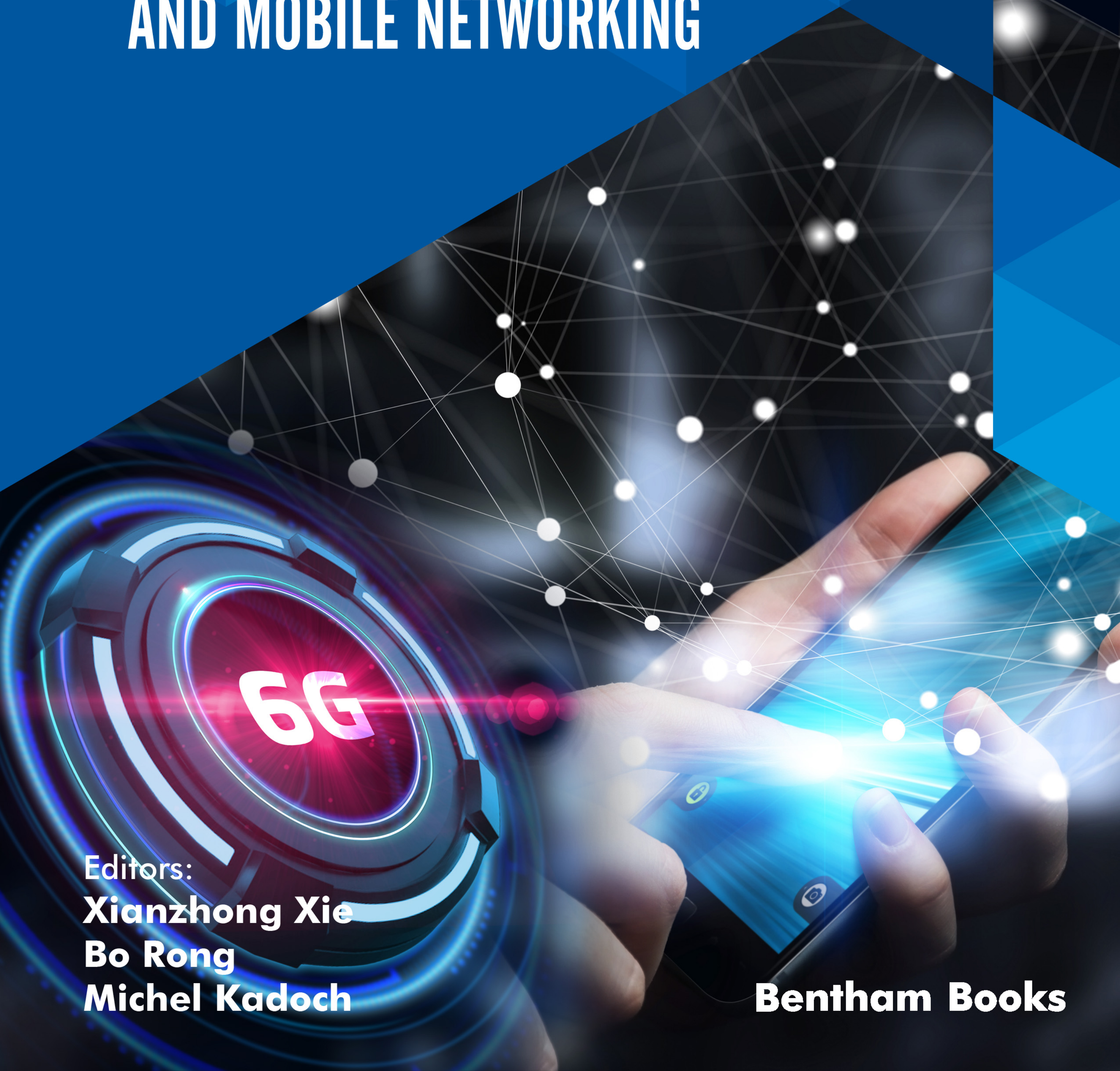
6G WIRELESS COMMUNICATIONS AND MOBILE NETWORKING



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Bentham Books

6G Wireless Communications and Mobile Networking

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CONTENTS

PREFACE

Although 5G mobile networks have been standardized and deployed worldwide since 2020, the requirements of wireless communication services are not completely met, taking into account industrial and other challenging applications. Thus, the 6G wireless technologies kicked off the initial research and are expected to be applied around 2030. Different from 5G, the next generation networks highlight new features like high time and phase synchronization accuracy, near 100% geographical coverage, and high cost-efficiency. Compared with Gbps-level transmission data rate in 5G, a number of useful applications in 6G, such as high-quality 3D video, virtual reality (VR), and a mix of VR and augmented reality (AR), need Tbps-level transmission data rate that could be achieved with terahertz (THz) and optical technologies. Due to the big datasets generated by heterogeneous networks, the technology of artificial intelligence (AI) is regarded as a promising aid to wireless systems in a bid to improve the quality of service (QoS), quality of experience (QoE), security, fault management, and energy efficiency.

With the booming of higher frequency and more energy-saving equipment, THz and photonic communications become economically feasible. The advanced integrated circuit (IC) technology nowadays makes radio frequency (RF) devices and antennas more flexibly designed and highly integrated. Flexible RF components could work with artificial intelligence (AI) algorithms to make wireless networks more adaptive to user demand and RF environment. The 6G will undoubtedly expand the frequency from below 95 GHz to the high-frequency millimeter-wave and terahertz range. Those new frequency bands will focus on short-range communications by enabling the design of much tinier RF devices to support technologies like ultra-massive antenna arrays.

6G networks are envisioned to be full dimensional and would address every potential demand of services. A smart city is such a typical scenario where various Internet of things (IoT) applications proliferate to help citizen services. Other than conventional scenarios, smart city IoT services will rely on 6G networks for broad coverage, ultra-low latency, and reliable connection. As different IoT applications may have different service holders, it becomes necessary to employ network slicing (NS) to gain distinct virtual networks and differentiated quality of service guarantees. In the meantime, computing technologies such as cloud computing, fog computing, and edge computing are critical to network resilience, lower latency, and time synchronization. Cloud computing provides the ability to use flexible and telescopic services through various hosted services provided by the Internet. Edge computing, on the other hand, prefers the open platform using the network, computing, storage resources close to the site of the object in order to avoid the relatively long delay of accessing the cloud data center. Finally, big data technology can work with 6G to get hidden patterns, unknown relevance, potential trends, and other information.

