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Discussion of Key Issues in Next Generation Wireless Network

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Abstract

The rapid development of mobile Internet has risen fully awareness of the importance of the wireless network as the infrastructure. In addition to bringing a convenient interactive experience, the wireless network injects vitality into the industrial production and society operating. After the landing of standards and the commercial implementation for 5G, the next generation wireless network is attracting greater attention in terms of goals and technologies. This article outlines the next generation wireless network from multiple dimensions such as requirements, scenarios, architecture, and indicators. The potential key technologies and future challenges are also discussed, which point out the further research directions.

Keywords

Next generation wireless network, requirements, architecture, challenges.

1. Introduction

Do not number your paper: All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. The wireless network has experienced five generations of development from 1980 to the present, and each generation brings revolution to the interaction mode and content. The first generation provided analog voice transmission. The second generation offered digital voice transmission. The third generation realized the evolution of core service from voice to data, and the fourth generation promoted the real explosion of the mobile Internet. In the fifth generation, the goal of wireless network is to meet the demand of large connections, high bandwidth, and low latency scenarios, and then penetrate into all areas of society [1].

However, the existing commercial wireless networks still have many shortcomings. On the one hand, the current communication objects are mainly concentrated in the space with limited height on the land. Although the satellite network is under construction, the system standards are still relatively independent, and the breadth of information interaction is not enough. On the other hand, characteristics for enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive machine type communications (mMTC), are mutually independent in most cases, and cannot be satisfied at the same time. In addition, the development of new interaction mode and content, such as extended reality (XR) and Tactile Internet [2], requires the support of a new architecture of the network.

Although there has been some works [3-5], the research on the next generation wireless network is still in early stage, and some aspects still need to be fully discussed. This article gives a comprehensively discussion of the next generation wireless network. Firstly, the requirements and scenarios are analyzed. Then the architecture and indicators of the network are presented. Next, the potential key technologies are highlighted. Finally, the challenges for the next generation wireless network are revealed.

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2. Requirements and Scenarios

The essence of the wireless network is for establishing a connection, breaking the data silos, providing services and creating values for people, whether for the 4G/5G or the next generation. However, the "connection" in the future will highlight the characteristics of "depth", "wisdom", and "ubiquitous". The requirements and scenarios the next generation system will be a further expansion and upgrade of the current 5G requirements, which are shown in Fig.1 and summarized as follows:

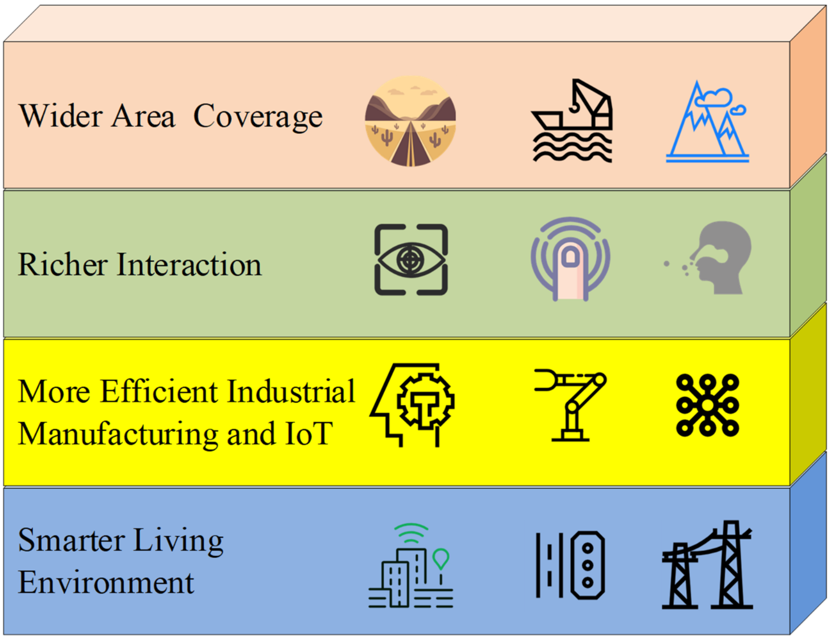

Fig.1 Requirements and Scenarios for next generation wireless network

2.1 Connection for Wider Area Coverage

From the perspective of communication network space coverage, the service of existing mobile communication systems based on terrestrial base stations is concentrated in a limited space with a limited height on the land surface. There are still huge blind areas such as deserts, mountains, and oceans that unable to share the convenience of the connectivity. The future mobile communication system will expand limited terrestrial applications to air applications, marine applications, etc. Through the establishment of an Space-Air-Ground-Ocean integrated network, ubiquitous connections can be achieved, and the digital divide will also be truly narrowed.

