020, the 5G systems are being learnt with various proposed technologies to create more effective and financially viable business models [14]. Some widely known use cases of the 5G systems can be listed as in Fig. 2, which consist of broadband experience everywhere anytime, smart

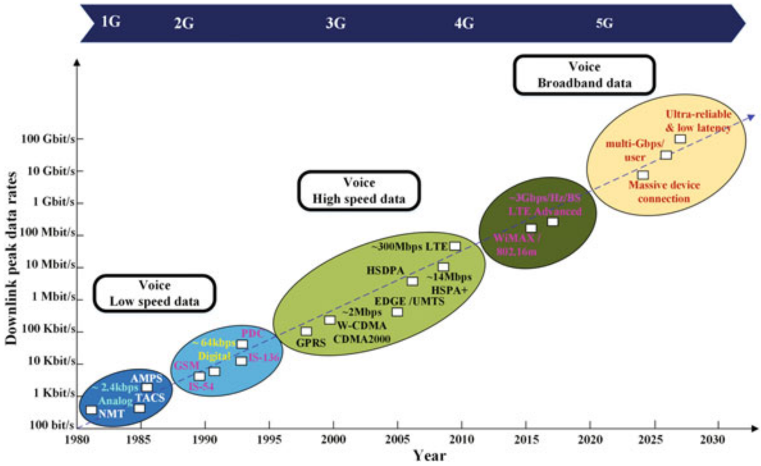


Fig. 1 Evolution of mobile technologies

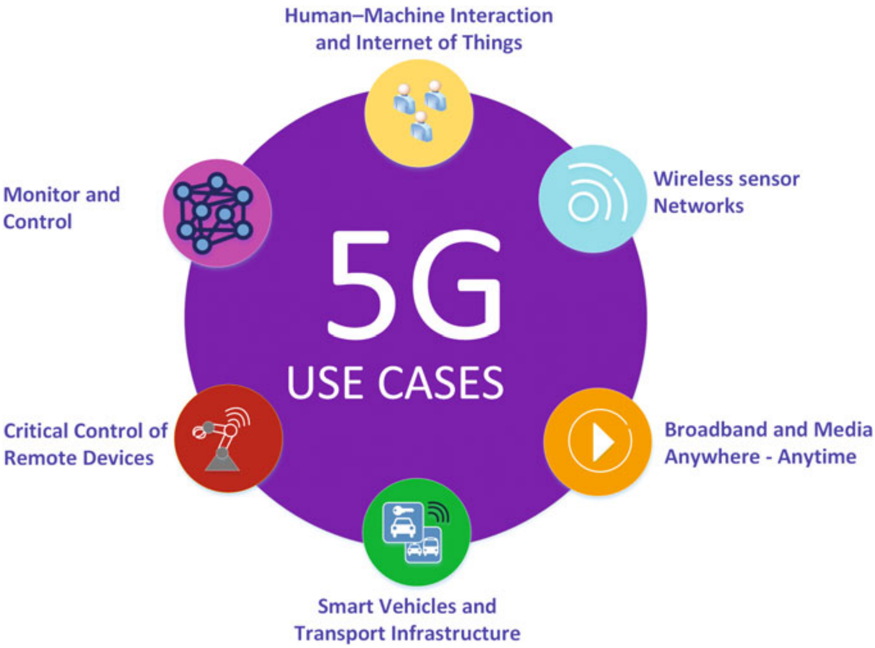


Fig. 2 5G use cases

vehicles transport and infrastructure, media everywhere, critical control of remote devices, and interaction between human and IoT.

Given the above use cases, it is totally optimistic that the 5G systems will offer significant benefits to all users and operators in the future mobile networks as long as all the challenges could be overcome. In the following, specific trends, targets, and requirements of the 5G networks will be briefly presented along with some of emerging challenges and major technical issues to be confronted.

3.1 5G Trends

As one of the key new services in the 5G networks, the IoT will influence the number of connected devices that will enter the marketplace. Additionally, the IoT will have a significant impact on 5G traffic patterns as well as their quality of service (QoS) requirements, all of which will also affect backhaul requirements and specifications. The aggregate data demand of the IoT should be very different from that of smartphone-oriented experiences. Capacity demands will grow and more base stations will have to be deployed to achieve the required QoS which are absolutely necessary for the IoT to be successful.

