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6G Network – A Literature Review

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Abstract - *Telecom Operators have commercially deployed the 5G telecommunication systems, providing 5G telecom users with the latest services, improved customer experience, and various industrial opportunities like Private 5G. There are few gaps and challenges in 5G services, so various international industrial, academic, and standards organizations have collaborated to research sixth generation (6G) wireless telecommunication systems. Much research, white papers, and survey papers have been published worldwide, which aim to define 6G in terms of industrial and user requirements, various application scenarios, and future technologies. The International Telecommunication Union for Radio has finalized its vision on 6G and how 6G should function; the related international discussions are still in progress. This paper provides the challenges of 5G and benefits and future vision for 6G, futuristic technical requirements, and telecommunication application scenarios, covering the visualization of 6G. Later, we will discuss the 6G network architecture and its latest technologies. To close with, we will discuss the lessons learned related to 6G networks.*

Key Words: 6G (Sixth Generation), mmWave (Millimeter wave), 6G application scenarios, 6G network architecture, 6G key technologies, 6G trends.

1.INTRODUCTION

With the rapid development of Telecommunication applications, communication technologies undergo revolutionary changes every decade. Up till today, the development of telecommunication systems has undergone various generations. Starting the first generation (1G) analog communication systems to fifth generation (5G) digital communication systems, each generation incorporates higher frequencies, larger bandwidths, and higher data rates. Since 2019, 5G has been commercialized by US Telecom operators, employing sub-6 Giga Hertz and millimeter wave (mmWave) bands, with a peak rate of 20 Gigabits per second. From the architecture's perspective, telecommunication systems have evolved towards more modern antennas, Service advancements, and Advanced multiple access technologies, as shown in Fig. 1.

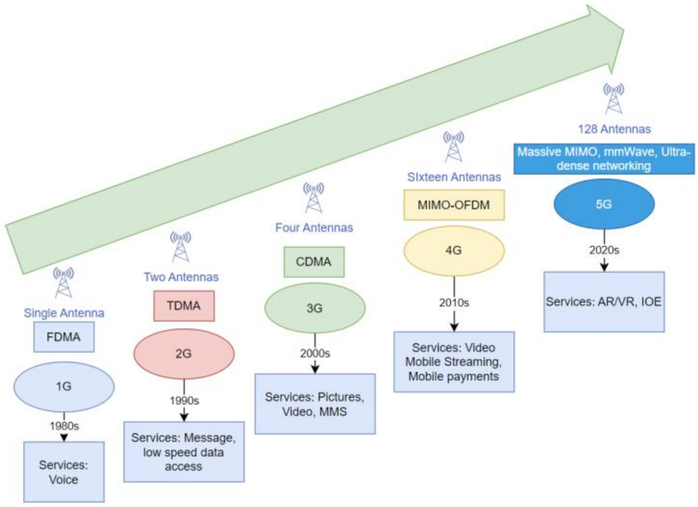

Fig1. 1G-5G: Antennas, multiple access technologies, and services.

Today the 5G base stations exploit massive MIMO (Multiple-input multiple-output) [1], mmWave, and UDN (Ultra-dense networking) technologies [2], supporting up to sixty four transceivers with more antenna elements. Commercial 5G base station products using 128 antennas are mature, and massive MIMO base stations will have up to 384 antennas. In addition, 5G Networks supports augmented reality (AR), Internet of Everything (IoE) and virtual reality (VR).

1.1 5G Limitations and Challenges

Although 5G offers significant improvements over fourth generation (4G) communication systems, it still has several limitations. Currently, there are applications and services requiring better communication performance that is beyond 5G's capabilities, such as global coverage, ultra-high data rate transmission, ultra-low latency, ultra-dense connection, high precision positioning, ultra-reliable and safe connection, low power consumption, high energy efficiency (EE), as well as ubiquitous intelligence. To address these limitations, we need 6G. Ultrahigh data transmission rate needs to be significantly improved so that the peak data rate can reach Tera bits per second level, supporting services such as ultra-high-definition video and telemedicine.

At low transmission speed, the end-to-end (E2E) latency needs to be less than 1 millisecond, while at high speed, the latency should reach the microsecond level. The connection density should reach 108 devices/square-kilometer, meeting the needs of connecting industrial equipment and dense crowd. Additionally, the positioning accuracy should be improved to achieve an outdoor centimeter level and an indoor sub-centimeter level for high-precision positioning. A series of novel applications, such as tactile Internet, vehicle to everything (V2X), and wireless data centers, have higher requirements for reliability. Energy consumption is also a vital issue for many applications. Consequently, power consumption must be optimal, and the network EE needs to be increased 100-fold—moreover, many intelligent applications prompt communication systems to have a higher intelligence level.