2.2 Connection for Richer Interaction

Hearing and sight are the mainly interaction modes of people-to-people and people-to-thing that provided by the existing mobile communications. As the sense of space and distance continuously reduced by information technology, the way of interaction will be further extended to touch, smell and even taste. The connection relationship between communication objects is no longer just perception, but also real-time control and response. The emerging network represented by the Tactile Internet is receiving more and more attention and attention. It integrates new technologies such as virtual reality, mixed reality and augmented reality, enabling users to interact with the virtual environment in a more natural way. Thus, a new mobile communication system is required to meet those demands.

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2.3 Connection for More Efficient Industrial Manufacturing and Iot

In the future, smart factories will carry out in-depth control and refined operations from multiple dimensions such as production plan release, material distribution, standard operations, and quality tracking, which lead to higher requirements for the timely, accurate and reliable transmission and interaction of on-site information. On the other hand, a vast number of wireless nodes will not only bring higher connection density, but also bring unprecedented challenges to energy consumption. Therefore, green and energy-saving communications are particularly important and urgent. The commercialization of 5G has made some indicators improved compared with previous generation systems. But in the foreseeable future, the performance and energy consumption requirements will not be satisfied well for the fast-growing connections in industrial manufacturing and IoT.

2.4 Connection for Smarter Living Environment

With the development of urbanization and the construction of metropolitan areas, the future travel appears in multiple spatial circles include urban interiors, metropolitan areas, urban agglomerations, and across non-neighboring provinces, with massive populations and complex structures. Intelligent transportation will realize in-depth vehicle-road coordination, meet more advanced autonomous driving application scenarios, and serve various fields such as urban transportation, highways, high-speed railways, and airport passenger transportation. By building an integrated network of intelligent traffic management, intelligent dynamic information services and intelligent vehicle control, people can enjoy more convenient, safer and personalized travel. Furthermore, the next generation network will penetrate into various aspects of the human living environment, which help not only the digitized and intellectualized reconstruction of traditional infrastructure such as water, electricity, gas, and roads, but also the construction and management of smart cities as new an infrastructure.

3. Architecture and KPIs

The architecture of the future network is shown in Fig. 2. As can be seen, four types of networks (space network, air network, ground network, ocean network) are established and together form an integrated network.

