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A Survey on 6G Networks: Vision, Requirements, Architecture, Technologies and Challenges

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ABSTRACT

Our society is increasingly dependent on digitization. For example, different types of physical and virtual objects are connected to the Internet of Things, all services are digitized, and the number of connected devices continues to grow, which leads to the exchange of large amounts of data. The current communication network 5G cannot meet the needs of the future. Therefore, the demand for high-speed mobile communications is essential to better prepare for the arrival of new services and emerging applications. Namely, extended reality, holographic communication, sensory internet, human digital twin, smart city and industry, etc. These new use cases are applied in many different areas. For example, health, autonomous transportation, climate, network security, etc. Therefore, the research of the new generation network 6G has begun to bear the limits of 5G and deal with new challenges. This paper conducts a related investigation on the sixth-generation communication network. First, the vision, requirements, and expected application scenarios of the 6G network are introduced. Then, it describes the integration of intelligent architecture and space, air, ground, and sea networks. Subsequently, the most important potential key technologies needed for the future sixth-generation were exposed and analyzed. Finally, the main research activities carried out are introduced.

1. INTRODUCTION

In recent years, the development and emergence of technology have changed and improved many systems in various fields. The wireless communication systems are mandatory and indispensable for the innovation of new and efficient technologies and the advancement of existing technologies. Therefore, researchers and experts should consider the needs of communication systems to explore the future computer society and improve the research field of next-generation mobile technology [1].

With the full standardization and deployment of 5G systems in several countries [2], 5G uses revolutionary technologies and has been used in many fields thanks to its reliability, high-quality data rates, and energy efficiency. However, considering the current and emerging advances in wireless communications, 5G may not be able to meet future needs for the following reasons:

(i) It is expected that the future mobile network will be an ultra-large-scale, highly dynamic and extremely complex system, such as a large number of heterogeneous devices in the Internet of Things. However, the current wireless network architecture is usually fixed, and the optimization task is defined as meeting specific and identified challenges and services. Therefore, the popular manual-based optimization and configuration tasks are no longer suitable for future networks [3, 4].

(ii) Given the growing deployment of IoT devices, there is a particular need to further increase the connection density and coverage of 5G-enabled IoT networks [5].

(iii) IoT emerging services such as telemedicine, mind-computer interface, and extended reality will change the original 5G service category. To provide such technologies for mobile devices, future mobile networks must simultaneously offer high transfer rates, high reliability, and low latency, which greatly exceeds the original goals of 5G networks [6, 7].

In response to the aforementioned challenges, 6G networks are expected to provide new service categories, use a new wireless communication spectrum, huge network capacity, ultra-low latency communications, and adopt new energy-saving transmission methods.

Therefore, research on 6G mobile communication systems has also begun. Cisco expects 6G systems to be commercially deployed before 2030, by which time there will be 14.4 billion connected devices [8].

Usually, it takes more than ten years for a new technology to be put into commercial use. Therefore, as mentioned earlier, we need to explore new 6G technologies and create new challenges for this topic.

The strength of 5G lies in its variety of services such as Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), Massive Machine Type Communication (mMTC), each offering high data rates of 1G bits/s for mobile connectivity, 99.99% reliability and millisecond latency for communications, and 1 million connections per Km^2 [9].

However, with the new emerging technologies, the demand in 2030 will be 100 times the current number and there will be new applications. New innovative technologies and devices are emerging for the Internet of Things (IoT) that send and share huge amounts of data, such as hologram technology, augmented reality, high-definition imagery, autonomous vehicles, and more. All this is increasingly generating colossal amounts of data, forcing us to think about new communication systems in various fields: health, transport, climate, cybersecurity, civil and military, etc. To implement these IoT services, future wireless generation networks should offer high transmission speed, high reliability and low latency that 5g systems do not.

All of this limits the original goal of 5G IoT. Therefore, there is an urgent need for a disruptive 6G mobile system whose design is suitable for the performance requirements of IoT applications and the accompanying technology trends.

The 6G system is expected to be an extraordinary revolution that is significantly different from other generations and will outperform the mobile Internet. Moreover, 6G is expected to strengthen ubiquitous AI services from the core to the end devices of the network. Consequently, AI will play an important role in the development and optimization of 6G architectures, protocols, and operations [10, 11].