1.2 Recent Developments

The evolution of wireless communication systems is an iterative process every ten years. The research on 6G is in the early stage of exploration, and a collection of countries and standardization organizations worldwide have announced their plans for 6G research. The Federal Communications Commission (FCC) opened the terahertz (THz) spectrum in the United States for 6G research. It proposed developing 6G based on “mmWave + THz + satellite” in Mar. 2019. In Oct. 2020, the Alliance for Telecommunications Industry Solutions (ATIS) led the formation of the NextG Alliance, a trade organization specializing in managing 6G development in North America. The 6G Smart Networks and Services Industry Association (6G-IA) was set up in Europe to provide next-generation networks and services. As an international organization for standardization, the International Telecommunications Union (ITU) released the initial schedule of 6G research in Feb. 2020. Research and development for the 6G and its corresponding technical propositions will be completed soon.

2. LITERATURE REVIEW

With continuous application and technical requirements development, the primary application scenarios in the current 5G are expected to be highly enhanced and expanded in 6G. Novel application scenarios, such as digital twins, communication, computing, and sensing integration, and distributed AI applications, are also envisaged in 6G. It is necessary to revolutionize the entire communication network at the architecture level to enable the network to provide diverse applications and reduce cost and energy consumption.

From 1G to 5G, communication network architecture is developing in the direction of modularization, softwareization, virtualization, and cloudification. Key network architectures in 5G include network slicing, network functions virtualization (NFV), software-defined network (SDN), and service-based architecture (SBA), which make the network more flexible and improve multiple aspects, including application services and costs.

However, there are still many challenges in deploying these network architectures in real networks. For the sake of application requirements, technical requirements, and cost considerations, the 6G network architecture will integrate novel network architectures and technologies based on the further evolution of the 5G network architecture, moving towards the following five directions: 1) 3D multi-network integrated; 2) Secure and trustworthy; 3) Integration of communications, sensing, and computing; 4) Green, flexible, and lightweight; 5) Natively intelligent.

Fig. 2 summarizes the development trends of the 6G network architecture. In this section, we will introduce each trend and then comprehensively follow the 6G communication network architecture.

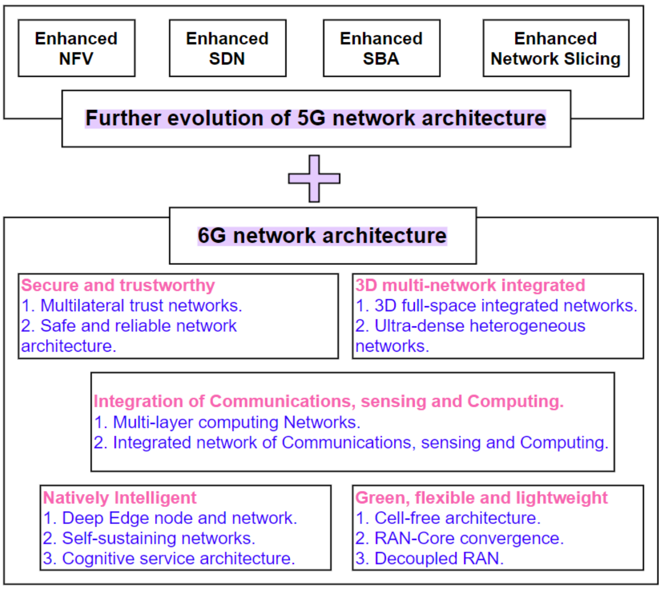

Fig2. 6G Network development trends.

Development Trends of the 6G Network

1) 3D Multi-Network Integrated: 5G networks and previous generations of communication networks have mainly focused on deploying network access points to connect telecom devices on the ground. However, communication in remote locations is limited by low wireless coverage. In addition, systems that rely only on terrestrial communication networks have poor robustness and cannot provide timely communication during various disasters. The future Sixth Generation network will be a 3D full-space network deeply integrated with the ultra-dense terrestrial heterogeneous communication network.