There are five key trends of the underlying 5G networks as the IoT expands [14], which can be listed as follows:

- **More capacity per device**: In order to meet the requirements of ultrahigh capacity per end device, as the first trend of the 5G networks, either more spectrums for improved spectrum efficiency or enhanced technologies are required.
- **More devices of different types**: The average number of devices per person is anticipated to rapidly increase in both quantity and diversity with a variety of device types for different services, such as smartphones, tablets, and wearable devices like smart watches and glasses. The 5G systems are therefore required to overhaul such exponential augmentation of devices.
- **Higher capacity for denser networks**: With the increased number of devices, the 5G systems aim at increasing the site capacity by up to 1000 times of the current networks. Although such task sounds feasible given numerous evolved technologies, several challenges need to be addressed. For instance, the current wireless backhaul links need to support a data rate of ten Gigabits per second (Gbps) or higher and are also required to cover denser networks.
- **Enhanced backhaul capability for critical applications**: Many new service types are developing in mission-critical networks for government, transportation, public safety, healthcare systems and military services. For these critical applications, the coverage, ultralow latency and strict security are dramatically the needs of wireless backhaul infrastructure in the 5G systems to lessen the risks of communication failure.
- **Diverse virtual and cloud-based services**: With cloud technology, it is promising that capital expenditure and operating expenses would be saved along with the openings of potential markets for a variety of virtual and cloud-based services. The 5G wireless systems will therefore give the operators and researchers the opportunity of reviewing and adapting the current technologies to the cloud platform.

3.2 5G Targets

The mobile data traffic is tremendously growing every year as per increasing users' demands over a number of applications and services with different smart devices. The present 4G networks, although have been shown to be satisfactory, may not be able to cope with such rapid growth in future. So, will the 5G networks be able to support a million connected devices per square kilometer with a download rate of up to 10 Gbps and a latency of less than one millisecond? The 5G systems are full of promise, incorporating a number of targets that require a lot of efforts. Some of the 5G targets are as follows:

- **Enhanced user experiences**: The 5G systems will not simply an enhanced 4G systems as an evolution, but they will aim at bringing new network and service capabilities given limited bandwidth and power resources. With novel design in the 5G networks, user experiences will be enriched guaranteeing that users can continuously access mobile broadband networks, especially in critical circumstances; for instance, in high-mobility trains, airplanes, dense areas, etc.
- **Platform for IoT**: The 5G systems will be driven toward providing a platform for IoT. A massive number of smart sensors will be connected to deliver various kinds of service in our daily life given an inevitable fact that they have severely limited power and short lifetime.
- **Improved mission-critical services**: The 5G systems will be destined for mission-critical services, such as public safety, healthcare, disaster, and emergency services, which require high-reliability communications with low latency and high coverage.
- **Unified network infrastructure**: The 5G systems will be tailored to meet the requirements of various network infrastructures in order to bring them together in a unified infrastructure. This integration will not only provide scope for optimizing all networking, computing, and storage resources but also enable dynamic usage of these resources along with convergence of services.
- **Incorporated market for operators**: The 5G systems will be directed to enable operators to collaborate over a digital or virtual market by taking advantage of cloud computing. Such market will make room for further development of the 5G networks.
- **Sustainable and scalable network**: The 5G systems will be particularly focused on energy consumption reduction and energy harvesting, targeting at compensating the radical increase of energy usage. With automation integration and hardware optimization, the operational cost will be expected to considerably reduce for sustainable and scalable network model.
- **Ecosystem for innovation**: The 5G systems will be means for involving vertical markets in different sectors and areas, such as energy, transportation, manufacturing, agriculture, health care, education, government, and so on. This will be an excellent opportunity to encourage startups and innovations in these diverse trading businesses.

3.3 5G Requirements

Aiming at enabling new services as well as enhancing current services in the next few years, there are a number of expected requirements for the 5G networks, which are more diverse than those for the 4G networks. Specifically, the 5G networks need to meet the following requirements:

- **User experiences** should be consistently and ubiquitously delivered in the 5G systems at a high data rate and low latency with optional mobility support for specific user demands of certain services.
- **Networks/systems** are required to support massive connected devices with high traffic density, high spectrum efficiency, and high coverage.
- **Devices/terminals** are desired to be smarter allowing operator control capabilities with programmability and configurability, supporting multiple frequency bands, increasing battery life, and improving resource and signaling efficiency.
- **Services** are indispensable to provide connectivity transparency with seamless, ubiquitous and high-reliability communications for mobile users, improve localization with additional three-dimensional space attributes, protect users' data from possible cybersecurity attacks, as well as ensuring the availability and resilience of mission-critical services.
- **Network deployment, operational, and management** are all needed to provide the new enhanced services in a low cost and low energy consumption for ensuring sustainability of the 5G and beyond networks, and also should facilitate the future upgrade and innovation assuring flexibility and scalability.

3.4 5G Challenges

Although the 5G systems are optimistic encouraging researchers in both academia and industry to overcome limitations of the current standards and theories, there are several challenges that need to be tackled in order to meet the requirements as stated in Sect. 3.3 and also to achieve the proposed targets in Sect. 3.2.