In the literature, 6G mobile networks have been discussed in various papers, especially their vision, requirements, applications, potential solutions, and research challenges.

The main topics presented are 6G visions, applications, challenges, and requirements [11-15]. In addition, potential service classes and network architecture of 6G are analyzed in [14, 16-19], as well as key enabling technologies [20, 21].

In addition, various 6G technologies and ideas are explained and discussed from different aspects, e.g., holographic communication, intelligent communication, etc. As far as we know, most of the existing reviews on 6G do not cover all aspects of 6G networks, each paper covers only some aspects. Compared with the existing literature, the aim of this paper is to provide a comprehensive overview of 6G networks from various aspects, such as the reasons for the need of a new generation of mobile networks, the basic requirements for the realization of 6G networks, the recent research activities and application scenarios, the various key technologies, the expected future challenges and open issues in the 6G era.

For better understanding and studying 6G networks, we extend our present paper by introducing all the key points of 6G mobile communication. This work goes beyond the previously mentioned work and focuses on the fundamental aspects of 6G networks. Unlike existing work, it does not fully cover all fundamental aspects of 6G. Also, identifies 12 potential key technologies, including air-space-earth-sea integration, artificial intelligence, terahertz, visible light communication, orbital angular momentum, blockchain technology, etc.

The rest of the paper is organized as follows: The first section explains the 6G vision, requirements, and application scenarios, the second section describes the 6G network architecture, the third section explores the potential key technologies of 6G, and finally, the fourth section draws brief conclusions. The remainder of this paper is summarized in Figure 1.

2. VISION, REQUIREMENTS, AND APPLICATION SCENARIOS

2.1 Vision and requirements

5G has realized the evolution from the mobile Internet to the Internet of Things. While 6G will greatly increase the capacity and efficiency of mobile networks, it will further expand and deepen the scope of the Internet of Things, compatible with new information and communication technologies (ICT) such as artificial intelligence and big data. So as to realize an interconnected, intelligent and intelligent society of all things. It is expected that the new generation of mobile communication 6G will have the following characteristics (see Figure 2).