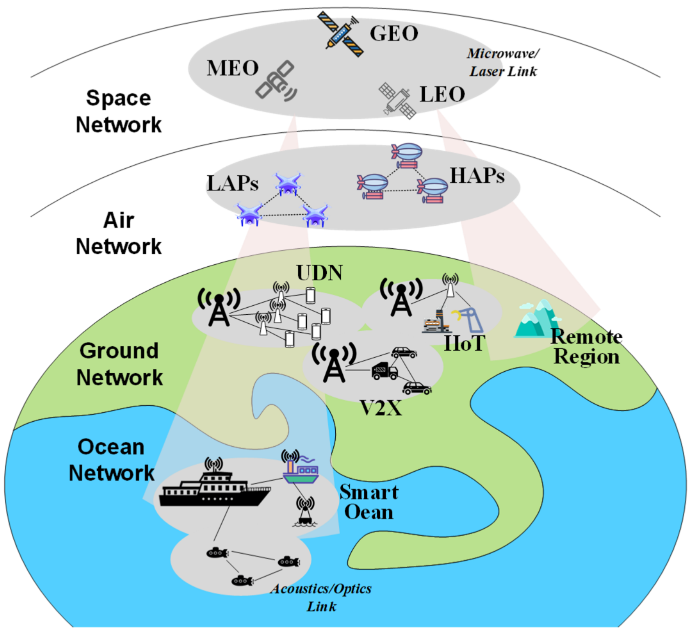

Fig. 2 Architecture of next generation wireless network

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The space network is composed of satellite communication systems distributed in different orbits, include geostationary-earth-orbit (GEO) satellites, medium-earth-orbit (MEO) satellites, and low-earth-orbit (LEO) satellites. As the orbital height decreases, the transmission delay and loss of the satellite communications are reduced. Satellite communications in lower orbits can support higher-speed communications services, but at the same time, more satellites are needed to achieve wide-area coverage. The air network mainly includes the low altitude platforms (LAPs) represented by the unmanned aerial vehicles (UAVs), and the high-altitude platform (HAPs) represented by the balloons. The LAPs and HAPs not only can provide the mobile cellular coverage, but also reduce the wired communication links between the base stations. The ground networks or the terrestrial networks are still the main providers of future wireless connection services. However, the frequency band will expand from the Sub-6G, millimeter wave of the 5G to terahertz (THz) band, to meet the transmission service requirements with the peak rate as high as 1Tbps, and the delay as low as 10 us. In addition, the terrestrial network will be a heterogeneous network in the future, including specific forms such as the ultra-dense network (UDN), the industrial internet of things (IIoT), and the vehicle to everything (V2X). The ocean network is divided into the maritime network and the underwater network. As an extension of the terrestrial network, the maritime network uses radio electromagnetic wave as the main means for the communication between ships, drilling platforms, buoys, and island stations. The underwater network is an important manifestation of the 3D mobile network, and an important means to achieve ubiquitous connectivity. The low-frequency electromagnetic communication, undersea acoustic communication, and undersea optical communication are the primary communication methods for the submarine targets, underwater vehicles, and seabed bases. Besides, the buoys or autonomous underwater vehicles (AUVs) can be used as the gateway nodes to realize full connection between undersea and other networks.

The key performance indicators (KPIs) for the next generation wireless network is summarized in table 1. One can see that the performance of next generation wireless network has a comprehensive improvement compared to 5G.

Table 1. Comparison of KPIs between 5G and next generation

Indicators	5G	Next generation
Data Rate	Peak: 20 Gbps, Experienced: 0.1~1Gbps	Peak:1 Tbps, Experienced:1~10 Gbps
Latency	1ms	10us~100us
Traffic Capacity	10 Mbps/m2	1-10 Gbps/km2
Connectivity Density	106 devices/km2	109 devices/km2
Mobility	500km/h	1000km/h
Spectrum Efficiency	30 bps/Hz	100 bps/Hz
Network Energy Efficiency	100bits/J	200bits/J
Jitter	NS	1 usec

4. Potential Key Technologies and Challenges

4.1 Potential Key Technologies

4.1.1. Air Interface Technologies

Orbital angular momentum (OAM): Orbital angular momentum is an important physical quantity in another dimension of electromagnetic waves in addition to frequency, phase and space. It is embodied in that electromagnetic waves have a spiral characteristic in a plane perpendicular to the direction of propagation. OAM multiplexing technology uses the orbital

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angular momentum of electromagnetic waves as a new degree of freedom to obtain extremely high transmission capacity and spectral efficiency. Based on the orthogonality of the OAM mode, the multi-channel signal is modulated on different OAM modes, thereby providing the possibility to construct a super-capacity wireless communication system. [6] has already demonstrated a 32Gbs orbital angular momentum millimeter wave communication link.

Super massive MIMO: Multi-antenna technology, especially MIMO, has played a key role in modern wireless communication by significantly improving the system capacity through spatial multiplexing and diversity. In the next generation network, it is expected that MIMO with super massive scale of antenna units will be built to achieve ultra-high performance in spectrum efficiency, network throughput, and latency reduction.

Holographic beamforming: Holographic beamforming is a new beamforming technique that different from traditional phased arrays. By using the hologram to manipulate the antenna array to send electromagnetic signals in a specific direction, high gain directional narrow beam and higher spatial resolution can be achieved. Besides, devices of holographic beamforming have advantages in size and weight.

4.1.2. Cross-band Communication Technology

Terahertz communication: Higher frequency bands will bring more abundant spectrum resources. In next generation of wireless networks, terahertz communication will be introduced to achieve Tbps level data transmission. Terahertz communication has obvious advantages over existing communication in terms of bandwidth, beam directivity, and antenna array integration [7]. At the same time, the atmospheric window could happen in terahertz frequency band, which is suitable for satellite communication.