As one of the critical issues in the existing technologies, energy performance needs to be improved with appropriate resource allocation. The resources should be optimized to facilitate better utilization in a dynamic and adaptable manner. Additionally, given the scarcity of spectrum resource, an efficient spectrum usage is crucial in the 5G systems to support massive connected devices of different kinds.

In particular, a higher coverage with a higher density of mobile broadband users needs to be coped with in the 5G systems. Indeed, the 5G systems will need to manage a very dense heterogeneous network. As illustrated in Fig. 3, the radio resource management will become a paramount problem to handle the dense deployment of small cells in coordination with existing macrocells and billions of connected devices.

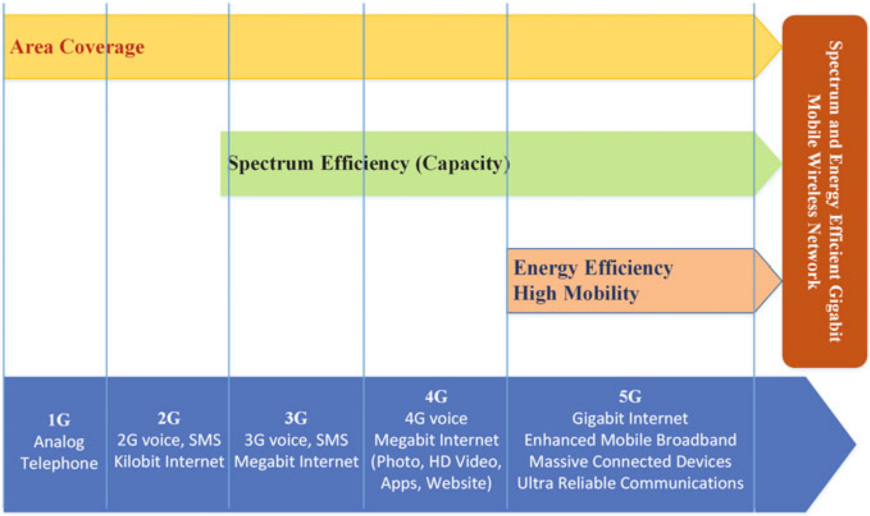


Fig. 3 Radio resource management in 5G

4 5G Enabling Technologies

Working toward 5G and beyond systems, a variety of enabling technologies have been being researched and developed, of which some are at still at early stage along with those well proposed in the literature as illustrated in Fig. 4. In this section, these technologies will be sequentially presented outlining their key concepts with relevant works.

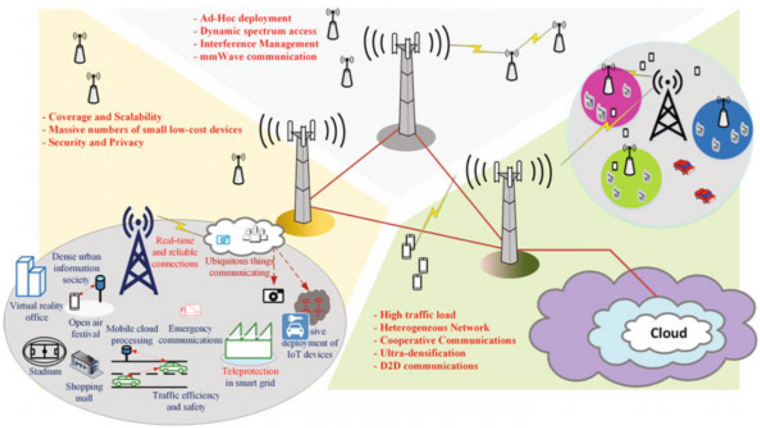


Fig. 4 5G enabling technologies

4.1 Massive MIMO

Massive multiple-input multiple-output (MIMO) (also known as large-scale MIMO or large-scale antenna systems) is an emerging technology in the next-generation mobile system, i.e., 5G and beyond, which has been upgraded from the conventional multiuser MIMO (MU-MIMO) technology. A typical massive MIMO architecture is illustrated in Fig. 5.

The massive MIMO has shown to be potential in dealing with the high sensitivity to blockages and distance-dependent propagation effects. In an effort to achieve all the gains of the MU-MIMO, the massive MIMO is promising to provide a larger scale in terms of energy and spectrum efficiency [15]. In particular, the massive MIMO exploits the spatial multiplexing gain to increase almost ten times of the capacity and 100 times of the energy efficiency compared with the MU-MIMO systems. In the massive MIMO, large arrays of antennas that contain a few hundred of antenna elements are deployed at base station (BS) to simultaneously serve several terminals using the same time–frequency resources.