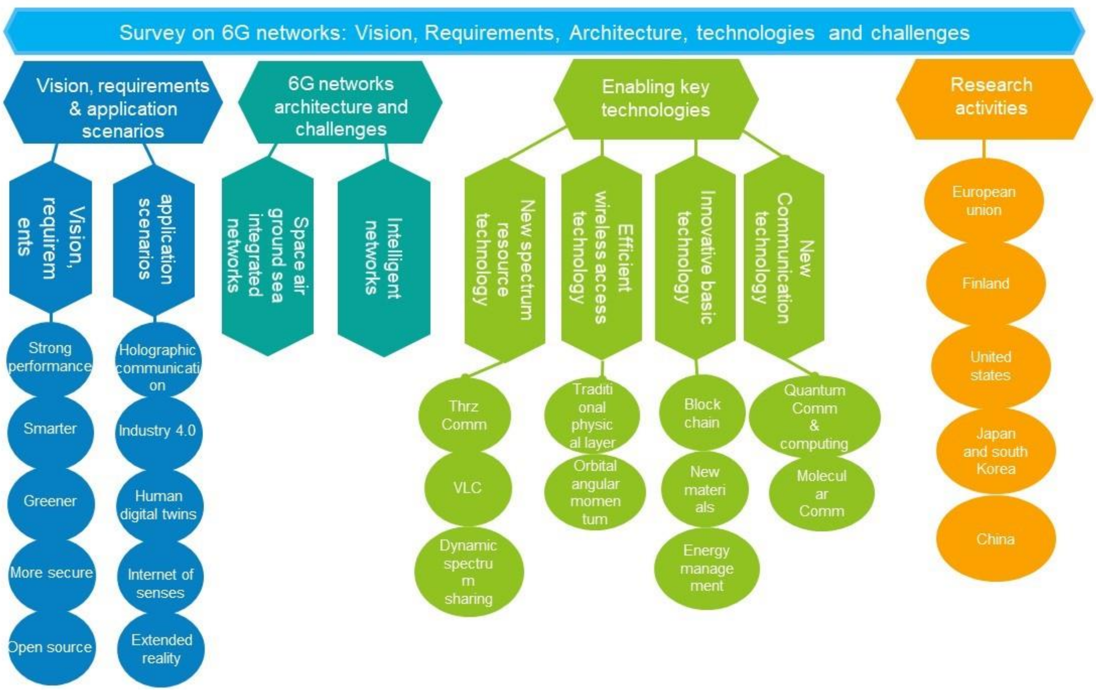

Figure 1. The structure and organization of the survey

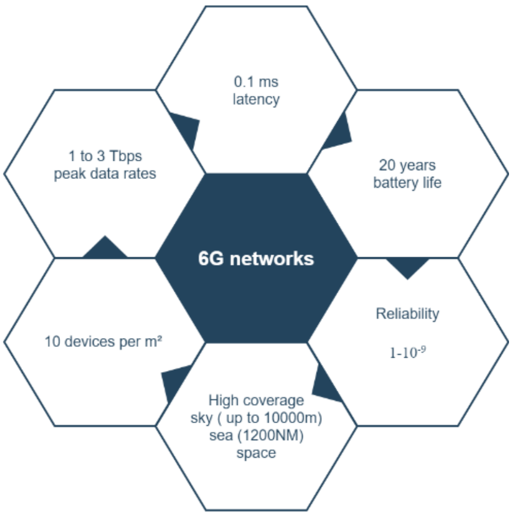

Figure 2. 6G networks requirements

(a) Strong performance

First, the realization of 6G communications networks requires higher frequency bands that can reach 1 to 3 terahertz (THz) and support the expected 6G use cases. Second, 6G latency is expected to be 0.1 ms and approach zero in some cases, such as future telepresence applications. Finally, the density of connected devices is expected to support 10 million connections per square kilometer. According to these three aspects, 6G performance will be improved by 10 to 100 times compared to the fifth generation.

(b) Smarter

To be more adaptive and robust, 6G should be self-managed. Therefore, the use of technologies such as artificial intelligence, machine learning and Big Data makes a lot of sense. First, to enable network nodes to have intelligent capabilities that are beyond human control. Then, to achieve comprehensive self-organization, self-learning, self-healing, self-aggregation, self-protection, and self-optimization of the network. In addition, artificial intelligence (AI) helps 6G deliver highly personalized networked intelligent services to individuals, enterprises, and other users to meet refined requirements.

(c) Greener

While improving network performance, the cost and energy consumption must be effectively reduced, and the energy efficiency of the system per bit must increase by tens or even hundreds of times. This is to be achieved by supporting the concept of green development and energy harvesting.

(d) Wider coverage

The coverage of 6G network will be extended from terrestrial to non-terrestrial networks (NTN). It will include air-space-ground-sea links that are closely interconnected to provide comprehensive global coverage. In the future, mobile network coverage will be as ubiquitous as sunlight and air.

(e) More security

By designing the physical signals, architecture, protocol, and applying new technologies such as blockchain and quantum communication, the security of the 6G network will be ensured and the reliability of communication and information security will be improved.

(f) Open-source

The 6G network will be decentralized and flattened. In addition, network equipment and terminals will realize platforms, software, and open-source, and create an open and fair ecological environment for competition.

2.2 Application scenarios

Given the above 6G vision and requirements, 6G application scenarios will be more extensive than those of 5G. The integration of new improved technologies will enable new applications and use cases. This section presents the envisioned applications to be implemented after the deployment of 6G networks.

(a) Holographic communication

One of the most important applications of 6G is holographic telepresence [22]. It will allow people to connect remotely and communicate with real 3D images of objects. Holograms would be used in many scenarios, such as social communication, entertainment games, office design, telemedicine, etc. 5G networks are not able to implement such scenarios with high reliability. Especially not with a high data rate, which could be up to 4Tbits per second and requires an extremely low latency of less than one millisecond.

(b) Industry 4.0

In the 6G era, Industry 4.0 will experience large-scale transformation. More and more smart factories will integrate the intelligent manufacturing mode of human, machine and material collaboration. Intelligent robots will replace humans and existing robots and become the main force of agile manufacturing, and industrial manufacturing will become more self-controlled and intelligent. The development of nanotechnology will provide a new way to monitor aspects and processes of industrial production. Nanorobots can become a part of products and control them throughout their life cycle. Industrial production, storage and sales plans will be analyzed in real time based on dynamic market data, guaranteeing maximum benefits for industrial production. To this end, 6G networks must provide high levels of reliability, very low latency, extremely high bandwidth, and emergency communications for complete coverage.