The content of this book is summarized as follows.

1. In Chapter 1, we provide readers with a general vision of 6G, including the inevitability of 6G research, the international organizations for 6G standardization, and also the 6G research progress.

2. In Chapter 2, we introduce millimeter-wave technologies in 6G, including large-scale MIMO systems, precoding technology, and different kinds of beamforming structures. It also systematically summarizes the requirements on 6G millimeter-wave devices.

3. In Chapter 3, we focus on the development of the latest 6G antenna technology. In particular, it highlights the technical trends of a large-scale antenna from antenna design and synthesis to feed network and antenna selection.

4. In Chapter 4, we highlight the characteristics and application fields of the terahertz wave, especially the application in wireless communication. Two mainstream terahertz wireless communication systems are explained in detail under the context of 6G.

5. In Chapter 5, we propose a self-organizing network (SON) driven network slicing architecture, where software-defined networking (SDN) and network function virtualization (NFV) act as the key enablers. Some preliminary simulation results are given to validate the efficiency of the design.

6. In Chapter 6, we present an overview of the developing trend of IoT applications and discuss its relation to 6G. This chapter also sheds light on the challenges and solutions to future cellular massive IoT.

7. In Chapter 7, we give a systematic introduction to the cloud/edge computing and big data system in 6G. New applications, such as sensing, positioning, and slice-specific function, can significantly benefit from the new network computing architecture and AI-powered big data analysis.

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CHAPTER 1

Explaining 6G Spectrum THz, mmWave, Sub 6, and Low-Band

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Abstract: This chapter aims to provide readers with a general vision of 6G. Firstly, we give a simple overview of various aspects related to 6G, including inevitability of 6G research, international organizations for standardization, and also 6G research progress of some countries/regions. Then, 6G spectrum compositions are discussed in detail with emphasis on SUB-6, mmWAVE, and Terahertz (THz).

Keywords: 6G, Frequency spectrum.

THE SIXTH GENERATION MOBILE COMMUNICATION (6G)

The development of mobile/wireless communication has gone through the process of 1G/2G/3G/4G, and it has entered a critical stage of 5G commercial development. From the historical perspective of industrial development, the mobile communication system has been updated every ten years. The increasing demand for user communication and the innovation of communication technology is the driving force for the development of mobile communication [1]. However, 5G will not meet all requirements of the future of 2030 and beyond [2]. Researchers now start to focus on the sixth-generation mobile communication (6G) networks. Some countries and organizations have already initiated the exploration of 6G technology with the launch of 5G commercial deployment in major countries around the world.

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THE INEVITABILITY OF 6G RESEARCH

The 10-year Cycled Rule

Since the introduction of the first generation (1G) mobile communication system in 1982, a new generation of wireless mobile communication systems has been updated approximately every 10 years, as shown in Fig. (**1**). It will take about 10 years from conceptual research to commercial applications [3]. In other words, when the previous generation enters the commercial period, the next generation begins conceptual and technical research. 5G research started 10 years ago, and now 6G research is in line with the development law of mobile communication systems. It may take about ten years for 6G to arrive, but research on 6G cannot be delayed. Mobile communications will stride towards the 6G era.

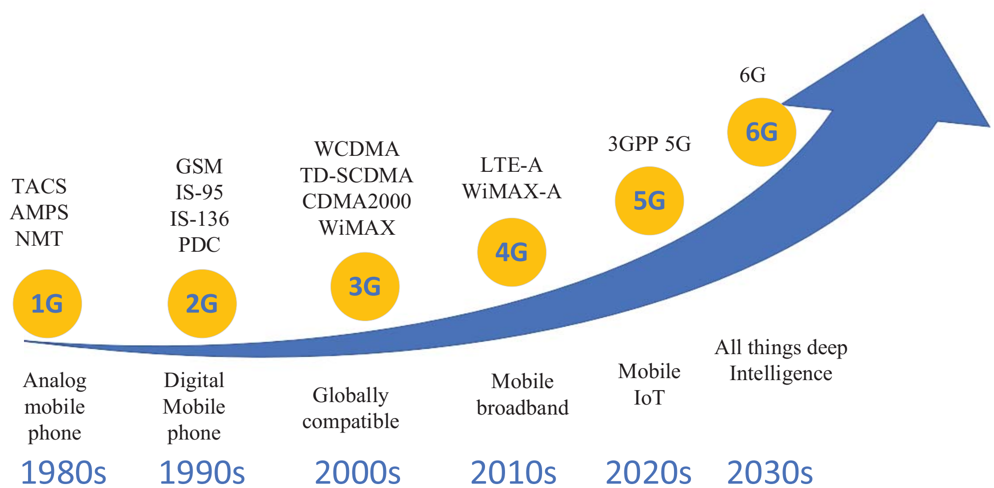

Fig. (1). The evolution of mobile communication systems.

"Catfish Effect"

The "catfish effect" means that it also activates the survival ability of the small fish when the catfish disturbs the living environment of the small fish. It is to adopt a means or measures to stimulate some enterprises to become active and invest in the market to actively participate in the competition, which will activate enterprises in the same industry in the market. 5G is different from previous generations of mobile communication systems mainly aimed at IoT/vertical industry application scenarios. Many vertical industry members will definitely participate in the 5G ecosystem with the large-scale deployment of 5G networks. The in-depth participation of emerging companies (especially internet companies born with innovative thinking) in the future will have a huge impact on the traditional communications industry and even a revolutionary impact compared with the status quo dominated by traditional operators, which is called "catfish effect".