In the MU-MIMO systems, to achieve both uplink and downlink spectral efficiencies, both the BS and the terminals must handle several complicated signal processing operations and have the channel state information (CSI) on the downlink which is accommodated by transmitting pilots in both directions [16]. With the increase in the number of antennas, the CSI process in the MU-MIMO systems is nevertheless unreasonable for the massive MIMO systems, especially in high-mobility conditions. In order to deal with such issue, the massive MIMO makes use of time division duplex (TDD) mode for pilot transmission based on an assumption that the uplink and downlink channels are reciprocal, and thus linear signal processing techniques can be employed to provide near-optimal performance with a low complexity [17].

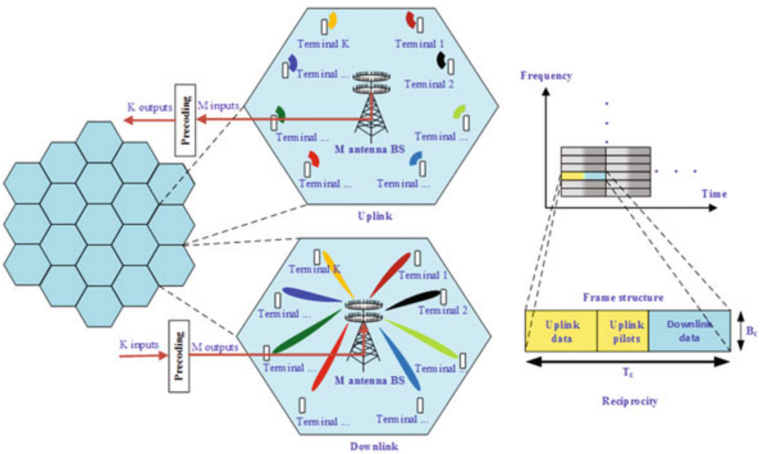


Fig. 5 Massive MIMO concept

4.2 mmWave Massive MIMO

Current mobile systems are all allocated in the microwave frequency bands of which most operate in the bands below 3 GHz and share the scarce spectrum resources of 600 MHz divided among operators. In contrast, mmWave frequency bands ranging from 3 to 300 GHz can offer multi-GHz of unlicensed bandwidth [18].

Some mmWave propagation measurements performed recently in both indoor and outdoor environments have similar general characteristics to the microwave propagation that reveals the great potential for small-cell communications [19]. Large arrays of antennas can eliminate the frequency dependence of path loss significantly compared with omnidirectional antennas. In addition, the narrow beams provided by adaptive arrays of antennas are able to reduce the impact of interference. In addition, the extremely short wavelength of the mmWave signals allows small antenna to direct them in narrow beams with enough gain to overcome propagation losses [20]. So, it is very likely to build a large number of antenna elements in a small area enough to fit into the mobile phones. This is the most important feature that helps to realize the massive MIMO at mmWave bands in realistic environments [21, 22].

mmWave massive MIMO has potential to provide ultra-large bandwidth and high spectrum efficiency that may significantly improve the overall system throughput in the future 5G cellular networks. An example of its deployment is illustrated in Fig. 6. However, due to the special propagation features and hardware requirements of the mmWave systems, there are several challenges when deploying the mmWave massive MIMO at the physical and upper layers. Particularly, the network architecture and protocols must be considered carefully in the network design to adapt signaling and resource allocation, as well as to cope with severe channel attenuation, directionality, and blockage [23].

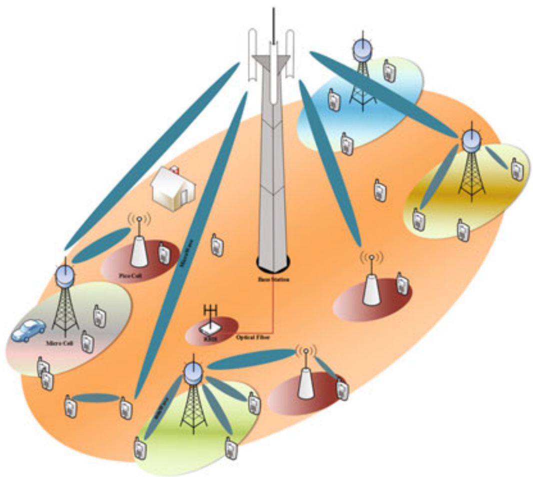


Fig. 6 mmWave massive MIMO deployment

4.3 Cloud Radio Access Networks

In general cell site architecture deployed in the 3G systems, BS contains two separated sectors including remote radio head (RRH) or remote radio unit (RRU) and baseband unit (BBU) or DATA UNIT (DU). The RRH performs radio frequency (RF) processing, digital-to-analog conversion (DAC), analog-to-digital conversion (ADC), and power amplification and filtering, while the BBU provides baseband-processing functions. In contrast to the traditional radio access networks (RANs), cloud radio access network (C-RAN) has recently emerged as a novel architecture for the RAN in which the baseband processing is now centralized and based on cloud computing technology [24–29].