Optical communication: Optical communication will play an important role in next generation of wireless network, especially for laser and visible light communication. Compared with other wireless communication methods, optical communication has outstanding advantages in terms of spectrum resources, capacity, and security. As the layout of the light source can be combined with the existing lighting facilities, there is no worry about the electromagnetic radiation. Optical communication is also a potential means in underwater communication.

Acoustic communication: Acoustic communication is the most widely studied technology in underwater communication. Acoustic waves in water can be used as carriers to transmit information, which has the superiority of long transmission distance and slow attenuation compared to electromagnetic waves. With the support of advanced coding, modulation and anti-multipath technologies, underwater acoustic communication has evolved from point-to-point to multi-node network communication [8], which is a critical way towards future wireless network.

4.1.3 New Security Technologies

Quantum communication: Quantum communication is a new communication method that uses quantum superposition state and entanglement effect to transmit information. The quantum key distribution can realize the secure quantum key sharing between two communication objects by means of the transmission measurement of quantum superposition state. It will provide highly secure and confidential communication for the next generation wireless network.

Blockchain technology: The blockchain is essentially a decentralized distributed ledger database, which can safely register and update transactions without the intervention of the center. It enables the entire network entity to safely access critical data, and an unmodifiable distributed ledger containing all data is shared among all related entities, thereby ensuring the security of the entire communication process. In addition, blockchain technology can improve spectrum efficiency, by replacing the centralized database in the spectrum sharing system.

4.1.4 Other Important Technologies

Cell-free communication: Current user movement between cells in dense cellular networks need frequent handover operations, resulting in throughput degradation and latency. Cell-free communication will make full use of spatial freedom, large-scale antenna technology, and aerial unmanned base stations to provide wireless connections for users within the coverage of multiple base stations at the same frequency, achieving truly seamless movement and improving user experience [9].

Artificial intelligence: Artificial intelligence (AI) uses data learning and training to realize the self-update and self-evolution of the model. It will deeply participate in the construction of the next generation wireless network, from back-end in management, to front-end in resource allocation [10]. The transformation to wireless network by AI will be comprehensive, instead of a partial application. AI is one of the key technologies for future "autonomy network".

4.2 Challenges

4.2.1 Interface Design

The next generation wireless network includes different means such as terahertz, light, underwater sound, and even molecule and quantum. The encoding methods, transmission rates, and carriers of each means are very different, and so as to the network protocols. When terminals using different means need to be connected, the interface design is critical to meets the requirement of interaction.

4.2.2 Management of Heterogeneous Network

As described above, next generation wireless network is constituted of four geographically distributed networks with great diversity, such as space network and ocean network. The internal sub-networks at the same geographical position, such as V2X and IIoT, also present an obvious distinction by diverse applications and terminals. The need to effectively integrate networks with different characteristics will put forward higher requirements for network management, mobility management, spectrum resource allocation, and so on.

4.2.3 Security and Privacy Issues

The next generation wireless network must be a highly automated and autonomous network due to its complex characteristics. The amount of interaction information between people and people, people and things, things and things can be quite extensive. With the introduction of AI in the wireless network, massive amounts of data that discarded in the past will be collected, stored and analyzed, which involves great risk. Meanwhile, the existing quantum communication and blockchain technology are still imperfect. Once the network is breached, a series of problems will arise such as privacy leakage, financial loss, traffic paralysis, and even social failure.

4.2.4 Cost-effectiveness

Different from the 5G network mainly supported by ground base stations, the next generation wireless network is three-dimensionally deployed, which includes access points and networks in the space, air, and underwater. Although full coverage is achieved, a huge and expensive effort need to be made in network laying and operation, maintenance and repairs of equipment, and energy supply. Besides, the price of components in terahertz band is also expensive, which may bring difficulties in providing users with high-quality, low-cost service.

5. Conclusion

In this paper, the key issues in next generation wireless network are discussed in details. We also proposed a network architecture from the space to the ocean. As can be seen, the goals of the next generation are forming connections for wider area coverage, richer interaction, more

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efficient industrial manufacturing and IoT, and smarter living environment. Potential key technologies such as OAM, holographic beamforming, and terahertz communication, are presented for achieving those goals. It should be noted that, only after solving problems such as interface design, privacy and cost-effectiveness, can we make progress towards the vision of the next generation wireless network.

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