The Explosive Potential of IoT Business Models

IoT is the inevitability of the internet from top to bottom in the industry. It is an extension from the inside out, with the cloud platform as the center. Just as the emergence of smartphones stimulated 3G applications and triggered the demand for large-scale deployment of 4G, it is believed that certain IoT business models will also stimulate the 5G industry to burst at a certain point in the 5G era, which will stimulate the future needs of 6G networks. To accommodate the stringent requirements of their prospective applications, we need to have enough imagination. We must prepare in advance for the possible future network and lay a good technical foundation [4]. Based on the above analysis, we can draw the conclusion that now is the right time to start the research on the next generation wireless mobile communication system.

The 5G Performance Would Limit New IoT Applications

Despite the strong belief that 5G will support the basic MTC and URLLC related IoT applications, it is arguable whether the capabilities of 5G systems will succeed in keeping pace with the rapid proliferation of ultimately new IoT applications [5]. Meanwhile, following the revolutionary changes in the individual and societal trends, in addition to the noticeable advancement in human-machine interaction technologies, the market demands by 2030 are envisaged to witness the penetration of a new spectrum of IoT services. These services deliver ultrahigh reliability, extremely high data rates, and ultralow latency simultaneously over uplink and downlink [6]. The unprecedented requirements imposed by these services will push the performance of 5G systems to its limits within 10 years of its launch. Moreover, these services have urged that 6G should be capable of unleashing the full potentials of abundant autonomous services comprising past as well as emerging trends.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

International Telecommunication Union (ITU)

According to the ITU work plan, the RA-19 meeting in 2019 will not establish a new IMT technical research resolution. It indicates that the research cycle from 2019 to 2023 is still mainly for 5G and B5G technology research, but the 6G

CHAPTER 2

Millimeter Wave Communication Technology

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Abstract: Millimeter-wave plays an indispensable role in the new generation of mobile communication because of its abundance of unexplored resources, which can be used to meet the requirements of greater bandwidth and ultra-high data rate. This chapter firstly introduces the development, characteristics, and applications of millimeter-wave. Then the application of millimeter-wave in mobile communication systems is described in detail, and the common channel model is listed. Secondly, a large-scale MIMO system, precoding technology, and three kinds of beam forming structures are introduced. Finally, combined with the current development of mobile communication, the requirements on the millimeter-wave devices for the new generation of mobile communication system are summarized, and some typical millimeter-wave devices are listed.

Keywords: Backhaul, Channel model, Millimeter wave, Propagation model, Wireless communication, Wireless network.

INTRODUCTION

The birth of each generation of mobile communication technology has provided great convenience for our life. The emergence of second-generation mobile communication technology (2G) has provided us with convenient voice calls. In the 3G era, we can use the mobile Internet to achieve some basic network functions. For the last ten years, high-speed mobile Internet in the age of 4G has brought video calling and mobile movie-watching into our lives. The 5G is the era of the Internet of everything, which takes the advantages of higher channel capacity, faster network speeds, and lower latency compared to 4G. Based on these characteristics, telemedicine, smart home, artificial intelligence (AI), the Internet of things (IoT), and so on will be developed and applied better.

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5G spectrum resources are divided into FR1 and FR2 by frequency. FR1 is the low-frequency part of 450~6000 MHz, which is also named Sub 6 GHz. FR2 is part of the millimeter wave (mmWave) frequency band (24.25~52.6 GHz). The specific division of the 5G spectrum in China was completed in 2018. Since low-frequency electromagnetic wave has a long wavelength, it has the small path loss and the large coverage area. Meanwhile, the relevant communication technology of low-frequency band is mature, and the application cost is low, which can quickly realize 5G deployment. Therefore, Sub 6 GHz is the main frequency band for the development of China's mobile communication at this stage. However, the mmWave frequency band is still an important frequency band for the future development of 5G in China. Compared with Sub 6 GHz, the bandwidth of the mmWave frequency band is GHz, which can realize a higher transmission rate and accommodate more data information. It is often located in a densely populated area and has high application value in the industrial field.

In recent years, with the development of mobile communications, the research on mmWave communications has become a major international focus. The mmWave communication and massive MIMO are considered to be the two key technologies of 5G. Because of the large bandwidth of the mmWave frequency band, the high transmission rate requirements of mobile communication systems for the new generation could be met. Since the mmWave has a short wavelength, the size of large antenna arrays could be miniaturized. Meanwhile, the use of the directional beamforming gain provided by the massive MIMO system can effectively compensate for the path loss of mmWave signals in the wireless channel. The current research on the new generation of mobile communications, from the planning and authorization of spectrum resources with specific needs to the research and development of various mmWave equipment and the construction of a new generation of mobile communication systems, has made tremendous progress. In general, the challenges faced by millimeter-wave frequency communications are mainly considered as high-frequency devices. Related high-frequency core components mainly include power amplifiers, low-noise amplifiers, phase-locked loop circuits, filters, high-speed and high-precision digital-to-analog and analog-to-digital converters, array antennas, *etc*.

CHARACTERISTIC AND APPLICATION OF MILLIMETER WAVE

With the acceleration of the informatization of human society, the application scope of the electromagnetic spectrum is expanded. In the 1970s, the World Radio Conference held by the International Telecommunication Union (ITU) divided and allocated the 30~70GHz frequency band used by communication services. In recent years, due to the continuous growth of demand for broadband and large-capacity information transmission, personal communications, and military confidentiality/anti-jamming communications, the mmWave and even submillimeter-wave fields have become an extremely active field in the research, development, and utilization of international electromagnetic spectrum resources, which contains abundant information resources. To increase the communication capacity and avoid channel congestion and mutual interference, the communication frequency must be developed into a higher frequency band. Therefore, the developments of electromagnetic spectrum resources in the mmWave and terahertz bands are recently the key research fields in electronic science, and the spectrum resource of mmWave band has significant application values. Generally, electromagnetic waves with a frequency range of 30~300GHz are called mmWave, and can be divided into several frequency bands. The frequency band codes and frequency ranges are shown in Table **1**.