In C-RAN architecture, all baseband computational resources are processed and aggregated within a central pool, also known as a virtualized BBU Pool. The geographically distributed RRHs/antennas are connected to a cloud platform through an optical transmission network. This model allows reducing the number of BBUs while maintaining similar coverage and offering better services compared to the traditional RAN architecture [30–33]. In fact, several cell sites can effectively share the computation resources, and thus help save a lot of operation and management cost leading to a significantly reduced capital expenditure. In addition, the virtualization in cloud computing has also the potential to achieve load balancing and scalability. This means that it is able to allocate and utilize the resources more efficiently under busty traffic conditions thus reducing waste of computation resources and power consumption [34]. Moreover, the resource cloudification in the C-RAN allows network operators to provide the RAN as a cloud service [35].

A comparison of C-RAN architecture and the traditional BS architecture is illustrated in Fig. 7. In Fig. 7a, the antenna module is located a few meters from the BS and connected to the BS by using coaxial cables with high signal attenuation in the traditional BS. Another configuration is shown in Fig. 7b where the BS with RRH is separated into two parts including RRU and BBU, which are connected by fiber optic cable, while the coaxial cable is only used to connect the RRH and the antenna. Finally, the fully centralized C-RAN architecture, as shown in Fig. 7c, is characterized by a large number of the RRHs located at different antenna sites connected to a BBU pool cloud located in a centralized cloud server through an optical transmission network.

4.4 D2D Communications

Device-to-device (D2D) communications is one of the most important technologies in 5G systems. In D2D communications, mobile user equipment (UE) communicates with each other in short range without involving eNodeB or the core network on the licensed cellular network.

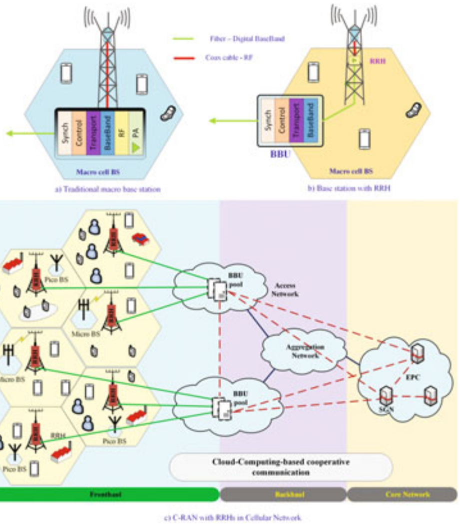


Fig. 7 Base station architecture evolution

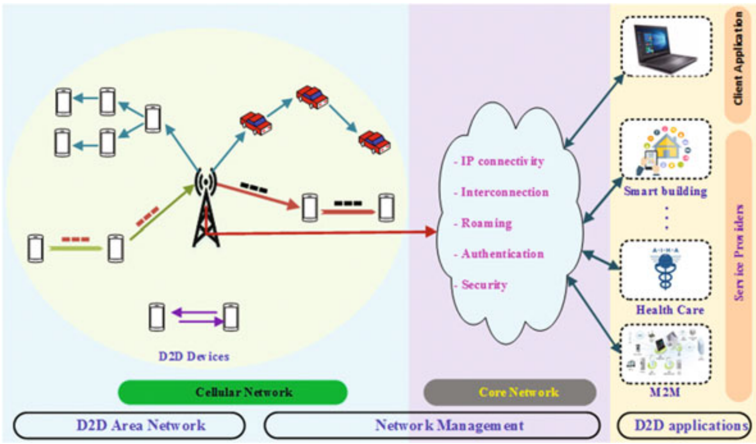


Fig. 8 Typical use cases of D2D communications in cellular networks

The D2D communications not only provides a flexible communication platform based on multiple radio access technologies embedded on mobile UEs but also promises to considerably improve energy efficiency, throughput, spectrum efficiency, and so on [36, 37]. In addition, it is feasible for integrating cooperative communication and cognitive radio along with performance optimization combining both ad hoc and centralized communications in the D2D communication. Figure 8 illustrates typical use cases of the D2D communications which can be found in smart building, healthcare, and public safety networks, e.g., [38, 39].

The D2D communication, however, faces several challenges including interference management, resource allocation, as well as delay-sensitive processing. In fact, in the 3GPP LTE architecture, there are many pairs of D2D UEs sharing cellular resources of eNodeB that may cause severe interferences including the interference from the eNodeB within the same cell, those from other co-channel D2D UEs in the same cell, and also those from the eNodeBs and co-channel D2D UEs within other cells [40, 41]. The resource allocation is also one of the most important concerns in the D2D communications given a limited number of subcarriers in the 3GPP LTE networks. Based on the quality of service requirement, the resource allocation technique will be selected consist of D2D mode or power control in cellular networks [42].