(c) Human digital twins

As for the applications of human digital twin, 5G will mainly realize functions such as human health monitoring and primary prevention of diseases. With the revolutionary advances in molecular communication theory and key technologies such as nanomaterials and sensors, this application will further advance the digitization of the human body and the intelligence of medical treatments.

By digitally reconstructing the human body in the real world, human digital twins will build a personalized "digital human" in the virtual world. Through health monitoring and management of the "digital human", human vital signs can be fully and accurately monitored, targeted therapies can be carried out, pathological diseases can be researched, and serious disease risks can be predicted, thereby protecting the lives of healthy people.

Human digital twins can become a reality in the 6G era, considering the requirements of high real-time and reliability, high-speed airborne Internet access with high mobility and complete coverage.

(d) Internet of senses

The Internet of the Senses is a kind of experience transmission network that connects multidimensional senses to enable intersensory communication. Through the networked infrastructure, people can fully mobilize vision, hearing, touch, smell, taste and even emotion, and realize the remote transmission and interaction of these important feelings. No matter where you are, you can experience music, art, sports and other skills in a real environment, you can try real food and skin care products without consuming real objects.

(e) Extended reality

In particular, 5G is said to be very effective especially for XR (AR (Augmented Reality), VR (Virtual Reality) and MR (Mixed Reality) services. Multiple technologies from emerging 5G communication systems are intertwined to achieve an immersive XR experience [23, 24].

With the latest technologies such as AR, VR and MR, large capacity content such as video and 3DCG (three-dimensional computer graphics) are to be provided as a service, so high speed and large capacity traffic is required. In VR and AR, the content needs to be changed according to the user's movement, so immediacy is also required.

The increasing adoption of XR applications will exhaust the 5G spectrum, especially for some useful use cases such as remote operations. A system with very low latency of less than 0.1 ms and high transmission capacity is needed. AR /VR cannot be compressed (encoding and decoding is a time-consuming process); therefore, the per-user data rate must reach the gigabit per second, as opposed to the more relaxed 5G target of 100 Mb/s.

This diversity of application scenarios is a unique feature of the 6G standard, whose full potential can only be unlocked through a strong network architecture and revolutionary technological advances as described in the next sections.

3. 6G NETWORK ARCHITECTURE AND CHALLENGES

Based on the 6G vision, requirements, and application scenarios, 6G networks are expected to realize the seamless wireless connectivity of society on a global scale, integrating communications, computing, navigation, and sensing. By integrating air, space, and ground in a three-dimensional aspect with intelligent and autonomous operation and maintenance. AI networks can provide intelligent hyperconnectivity with an ultra-high capacity, near-instantaneous, reliable, and unlimited capacity [16].

3.1 Space-air-ground-sea integrated network

The current terrestrial network cannot extend the depth of communications reach. At the same time, the cost of connections on a global scale is very high. To support full network coverage and high-speed user movement, 6G will optimize network infrastructure in air, space, ground, and sea, integrating ground-based and non-terrestrial networks to provide full and unlimited coverage.

Space networks based on satellite communications provide wireless coverage to unserved and uncovered areas by deploying satellites in dense orbit. Figure 3 depicts an example implementation of a space-air-ground integrated network, which shows the seamless coexistence of multiple services communicating with satellite networks and terrestrial networks.

The low altitude air network can be deployed faster and reconfigured flexibly to adapt to the communications environment and provide better performance for short-range communications.

The air network of the high-altitude platforms can be used as a relay node for long-distance communication to promote the integration of terrestrial and non-terrestrial networks. The terrestrial network will support the terahertz frequency band, and it's extremely small network coverage will reach the limit of improving system capacity. The network architectures "de-cellular" and user-centric ultra-dense network [11] will emerge as time demands. Submarine networks will provide coverage for military or commercial applications and Internet services for wide- and deep-area activities. However, it is debatable whether underwater networks can become part of the future 6G network.