Table 1. Millimeter wave frequency division.

Band Code	**K**	**K_a**	**Q**	**U**	**E**	**W**	**F**	**G**	**M**
Freq (GHz)	18~26.5	26.5~40	33~50	40~60	60~90	75~110	90~140	140~220	170~260

Characteristic of Millimeter Wave

The wavelength of millimeter wave is located in the overlap range of microwave and infrared waves, which has the characteristics of both ones. The theory and technology of millimeter wave are the extension of microwave to high frequency and the development of light waves to low frequency [1].

Usable Frequency Bandwidth and Large Information Capacity

The mmWave frequency band ranges from 30 to 300 GHz, with a bandwidth of up to 270GHz, which is more than 10 times the full bandwidth from DC to microwave. Considering the atmospheric absorption, there are mainly four propagating windows for mmWave. The total bandwidth of these four windows can reach 135GHz, which is five times the sum of the bandwidth of each band below the microwave. Therefore, the main advantages of mmWave communication are bandwidth and large information capacity, which can be used for multi-channel communication and television image transmission. Furthermore, the high transmission rate is conducive to the realization of communication with a low probability of interception, such as spread spectrum communication and frequency hopping communication. High-loss frequencies (such as 60 GHz, 120 GHz, and 180 GHz) can also be used for military confidential communications and satellite communications.

CHAPTER 3

Antenna Evolution for Massive MIMO

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Abstract: Massive MIMO technology is one of the key technologies of the 6G communication system and the basis of high-speed transmission in the wireless communication network. At the same time, massive MIMO puts forward new requirements for antenna devices in the communication system, such as active integration, miniaturization, broadband, *etc*. This chapter first reviews the development process and the latest progress of antenna technology in wireless communication. The requirement of a 6G communication network for the base station antenna and the terminal antenna is emphasized. The theoretical basis of massive MIMO technology in the 6G communication system is described in detail, and RIS technology which is closely related to massive MIMO, is introduced. The technical characteristics and development trends of massive MIMO antennas are discussed in detail, including antenna design and synthesis, feed network, and antenna selection technology. Finally, combined with the development of current antenna measurement and calibration technology, the measurement engineering technology closely related to the antenna feeder industry in 6G communication is introduced.

Keywords: Antenna array, Antenna measurements, Beam forming, Feed network, Massive MIMO.

INTRODUCTION

With the further development of the multi-antenna technology theory and the progress of baseband processing ability, RF (radio frequency), and antenna technology, the standardization development of multi-antenna technology is gradually moving towards the direction of further improving the multi-antenna dimension, supporting more users and more parallel transmission of the data stream. In the 6G system, massive MIMO technology, supporting tens, hundreds, and thousands of antennas, will become an important technical way to further

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improve the efficiency of the wireless access system, which can satisfy the explosive increase of the user quality and business volume.

The deployment of Massive MIMO can be divided into a distributed structure and a centralized structure. The antenna spacing of the distributed structure is far greater than 10 times the wavelength. In the hot spot area or indoor environment, multiple antennas are distributed in different geographical locations to form different access points [1]. Many access points can be gathered to baseband processing nodes or computing centers through optical fiber or other forms of back-propagation network. In order to achieve high-speed transmission and capacity improvement, the distributed large-scale antenna array is used based on the cooperation between antenna ports. For the centralized large-scale antenna array, the deployment model of small spacing is adopted (small spacing refers to 1/2 wavelength of the electromagnetic wave). By utilization of the characteristics of centralized massive MIMO antenna array with small antenna spacing and the strong correlation between antennas, high gain narrow thin beam with higher spatial resolution can be formed to achieve more functions, such as making space division multiple access with good efficiency, improving the received signal quality and reducing the interference between users greatly, and enhance the system capacity and the spectrum efficiency. The centralized large-scale antenna is also known as large-scale antenna beam forming technology or large-scale antenna due to the use of beam forming signal transmission. Based on the beam forming technology, the centralized small spacing large antenna array plays an important role in promoting the efficiency of frequency band utilization, improving coverage, and suppressing interference. And the centralized large-scale antenna is the most popular technology to design and standardize the large-scale antenna system.

The large-scale antenna beam forming technology plays an important role in different frequency bands. In the Sub-6 GHz frequency band, the large-scale antenna beam forming technology can realize the spatial differentiation of users and suppress the interference effectively through high gain narrow thin beam with higher spatial resolution. In the frequency band above 6 GHz, a two-stage shaping structure with mixed digital and analog signals is generally adopted due to the equipment cost, power consumption, and complexity. The digital phase shifter is used to roughly match the spatial characteristics of signals in the analog domain to overcome the path loss. Then, the user level and frequency selective digital beam forming technique is used to precisely match the channel characteristics in the lower dimensional digital domain. The transmission quality is improved and the interference is effectively suppressed finally. In this case, beam forming technology will play a more important role in making up for the imperfect propagation environment and ensuring system coverage.

The centralized Massive MIMO (referred to as Massive MIMO) and large-scale antenna beam forming technology (referred to as large-scale antenna), based on the small antenna spacing array, are analyzed in the following sections of this chapter., which can form high-resolution, high-gain narrow and thin beams.

OVERVIEW OF ANTENNA IN WIRELESS COMMUNICATION

Evolution of Base Station Antenna

The antenna is a kind of converter to radiate and receive electromagnetic waves. It can be used as a transmitting device to convert high-frequency current into radio waves of the same frequency and can also be used as a receiving device to receive and convert radio waves into the high-frequency current of the same frequency. The antenna is widely used in mobile communication, broadcasting, radio, remote sensing, and other fields. For the mobile communication system, antenna is the converter of equipment circuit signal and electromagnetic wave signal. Since antenna is the entrance and exit of information, its performance affects the performance of the whole mobile network.