4.5 Ultradense Heterogeneous Networks

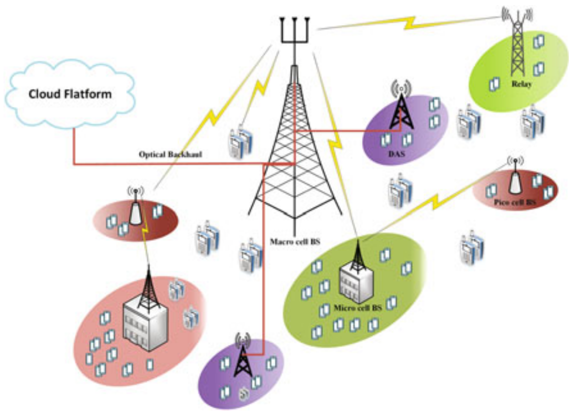
4.5.1 Heterogeneous Networks

In order to cope with the rapid growth of wireless traffic demands in 5G communications, the deployment of a large number of small cells (femtocell, picocell, and microcell) has been shown to be a feasible solution to achieve high capacity, leading to a heterogeneous network (HetNet). The HetNet is typically a multi-tier network architecture consisting of multiple types of infrastructure elements including macro-BSs, micro-BSs, pico-BSs, and femto-BSs with different transmission powers and coverage sizes.

In the HetNet, the powerful macro-BSs with high-power transmission are deployed in a planned way for covering large geographical areas whereas the small-cell BSs serving small coverage areas is used to complement the traditional macro-BSs. The range of a microcell or picocell is in the order of few hundred meters, whereas femtocells are used to provide indoor coverage within the range of few meters. A typical heterogeneous network is shown in Fig. 9 where the low-power BSs served for microcells or picocells which are deployed to cover a small area with heavy traffic such as a commercial center, airport, subway, and train station.

By deploying a variety of cells of different sizes, the HetNet architecture is highly probable for increasing the radio capacity, improving throughput, and serving several types of users with different QoS requirements in the next-generation cellular networks [43]. In addition, the deployment of low-power small-cell BSs in dense areas is one of the key solutions to enhance coverage and provide more capacity by covering smaller area than macro-BSs as well as improve the spectral efficiency of cellular networks. Moreover, the small cell integrated with macrocells provides a potential opportunity to decouple the control plane and user plane in which low-power small-cell BSs handle the control plane, while the overall control signaling to all users and cell-specific reference signals of small-cell BSs can be delivered to powerful high-power macro-BSs. Therefore, HetNets have advantages of serving hotspot customers with high data rates and busty traffic [44–48].

Fig. 9 Heterogeneous cellular network



Along with a number of advantages, the HetNet is facing a critical issue when too dense low-power small-cell BSs underlaid with macro-BSs reusing the same spectral resources could incur severe inter-tier interferences [45, 46]. Hence, advanced signal processing techniques are vital to fully obtain the potential gains of HetNets. Specifically, the advanced coordinated multipoint (CoMP) transmission and reception techniques have been proposed to suppress both intra-tier and inter-tier interference and improve the cell-edge user throughput [49, 50]. Another technique for enhancing the performance of the HetNet is co-locating massive MIMO BS and low-power small cell access in which the massive MIMO ensures outdoor mobile coverage whereas the small cell access equipped with cognitive and cooperative functionalities enables the HetNet to provide high capacity for indoors and outdoors with low-mobility users [26].

4.5.2 Distributed Antenna Systems

Another approach in dealing with dense networks is an employment of distributed antenna systems (DAS). The DAS has shown to be the high potential providing more uniform coverage, especially in shadowed and indoor areas, as well as enhancing the transmit capability of BS by adding multiple remote antenna units (RAUs) geographically distributed in a macrocell [51].

In the DAS, the spatially separated antenna units are connected to a BS or a central unit (CU) by using a high-bandwidth low-latency dedicated link that can be coaxial cable or optical fiber [52]. In this way, the BS can operate as a multiple-antenna system, although the antennas are located in different geographic locations. The DAS can accordingly improve indoor and outdoor coverage, reduce the outage probability, and increase the capacity of cellular systems in a variety of configurations. A typical DAS is illustrated in Fig. 10 where spatially separated antenna elements are connected to a macro-BS via a dedicated fiber/microwave backhaul link. This configuration indeed provides a better coverage since the terminals can connect to nearby antenna

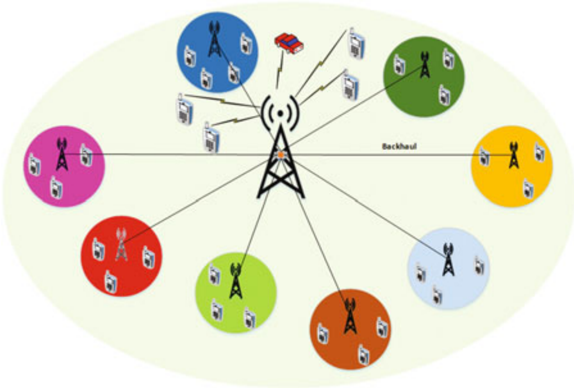


Fig. 10 Distributed antennas systems

elements, and thus a higher capacity gain can be achieved by exploiting both macro- and micro-diversities.