2) Trustworthiness and Security: It is critical to achieve the requirements of various applications in the 6G communication network, including security and trustworthiness. On the one hand, the fusion of communication technologies with data and industrial operation technologies and the marginalization and

virtualization of facilities will guide a more blurred Sixth Generation network security boundary. Therefore, the traditional existing security model can no longer meet the requirements of the 6G security and trustworthiness [3]. On the other hand, with the change of the network architecture and the emergence of new services and new terminals, 6G networks will face novel security threats [4], [5], e.g., the data privacy issue, security risks of models and algorithms, as well as software or network vulnerabilities. The new Sixth Generation network architecture must be based on a more inclusive multilateral trust model, considering security issues at the beginning of the network design to achieve endogenous security and trustworthiness.

3) Integration of Communications, Computing, and Sensing: The 5G network architecture introduced mobile edge computing to reduce service latency and backhaul costs and alleviate traffic pressure. The communication, computing, and sensing functions in the 6G era will be deeply integrated to achieve the vision of complete applications and meet the requirements of lightweight and dynamic computing. Individual network nodes will have the functions of sensing, data transmission and computing providing superior services for various 6G application scenarios.

4) Green, Flexible, and Lightweight: Beyond the flexible network slicing of 5G, the network architecture of the Sixth Generation will become flexible, greener, and more lightweight, using cell-free architecture, the RAN Core convergence architecture, fully decoupled RAN architecture, and other promising techniques.

5) Natively Intelligent: The 5G core network has added the network data analysis function (NWDAF), which improves the network's data collection and analysis capabilities. However, due to limited data sources and a lack of data privacy protection and support for external AI services, the NWDAF cannot provide native AI support for the network. With the fast development of AI technologies (including DL [6], reinforcement learning, and federated learning) and the enhancement of the comprehensive potential of network nodes, such as telecommunication, computing, and sensing, The Sixth-Generation networks will support native Artificial intelligence, which has two different aspects [7], i.e., AI for Network (AI4Net) and Network for AI (Net4AI). On the one hand, novel Artificial Intelligence technologies are used in network planning, system maintenance, and network optimization, enabling self-sufficient operation, self-maintenance, and self-healing capabilities. On the other hand, the network with native intelligence will be able to provide more intelligent AI application services for users. Currently, more and more research interests are focused on natively intelligent network architecture, such as cognitive service architecture, DEN2 (Deep edge nodes and networks), SSNs (Self-sustaining networks) and digital twin-based network architecture. These futuristic technologies will help to achieve natively intelligent 6G networks.

Key Technologies in 6G

In this section, the concepts, applications, developments and challenges of these potential 6G key technologies will be discussed as shown in Fig3.

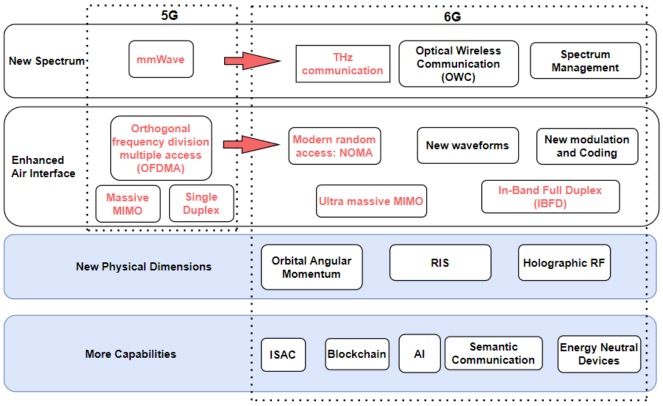

Fig3. 6G Key Technologies.

1) New THz Spectrum: The rapid growth of video services and the emergence of new applications, such as Virtual Reality, Augmented Reality, autonomous driving, etc, have led to the demand for high data rate transmission and low latency services [8]. Most existing 5G technologies are stuck in the mmWave band and can only achieve average rates of up to 1 Gbps [9]. Facing non-negligible spectrum congestion problems, more than 5G communication systems are required to meet the rapidly increasing demand for 6G data services. THz is the last spectrum gap between mmWave and optical frequency ranges. THz is characterized by high frequency, large bandwidth, high path loss, severe molecular absorption, abundant diffuse scattering, and extremely narrow beam. Although there is still some distance from practical applications, THz is regarded as the most promising technology for 6G because of its ability to provide robust support for ultra-high data rate services [10].