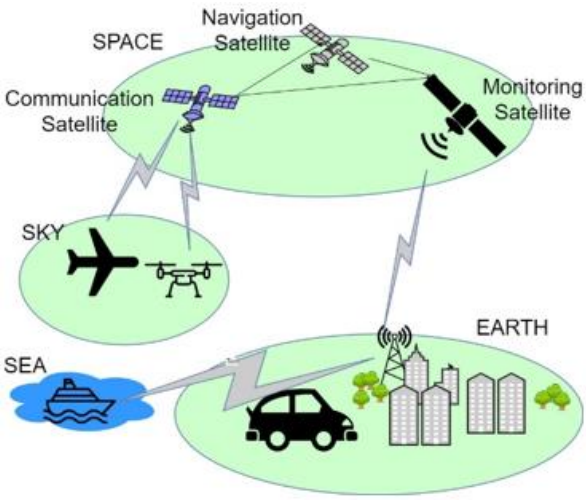

Figure 3. Non terrestrial networks architecture

3.2 Intelligent networks

To realize the vision of ubiquitous intelligent endogenous 6G mobile systems, the design of 6G architecture should fully consider the possibility of artificial intelligence in the network and make it an inherent feature of 6G.

In recent years, AI and machine learning (ML) have received a lot of attention in the industry. Initial intelligence has been applied to many aspects of 5G mobile networks, including applications at the physical layer (e.g., channel coding and estimation), applications at the MAC layer (e.g., multiple access), and applications at the network layer (e.g., resource allocation and fault detection). However, the application of AI in 5G networks is limited to the optimization of traditional network architectures, as they have not considered AI at the beginning of the architecture design. Therefore, it is difficult to fully exploit the potential of AI in the 5G era.

Initial intelligence is an implementation of perception-based AI that is unable to respond to unexpected situations. With the diversification of service requirements and the explosion of the number of connected devices, the network has become an extremely complex heterogeneous system. Therefore, there is an urgent need for a new kind of AI network with self-aggregation, self-organization, self-optimization, self-adaptation, and self-reasoning. Not only intelligence must be embedded in the whole network, but also the logic of AI must be embedded in the network structure, so that perception and reasoning can interact systematically, and finally all network components can be autonomously connected and controlled, and can autonomously detect and adapted to accidents. The use of centralized AI, distributed AI, edge AI, intelligent radio (IR), and the integration of intelligent wireless sensors and intelligent communication provide a strong guarantee for the intelligent 6G network.

4. ENABLING KEY TECHNOLOGIES

Through 6G reviews and investigations, statistics, and summaries of potential key technologies, we obtained 12 potential key technologies with the highest attention and word frequency. The corresponding advantages and challenges of each key technology are analyzed and summarized. See Table 1 for details.

Table 1. Potential key technologies of 6G networks

Key Technology	References	Advantages	Challenges
Novel network function technology			
Integration of air, space, ground and sea	[3, 11, 12, 18, 19, 25-33]	A full-coverage space with maximized capacity, dense ubiquitous connections, and high-density spectrum is formed	Scenarios that require low latency and high reliability Challenges
artificial intelligence	[3, 11, 12, 18, 19, 25-34]	Realize an autonomous and contactless novel network, adapting the network to ubiquitous application scenarios	Challenges in real-time, sharing, energy efficiency, etc.
New spectrum resource technology			
Terahertz Communication	[3, 11, 12, 18, 25-32, 34, 35]	It can meet the spectrum requirements of 6G's extremely high data transmission rate and has richer spectrum resources	THz spectrum propagation characteristics and limitations on the maturity of RF devices
Visible light communication	[11, 12, 18, 19, 25-28, 32, 33]	It has an ultra-wide band and it is widely available	Need to achieve breakthroughs in ultra-high-speed visible light transmission transceiver chips and modules
Dynamic Intelligent Spectrum Sharing Technology	[11, 12, 19, 25, 26, 28, 29]	Dynamic spectrum use is an important means to effectively improve the efficiency of existing spectrum utilization	It needs to be supported by a coordinated, rational and intelligent algorithm
Efficient wireless access technology			
Traditional technology enhancement	[12, 19, 25-27, 29, 30, 32, 33]	It satisfies more bandwidth, larger capacity, ultra-high data rate, and equipment deployment in a high-density manner	High frequency and high power make transceiver and antenna design, power efficiency design, and other technologies face challenges
OAM	[12, 25]	Multiplexing in parallel to achieve high spectral efficiency	The bottleneck of radio wave beam merging and separation
Innovative basic technology			
Blockchain	[16, 26-28, 30, 35, 36]	Provide a strong safety performance	Originated from challenges such as system security, data privacy, supervision, scalability, etc.
New materials	[19, 26-28]	Promote the innovation of batteries, devices and antennas	Solve the performance of key devices
Energy management	[18, 19, 26-28, 30, 32, 33]	Achieve efficient and flexible network operations	Need to integrate energy characteristics in the system
New communication technology			
Quantum communication and computing	[11, 18, 19, 27, 28]	Improve computing efficiency and provide strong security for 6G	Security issues and long-distance transmission issues under realistic conditions
Molecular communication	[11, 19, 27, 28]	Realize nano-scale communication and interconnection	Interface and safety assurance between electrical and chemical fields