Comparing with co-located-antenna systems, the DAS has been shown to achieve a much higher sum capacity due to higher water-filling gain and multiuser diversity gain. Moreover, DAS technique allows shortening considerably the radio transmission distance between the transmitter and receiver leading to support high data rate transmission and achieve significant improvement in power efficiency [53, 54]. Particularly, fully distributed antennas also result in higher sum rates than having multiple antennas at each RRU with the same number of antennas. Since all the RAUs in a macrocell are connected to a CU remotely, spatial diversity and spatial multiplexing can be exploited in the DAS in order to improve the system performance.

4.5.3 Ultradense Heterogeneous Networks

Demand for high-speed data traffic in the mobile and ubiquitous computing era has been growing explosively and exponentially in recent years. For instance, in apartments, enterprises, and hotspot environments where users with high traffic demand are densely distributed. Deploying ultradense heterogeneous small cells has been widely recognized as a promising technique to address such exponential traffic growth with enhanced coverage especially in indoor and hotspot environments [55, 56]. The networks with a large number of densely distributed heterogeneous small cells, also known as ultradense HetNets, are illustrated in Fig. 11.

In ultradense HetNet architecture, the low-power small-cell BSs are densely deployed within the coverage area, which is served by the high-power macrocell BS to enhance the spectrum efficiency and thus increase the network capacity. The ultradense HetNet has also been regarded as a network in which inter-site communications occur at very short distances with low interferences. In particular, the distances between the access nodes in the newly envisioned small cells range from a few meters for femtocells deployed in indoor up to 50 m for microcells or pico-

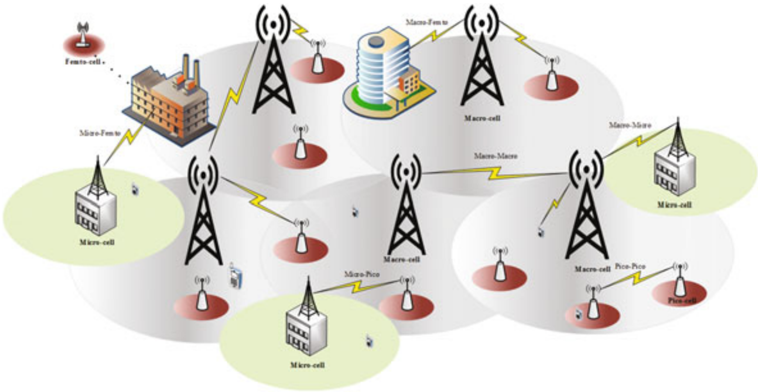


Fig. 11 Ultradense HetNets

cells with outdoor deployment [57]. Over the short distances between the users and the small-cell BSs, the received power of the desired signal at the user increases considerably, promising to provide a significantly enhanced network capacity.

Although the deployment of ultradense HetNets has been well identified as a feasible solution to manage the increasing traffic demands, the dense and random deployment of the small cells and their uncoordinated operation also bring several challenges in such multi-tier networks [58–61]. In this distributed network architecture, both backhaul and fronthaul traffics need to be relayed to the destination. Hence, an efficient multi-hop routing algorithm becomes crucial for such scenario. Since the coverage of the small cells in ultradense HetNet is less than that of the macrocell in the conventional cellular networks, the frequent handover in small cells causes a considerably increased redundant overhead and also reduces the user experiences. In addition, the mmWave antennas with beamforming technique equipped in the small-cell BS can provide strong directivity having the advantage of high-speed transmission but revealing the disadvantage in supporting the high-speed mobile users.

4.5.4 Security Issues

The security of mobile devices access in ultradense heterogeneous network is largely based on the specific features and architecture of the network system. We may find that the vulnerabilities of ultradense heterogeneous networks can occur in some cases, such as IP spoofing, interference management attack, handover management attack, unauthorized cell identification, RFID Tag, etc.