2) Modulation and New Waveforms: 6G enhancements pose new ideas for waveform design and modulation, and they are expected to achieve data rates reaching Tbps (terabits per second), enable high-density connections, offer a wide range of coverage, and facilitate the delivery of more intelligent and secure services. The unique characteristics and requirements of application scenarios need to be considered when developing waveforms, which are closely associated with the performance of the telecom system. More existing waveforms are detailed in [11]. In order to flexibly adapt to the possible application scenarios of the 6G communication system, new waveform designs are expected to provide better performance in a targeted manner. Compared with low frequency, the potential high-frequency scenarios of 6G lead to more challenges, such as significant transmission path loss and the need for efficient high-frequency broadband power amplifiers. In [12], a single-carrier system

with a low peak-to-average power ratio (PAPR) was studied to address these challenges. For high mobility scenarios, waveforms in the transform domain, such as OTFS (Orthogonal time frequency space), can describe information such as delay and Doppler more accurately [13].

3) New Coding: Efficient channel coding technology can improve the capacity, reliability, and quality of the services in the communication systems. As per Shannon's theory, error-correcting codes (ECCs) realize a leap from algebraic coding to probabilistic coding, significantly improving communication systems' capacity, reliability, and quality of service [14]. The probabilistic codes approach or even achieve the Shannon limit by introducing randomness and sparsity in coding and propagating soft messages based on factor graphs in decoding. Among them, the most representative ECCs are Turbo codes [15], low-density parity-check (LDPC) codes [16], and polar codes [17], which are the standard codes for 4G data channels, 5G data channels, and 5G control channels, respectively. Though their de-facto decoding algorithms and implementations are different [18], they are all derived based on Bayes' theorem and are competitive for 6G ultra-high speed and ultra-low power consumption requirements.

4) Modern Random Access: Long Term Evolution (LTE) employs OFDMA, and 5G New Radio uses optimized OFDM-based waveforms and multiple access, which are orthogonal multiple access (OMA) technologies. The connection density of 6G communication systems will increase tens of times compared to that of 5G. NOMA is recognized as the most encouraging modern random access technology for 6G, meeting the requirements of low costs, high dependability, low latency, enormous connectivity, and high throughput in the complex and variable scenarios of 6G communication systems [11], [4], [3], [5], [19].

5) New Physical Dimensions: To survive with the prospering development of massive IoT, Sixth generation communication is expected to achieve a higher data rate using the existing spectrum resources. In addition to relying on traditional air interface technologies, such as multiple antennas, modulation, coding, and duplexing, finding new physical dimensions and transmission carriers to achieve revolutionary breakthroughs can also help.

6) Reconfigurable Intelligent Surfaces: RIS is a surface composed of many programmable 2D meta-materials of sub-wavelengths, each capable of dynamically, intelligently, and independently manipulating incident signals to obtain the expected reflected signal or transmission signal. Compared with the radio transmitters with traditional structures, RIS technology is cost effective, energy efficient, and trouble-free deployment, which can remarkably increase network transmission rate, amplify signal coverage, and improve energy, frequency and cost efficiency [3], [20], [21], [22].

7) AI: Artificial Intelligence has developed rapidly and has overwhelming advantages in the telecom sector. ML and DL are essential subsets of AI that can learn and develop over time. AI technologies have high robustness, adaptive learning ability, and strong understanding and reasoning ability, which equip them with great potential in many elements, especially for scenarios where significant amounts of data are available for training. The telecom system will enable more significant throughput, lower latency, a greater number of connections, and more intelligent services.

8) Blockchain: The blockchain technique was first proposed for cryptocurrency in 2008. Using distributed databases connected by hash pointers, blockchain has the characteristics of decentralization, transparency, anonymity, immutability, traceability, and resiliency. Because of the flatter structure and more frequent data transformation in the 6G network, the traditional centralized security authentication and access control mechanisms will no longer be fully applicable. Blockchain, considered one of the essential technologies for 6G communication systems [3], [20], [5], provides a promising solution to the trust security-related issues among distributed and heterogeneous network devices and infrastructures. In the 2018 Mobile World Congress Americas (MWCA), the FCC drafted its vision for deploying blockchain in future Sixth Generation networks. In [23], blockchain-RAN (B-RAN) architecture was proposed for secure radio access in a decentralized system.

3. CONCLUSIONS

The Sixth Generation Network will promote intercontinental telecom services by steering in new telecom application scenarios, bringing fresh telecom experiences, and supporting growth. This paper has critically appraised the recent solutions disseminated in the relevant literature, focusing on the associated developments. This paper has also discussed the vision, trend, and technology for the 6G Network, indicating that 6G will be developed in multiple directions, aiming for global coverage, relying on a vast range of spectral bands, attractive applications, stimulating all human senses, and hinging on pervasive digital intelligence and robust security. Various research directions have also been analyzed from the perspective of fundamental research, green networks, and the associated critical technologies developed for supporting the proposed 6G vision.

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