With the development of mobile communication systems, the research of base station antenna has entered broadband and multiple frequency era. On the one hand, the evolution of mobile communication systems is a step-by-step process, and the coexistence of 2G, 3G, and 4G systems will be maintained for quite a long time. Multi-system common station and multi-system common antenna are economical and effective solutions. On the other hand, it is urgent to develop a compact and wide band base station antenna with increasing attention to visual pollution and electromagnetic radiation pollution.

Since the 1980s, the development of mobile communication technology has comprehensively promoted the evolution of base station antenna technology. The early base station antenna is omni-directional, which requires four antenna elements arranged around the vertical axis to obtain the omni-directional radiation pattern. The sector division of coverage cell makes the base station antenna develop into directional antenna with the popularity of cellular mobile communication system. Due to the expansion of channel capacity, compatibility of operation system and the flexibility of service mode, the working frequency band of base station antenna is prominently extended in recent years. Therefore, broadband, multiple frequency, miniaturization and integrated base station antenna which can meet the requirements of various systems are the research hotspots of base station antenna [2]. Based on the long-term research, the development trend of the mainstream base station antenna are as follows.

CHAPTER 4

Terahertz Technology Applied in Mobile Communications

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Abstract: Owing to its ultra-high frequency, the terahertz band becomes one of the candidate bands for 6G communication. In this chapter, the characteristics and application fields of the terahertz wave, especially the application in wireless communication, are introduced in detail. Firstly, the characteristics of the terahertz wave are briefly introduced, and then the terahertz technology, including terahertz devices and the main application fields of the terahertz wave, is introduced. Next, focusing on the application of the terahertz wave in the wireless communication system, it introduces two mainstream terahertz wireless communication systems, describes the key technologies, and finally describes the potential application prospect of the terahertz wave in the wireless mobile communication system.

Keywords: Device, Direct modulation, Solid-state, Terahertz wave, Wireless communications.

INTRODUCTION

The development plan of 6G communications includes the technological path and societal path that stimulate new services. Near-future services in the sixth generation of mobile communication networks include holographic communications, high-precision manufacturing, artificial intelligence, the integration of subterahertz or visible light communication in a 3D coverage scenario. The technologies supporting above mentioned new services can be categorized into five parts, *i.e.*, a new internet architecture that combines kinds of resources within a single framework, a distributed AI algorithm, a 3D communication infrastructure, a new physical layer incorporating subterahertz bands and VLC, and a distributed security mechanism [1].

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With the popularity of smartphones, the number of wireless network users and data demand is increasing rapidly. The rapid development of intelligent terminal applications requires that the future communication system can achieve ubiquitous ultra-high-speed access in a variety of complex environments. Therefore, one of the effective ways to improve spectrum efficiency is through advanced signal processing techniques and modulation schemes. However, due to the narrow bandwidth of the current operating frequency band, it is difficult to achieve a transmission rate of 100 Gbit/s. Another alternative is to use higher carrier frequencies to increase the channel bandwidth to provide sufficient transmission capacity.

Millimeter wave and terahertz band are the candidate frequency bands of high-frequency communication. They can cope with the problems faced by the current wireless communication system. In contrast, the terahertz band has greater potential than the millimeter wave band. Firstly, the bandwidth of the terahertz band is 0.1 ~ 10 THz, which is an order of magnitude higher than that of millimeter-wave, which can provide terabit per second data transmission rate support. Secondly, due to the decrease of antenna aperture, terahertz has higher directivity than millimeter-wave and is less prone to free space diffraction. Finally, the distance between transceivers in the terahertz band is much shorter than that in millimeter wave band, which will reduce power consumption and thus reduce carbon dioxide emissions [2]. Considering the shortcomings of the current communication system and the unique advantages of terahertz band, terahertz communication technology has attracted extensive attention in academic and industrial circles. It is considered to be the key wireless technology to meet the real-time traffic demand of mobile heterogeneous networks, which can alleviate the capacity bottleneck of the current wireless system and realize ultra-high-speed wireless communication. The huge bandwidth of the terahertz band and the super high-speed data transmission rate will realize a large number of new applications and services, such as vehicle communication, virtual reality (VR)/augmented reality (AR), health monitoring, satellite communication, *etc*.

According to the generation method of the terahertz wave, the current terahertz wireless communication equipment is divided into two parts. The first method is to use optoelectronic technology to convert optical frequency to terahertz frequency. That is, continuous or pulsed terahertz radiation is generated by semiconductor excitation. The second method is to use a frequency multiplier to increase the working frequency of electronic equipment from millimeter wave to terahertz range. The application of optoelectronic combination in terahertz wireless communication systems is often restricted by optical components, which is not conducive to the integration and miniaturization of chips. Therefore, the communication system based on frequency multiplier is widely used. However, there are still some difficulties in the large-scale application of terahertz communication systems, such as large volume and low integration of terahertz devices, high transmission loss of terahertz signal, and limited transmission power of terahertz RF devices. These problems require the industry to explore the development of new semiconductor materials and integrated circuit technology, research and development of advanced antenna technology, optimization of system resource allocation, and so on, so as to realize the miniaturization, low power consumption, and low cost of terahertz communication. The coverage of terahertz communication is enhanced, and the transmission rate of terahertz communication is improved. In order to better apply terahertz communication technology to support future ultra-high speed and low delay new applications, it is necessary to better capture the characteristics of terahertz band, understand the existing problems and technical challenges of terahertz communication, to build a more robust and efficient terahertz wireless communication system. This chapter firstly introduces terahertz technology, including terahertz wave and modulation devices, as well as its mainstream application scenarios. Secondly, the terahertz wireless communication technology is summarized, including the current terahertz channel propagation model, wireless communication system and mobile communication application scenarios. Finally, the possible important research directions of terahertz band in the future are prospected.

TERAHERTZ TECHNOLOGIES

Terahertz Wave

The term "terahertz" first appeared in the microwave field in the 1970s. It is used to describe the spectral frequency of interferometer and the frequency coverage of diode detector. At present, the electromagnetic wave with the spectrum of 0.1 ~ 10THz is named as terahertz wave. Its wavelength ranges from 30 μ m to 3000 μ m, which is between microwave and infrared light wave. It is located in the transition region between macro electronics and micro photonics.