From the number of the corresponding technologies in the second column of Table 1, it can be seen that the three major technologies of air-space-ground-sea integration, artificial intelligence, and terahertz communication are almost the principal key technologies of 6G. Among 18 research papers that we have studied, there are 15 articles related to these three technologies. It is inferred that this technology will mainly promote the development direction of 6G. Additionally, Visible light communication, dynamic intelligent spectrum sharing, physical layer enhancements, blockchain, energy management technologies are also highly concerned, and they will play a non-key role in the middle of 6G. Instead of orbital angular momentum, quantum communications and computing, new materials, and molecular communication are relatively less concerned, but they will have a great potential after breakthroughs in later technological challenges and greater demand emerge. Based on the presented potential key technologies, 6G network capabilities will be considerably improved by providing users with more impressive applications and services.

After analyzing and summarizing the relationship between future application scenarios, performance requirements, and potential key technologies, the mutual mapping relationship is noted (see Figure 4). It can be seen that to achieve the terabit-level peak rate requirements, the support of key technologies such as terahertz communication, visible light communication, dynamic intelligent spectrum sharing technology, and ultra-large-scale antennas are needed.

Among the above-mentioned 12 potential key technologies obtained from research and analysis, the two technologies of air-space-ground-sea integration and artificial intelligence have been condensed in detail in the second section of 6G Network architecture. Thus, this section will summarize the other key technologies.

4.1 New spectrum resource technology

Shannon's information theory will still be a relevant model basis for 6G networks. It suggests two main ways to increase system capacity: Increasing system bandwidth and improving spectrum efficiency [37]. At this point, Hertz communication, visible light communication, and spectrum sharing are mainly consistent technologies to increase 6G spectrum resources.