From there we can define security domains to access the network without fail, network accounts are not attacked, networks are stable, and quality of service meets the increasing needs of users. A typical security architecture of the user ultradense heterogeneous networks (UUDHN) is illustrated in Fig. 12 [62]. In this security

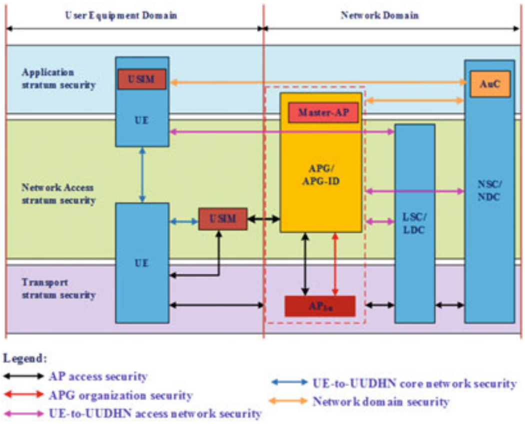


Fig. 12 User ultradense heterogeneous network security architecture

architecture, the UUDHN is a wireless heterogeneous network in which the access point (AP) density is comparable to the user density. The UUDHN organizes an access point group (APG) as the following coverage to serve each user seamlessly without user's involvement, and there are many security feature groups.

- The AP access security: The APs are very familiar to the user and even may be deployed by the user. The security threats of AP deployment which the UUDHN facing is the same as home evolved node B (HeNB) in long-term evolution (LTE) network. The HeNB supports a device validation method with either certification based or universal subscriber identity module (USIM) based mutual authentication, which helps prevent the attacker from exploiting the HeNB as a springboard to access the LTE networks [63]. In order to access the UUDHN, the APs also need to simultaneously authenticate between them and the UUDHN networks. When the authentication is successful, the APs then can enter into the working status.
- The APG organization security: The overall security of the UUDHN will be threatened by a malicious AP which counterfeits the APG. To cope with the APG security threats, two security aspects should be considered, including: (i) A security refresher for new APs joining the APG or AP registration leaving the APG, and (ii) A secure communication (e.g., collaborative signaling and data exchange, etc.) between the APG members.
- User equipment (UE) to the UUDHN access network security: Because the APG is refreshing, there are so many threats have emerged. The members of the APGs will be changed and the AP wireless connections may be entered by attackers. For instance, when the data transferred between the UE and the APs (APG), the attackers can eavesdrop on or manipulate the signaling and user data. The user's mobility between the APs may be also found or discovered where a particular user is located. These can pose a huge threat to user's privacy. It is the effective measures to protect the user's private data with the keys based on specific encryption algorithms. For instance, it is relied on the APG interim key to derive the keys for ciphering of user plane (KUPint) and also protects the integrity and encryption of

the radio resource control (RRC) signals between the UE and AP/APG (KRRCenc and KRRCint) is an effective way.

- The UE to the UUDHN core network security: In the UUDHN, the AP may pertain to multiple APGs (in another APG-ID) at certain time at a local service center (LSC). Obviously, there are threats that the APG or the AP may be counterfeited. Then, the UE may be attacked to access the other the APG or the UUDHN core networks by the counterfeited the AP. So as to prevent these threats, the mutual authentication mechanism between the UE and the LSC (APG-ID defined therein) needs to be considered to make sure the UE access security.
- Network access security: The set of security features providing users and entities with secure access to services and which particularly protect against attacks on the (radio) access link.
- Network domain security: The set of security features about the APG organization security, including the APG initiating, APG-ID/master the AP selection, the APG refreshing, the APG handover, and the AP security itself. They protect against attacks from the counterfeited the APs/APG.
- The APG domain security: The set of security features enabling entities to securely exchange signaling data and user data (among access network, serving network, and within access network) and protect against attacks on the wireline network.
- User domain security: The set of security features securing access to mobile stations.
- Application domain security: The set of security features enabling applications in the user and in the provider domain to securely exchange messages [64].

5 Conclusions

After nearly four decades since the birth of the first-generation networks, mobile communications networks have been continuously evolved as an important infrastructure offering distinct types of services in our daily life and activities. This chapter has sketched a picture for the evolution of the mobile technologies from 1G to 5G that has attracted interests of a number of researchers and developers. The upcoming 5G systems have indeed drawn their attention with a variety of trends, targets, requirements, and challenges to be tackled. Dealing with these challenges, this chapter has outlined different enabling technologies, including massive MIMO, mmWave massive MIMO, C-RAN, D2D, HetNet, DAS, and ultradense HetNet. These technologies have been shown to be promising candidates for the 5G wireless networks, meeting the strict requirements of high spectrum efficiency and energy efficiency as well as enhancing user experiences and services. With a number of evolved techniques, we are completely hopeful and optimistic that the upcoming 5G systems are going to fulfill the mobile users' demands in ultrahigh data rates, very low latency, high mobility, high coverage, long-life batteries, high reliability, and extraordinarily enhanced services.

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