With the development of mobile communication services, mobile users put forward higher requirements for wireless communication rate. According to Shannon's theorem, the channel capacity is proportional to its spectrum bandwidth. Therefore, larger bandwidth is the key factor to achieve ultra-hig--speed data communication. As a new band between microwave and light wave, terahertz has not been fully developed in the field of communication. Terahertz communication has the advantages of rich spectrum resources and high transmission rate, which is a very favorable broadband wireless access technology in future mobile communication. It can support higher data rates than millimeter

CHAPTER 5

Intelligent Network Slicing Management and Control for 6G Mobile Networks

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Abstract: The Internet of Things (IoT) is a key enabler of smart cities, where a variety of applications proliferate to help citizen services. As different IoT applications have different service holders, it becomes necessary to employ network slicing (NS) to gain distinct virtual networks, and differentiated quality of service (QoS) guarantees. Other than conventional IoT scenarios, smart city IoT relies on 6G networks for broad coverage, ultra-low latency, and reliable connection. This chapter proposes a self-organizing network (SON) driven network slicing architecture, where software-defined networking (SDN) and network function virtualization (NFV) also play important roles. Some preliminary simulation results are given to validate the efficiency of our design.

Keywords: Intelligent Network Slicing, Internet of Things, Self-organizing Network, Software-defined Networking.

INTRODUCTION

Different from 5G networks that are designed for digitalizing several urgent scenarios in modern society, such as massive connection, enhanced mobile broadband, and ultra-low latency, networks in the 6G era are envisioned to be full dimensional networks that would address every potential demand of network services. For example, a smart city is a promising solution to improve citizens' quality of life. However, it will heavily rely on 6G mobile networks, especially the mobile Internet of things (IoT), to connected utility infrastructure, public assets, *etc*., throughout the city to endow the governors and utility service providers with sharper insights to better their services [1]. These IoT devices may come for different utilization purposes, such as surveillance, metering, actuating,

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and from different utility service providers and public sectors, posing a wide range of preferences on the performance of network services. This is quite different from 5G, where services are roughly categorized into three types, namely massive machine type communication (mMTC), ultra-reliable low-latency communication (URLLC), and enhanced mobile broadband (eMBB).

How to serve network applications with extremely different performance requirements without impacting each other was once a critical issue when designing 5G, and network slicing (NS), the concept borrowed from computer network virtualization technologies [2], was thus introduced to address this issue. Through network slicing, 5G mobile network with nation-wide coverage, would be sliced into logically independent layers or parts, or network slice instances (NSIs) specifically. Network services with similar properties will be gathered into an NSI, which usually is allocated a predefined set of resources to keep from the impact of other services. Data flows are arranged in the slice granularity, so the reduced scheduling complexity and cost-effective resource consumption can be achieved.

Due to the logical independence, or isolation specifically, network slicing grants mobile network operators (NOPs) the valuable opportunity to stretch their business to public utilities and vertical industries. In the past, companies in these industries prefer to build private networks for business privacy and designable QoS policies. However, the new wave of society digitization is forcing these companies to extend their perception edge to places where their self-build private networks are hardly accessible. Further building private networks means utility service providers have to pose their network facilities out from their private domain into off-premises environments. Maintaining massive facilities in a huge metro or even nation-wide scope is challenging. Moreover, computational complex tasks, such as augmented reality, video data analyzing, will be a necessary part of future IoT applications, which require sufficient computational and storage resources available as close to the scene as possible. Budget, technology backups, privacy, and performance issues limit further expansion of self-built private networks. Instead, renting slices from mobile network operators becomes an attracting solution. Thus, the properties and types of network services is going to experience a boom before we are entering 6G era.

To satisfy the broad demands on customized IoT networks of smart city service providers, it is foreseeable that a lot of NSIs will be subscribed by different USPs (tenants in NOP’s view) simultaneously operating on the same network infrastructure, and each NSI is attached with an appointed service level agreement. How to optimally allocate various network resources to slice instances on demand turns one of the key problems in network slicing. The process, comprised of allocating heterogeneous network resources to NSIs and coordinating the allocations between them, should be flexible to the instant requests from tenants, which by no means can be manually accomplished. To facilitate the resource management process for network slicing, it is necessary to introduce automation properties into the process and frame it into a properly designed network slicing management architecture.

This chapter applies self-organizing approaches in 5G network slicing for smart city IoT. Specifically, a self-organizing network (SON) driven slicing management architecture framework is proposed, which consists of properties like self-organizing, traffic-aware, and robust-guaranteeing to make good utilization of network facilities. The functional framework and management process flow are characterized. A case study of network resource optimization for delay-sensitive (DS) slices and non-delay-sensitive (nDS) slices is given at last to exemplify the effect of flexible resources allocation, together with some analyses on the numeric results.

NETWORK SLICING AND ITS NEW REQUIREMENTS FOR 6G

This section first presents an illustration of network slicing for smart city scenarios with diverse IoT applications, and then introduces a general network slicing management architecture as well as the resource management issues during slicing.

The Concept of Network Slicing

The concept of network slicing is so vivid that it is not hard to imagine the key idea of the technology is to slice the same network infrastructure into several independent logical networks [3]. The way a network slice instance being implemented can be static or dynamic [4]. As to static slicing, network resources are reserved exclusively for individual network slice instances. Thus, static slicing can be easily implemented and naturally makes network services within a slice instance isolated from other network services, while it is obvious that static slicing has the disadvantages of underutilization of network resources. For dynamic slicing, resources are allocated dynamically according to the actual needs of services in the slice instances which is of course beneficial to improve the network resource utilization efficiency, but additional mechanisms are needed to form QoS guarantee of end-to-end (E2E) performance. Thus, both types of slices will be running in future 6G networks, but dynamic slicing contributes more complexity. Thus, a critical goal of network slicing management is to achieve dynamic slicing.

CHAPTER 6

Applications and Implementations of 6G Internet of Things

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Abstract: The Internet of things (IoT) has been the information infrastructure of a digitalized society and drives the newest wave of industrial development. With the rise of smart vehicular IoT applications, such as intelligent transport, smart navigation, and automatic driving, vehicular IoT is gaining some new features that cannot be fully addressed by current 5G networks. This chapter presents an overview of the vehicular IoT developing trend and discusses its relationship to 5G and the coming generation. It also presents some survey results from recent literature on the challenges and promising technologies for vehicular massive IoT.

Keywords: Automatic driving, Intelligent transport, Smart navigation, Vehicular IoT.

INTRODUCTION

Internet of Things

IoT is the "Internet of Everything Connected". It is the network that extends and expands on the basis of the internet. It is a huge network formed by combining various information sensing devices with the internet. It can connect people to people and people to things. The internet of everything has become a distinctive feature of 5G, which will profoundly change personal life and economic and social development. At the same time, the rapid development of the IoT will surpass the connection between things and enter a new era of cognitive or intelligent IoT. IoT and 6G will be more deeply integrated to generate a digital twin virtual world. Information can be transmitted between people and people, people and things and things and things in the physical world through the digital world. The twin virtual world is the simulation and prediction of the physical

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world, which accurately reflects and predicts the true state of the physical world. It realizes the “digital twin, intelligent endogenous” to help human beings further liberate themselves and improve the quality of life and the efficiency of production and governance of the entire society. Therefore, the vision of “digital creation of a new world, intelligent communication of all things” is realized.

The rapid development of communication and information technologies is making the massive connections between humans and machines has become a novel feature of communication systems. IoT provides ubiquitous connectivity for anyone and anything (including mobile phones, smart homes, industrial equipment and vehicles, *etc*.) at anytime and anywhere, enabling them to communicate, coordinate, and share information with each other so as to efficiently make decisions and perform their respective tasks. All types of communications, such as machine-to-machine (M2M), human-to-machine (H2M), and human-to-human (H2H), can be carried out in IoT. IoT is a vast area of research,having various forms, complex technologies and broad implications.

In light of the information life cycle of collection, transmission, processing and utilization, a five-layer architecture for IoT is widely adopted, namely, the perception and recognition layer, data communication layer, network interconnection layer, management layer and application layer. These layers perform different functions, but are also closely connected. Below the application layer, various technologies on the same layer are complementary each other to apply to different environments and constitute a full set of strategies for the technologies at this layer. And different layers provide configurations and combinations of various technologies to form a complete solution according to application requirements.

THE IMPACT OF IOT APPLICATION REQUIREMENTS ON 6G

As societal needs continue to evolve, there has been a marked rise in a plethora of emerging use cases that cannot be served satisfactorily with 5G. For example, the next generation of VAR, *i.e*., holographic teleportation, requires Tbps-level data rates and microsecond-level latency, which cannot be achieved with even the millimeter wave (mmWave) frequency bands within 5G. Further, increasing industrial automation and the move from Industry 4.0 to the upcoming Industry X.0 paradigm will push connectivity density well beyondthe106 km2 metric that 5G is designed for, in addition to requiring an overhaul of existing network management practices. Further, an increase in the connection density will also result in demands for improved energy efficiency, which 5G is not designed for. Consequently, the research community has gravitated towards addressing the aforementioned major challenges, and we posit that ongoing research in the domains of terahertz band communications, intelligent surfaces, and environments, and network automation, for example, may very well hold the key to the future of wireless.

The future development of 6G technology may involve but not limited to the following more important technical fields. These technologies include: (i) a network operating at the THz band with abundant spectrum resources, (ii) intelligent communication environments that enable a wireless propagation environment with active signal transmission and reception, (iii) pervasive artificial intelligence, (iv) large-scale network automation, (v) an all-spectrum reconfigurable front-end for dynamic spectrum access, (vi) ambient backscatter communications for energy savings, (vii) the Internet of Space Things enabled by CubeSats and unmanned aerial vehicles (UAVs), and (viii) cell-free massive MIMO communication networks. We also make note of three very promising technologies that are expected to shape the future of communications, yet will not be sufficiently mature for 6G. These include: (i) the Internet of NanoThings, (ii) the Internet of BioNanoThings, and (iii) quantum communications.

NEW FEATURES OF VEHICULAR IOT APPLICATIONS

During the recent years, the intensive deployment of low-cost wireless sensors with computing, and storing resource gives vehicles powerful information processing abilities to optimize driving decisions and enhance traffic safety [1]. With the improvement of the ability of vehicles to perceive their surroundings and communicate with other roadside utilities, the vehicular network is evolving towards the massive machine type of communication (mMTC) vision. Beyond-5G (B5G) is a promising technology to provide ubiquitous connected vehicle-t- -everything (V2X) links, including vehicle-to-vehicle (V2V), vehicle-t- -infrastructure (V2I), vehicle-to-network (V2N), and vehicle-to-pedestrian (V2P) communications [2]. Table **1** lists V2X services and restrictions. Besides the traditional massive IoT features, the increasing driving automation demand relies heavily on the safety-critical services that are delivered through vehicular networks; thus, strict requirements of latency, and bandwidth, *etc*. are imposed on vehicular IoT. These requirements are even more harsh owning to the highly dynamic and spatiotemporal complexity of network topologies and fast-varying wireless propagation environment caused by the strong mobility of vehicles [1].

VEHICULAR IOT DEMANDS MORE THAN 5G

To build smart transport system, vehicles need to share a large amount of data to support applications, such as updating real-time road traffic situation and emergency information, referring 3D navigation map for path planning, and even automatic driving [3]. Although a majority of information is processed by

CHAPTER 7

Cloud/edge Computing and Big Data System with 6G

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Abstract: This chapter gives a systematic introduction to cloud/edge computing and big data system. Cloud computing provides the ability to use flexible and telescopic services for cloud users and could implement through various hosted services provided by the Internet. Edge computing refers to the open platform which uses the network, computing, storage, and application core capabilities on the side of the object or data source and provides the nearest end service to avoid the relatively long delay to reach the data cloud center. Big data technology refers to the analysis of potentially useful information from a large number of data. Analysis of big data can get hidden patterns, unknown relevance, customer trends, and other messages to ensure comprehensive data management. In addition, the speed of 6G is faster, and its service field becomes more extensive compared with the previous generation communication technologies, which makes 6G play a more important or extensive role in the future of the technology field and society. In this regard, the authors also analyze the effect of 6G on cloud/edge computing and big data system. According to the future users' demand for 6G and the characteristics of 6G itself, cloud/edge computing and big data system will play an irreplaceable role in achieving high efficiency and benefits.

Keywords: Big data, Cloud computing, Edge computing.

CLOUD COMPUTING WITH 6G

The Development and Characteristics of Cloud Computing

With the number of mobile smartphone users increasing rapidly, more and more users are accessing the Internet *via* mobile phones. Meanwhile, cloud computing affects mobile services by changing the structure of Internet services. Cloud computing is developing every day, which provides a dynamic circumstance of a

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technical nature [1] [2]. In this environment, Cloud computing creates innovative solutions and services. In the past three years, enterprises wanted to explore more efficient and valid paths for using their IT investment so that they can adopt cloud computing rapidly. Cloud computing provides the ability to use flexible and telescopic services for cloud users. In consequence of that, users do not have to install the computing resources on their systems. Cloud computing promises that it could provide cheap and flexible services for users. Meanwhile, Cloud computing allows small-scale organizations and individuals to manage services around the world. Nevertheless, although people have been researching a lot in this field, some open challenges still exist. To start with and to run the applications of cloud computing smoothly, the Internet connection must be robust, steady, and rapid. Cloud computing needs a high-speed network and big data handling capacity. However, network resources are not limitless, so running cloud computing normally is inseparable from planning network resources reasonably. In addition, cloud computing is unsafe in applications. The TCP/IP system of the Internet is not safe at present. The process of network applications has some disadvantages, such as spreading viruses or eavesdropping on data. Therefore, it is not completely safe to put all the individual or enterprise data into cloud storage.

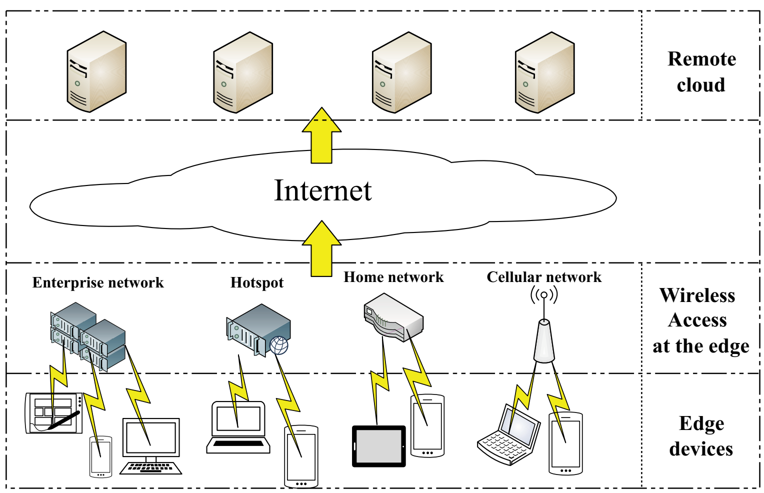

Fig. (1). Concept of Internet edge.

Cloud computing uses the concept of utility computing (Fig. **1**). It could implement through various hosted services provided by the Internet. Over the past decade, it has been developed with extremely fast speed. Its business model is the pay-as-you-go model of metered services as people are familiar with [3]. In this model, users only pay charges for what they use instead of paying for all the things. Meanwhile, this model could meet the extra requirements of services in real-time. Inspired by general low-cost, high-speed Internet, the capability of virtual processing, and the technology of parallel and distributed computing, the idea of cloud computing was proposed.

BASIC CONCEPTS OF CLOUD COMPUTING

Cloud computing is characterized by manageability, scalability, and availability. Besides, cloud computing has a variety of advantages such as convenience, service on demand, versatility, flexibility, stability, *etc*. Three service delivery models are primarily provided by cloud computing: infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). Also, Cloud computing provides four development patterns: public cloud, private cloud, hybrid cloud, community cloud, and virtual private cloud, which is presented in Fig. (**2**).

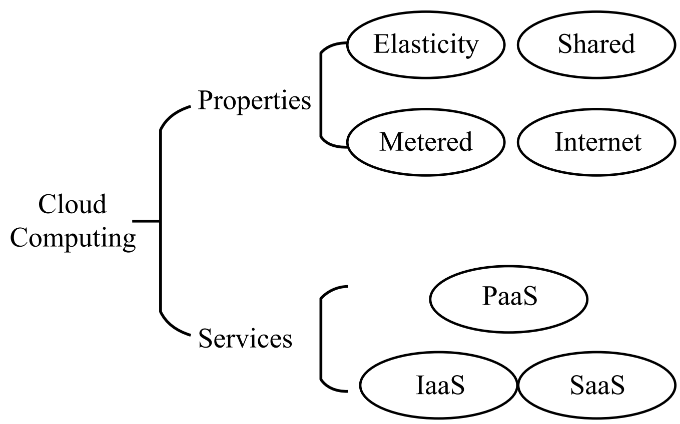

Fig. (2). Cloud computing infrastructure.

Private Cloud

In this kind of development pattern, cloud is owned by a private organization, due to cloud applications aim to serve its own business, information in cloud is only shared within its organization. Cloud applications may be internal or external and could be supervised by a third party or the organization [4]. A private cloud guarantees the performance, reliability and security at the highest level.

Community Cloud

Community cloud means basic facility of cloud is used by several organizations at the same time, and it supports specific community which has common concerns such as security requirements, assignments and so on. Community cloud resembles a private cloud. It has some additional functions and could provide services to the organizations that have similar demand type.

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Xianzhong Xie

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