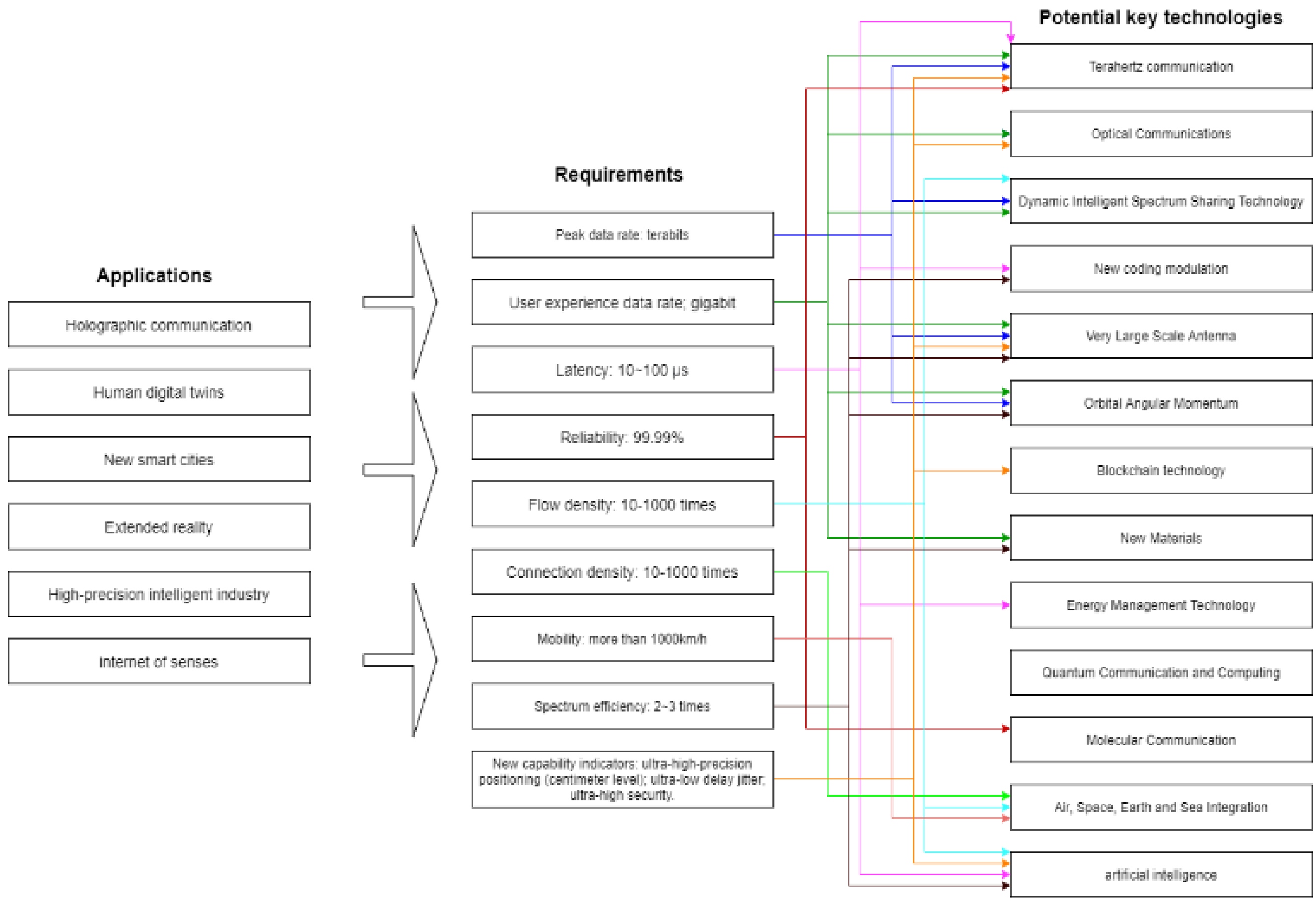

Figure 4. The mapping between 6G applications, requirements and potential key technologies

(a) Terahertz communication

The terahertz frequency band (0.1 THz ~ 10 THz) is very high and is not currently regulated. It is considered an ultra-wide frequency band in which extremely high-rate communication is possible, which can alleviate the current spectrum scarcity and capacity limitation. The narrow beam and short pulse of the terahertz band limit the possibility of eavesdropping and enable secure communications and high-precision positioning. The high penetration capability of the terahertz wave opens up broad applications in ultra-high-speed wireless communications and space communications. However, terahertz communication still has technical problems that need to be solved in terms of high-frequency hardware components, channel modeling and estimation, and directional networks.

(b) Visible Light Communications (VLC)

Another technology expected to reach 6G operates in the frequency range of 400 THz to 800 THz and uses visible light generated by light-emitting diode materials (LED) to transmit data. VLC uses ultra-high bandwidth to achieve high-speed data transmission and availability. It has several features such as communication, illumination, and positioning that are suitable for indoor hotspots and other scenarios. However, VLC also faces challenges such as modulation bandwidth limitation and nonlinear compensation.

(c) Dynamic spectrum sharing technology

The spectrum allocation mode of the existing system causes the spectrum resources to be fully occupied when the usage rate is low. Dynamic intelligent spectrum sharing technology allows unauthorized users to use the spectrum that is underutilized by the primary user in the temporal and geographical dimensions, which greatly improves the spectrum efficiency. To manage large-scale connectivity in 6G applications, distributed and efficient interference mitigation technologies must be deployed to improve system performance. Blockchain and Deep Learning technologies are effective methods for dynamic and intelligent spectrum sharing.

4.2 Efficient wireless access technology

4.2.1 Traditional physical layer technology enhancement

(a) New coding modulation

The coding and modulation technology of 6G requires targeted design and optimization of transmission characteristics of complex communication application scenarios such as terabit throughput, ultra-large channel bandwidth, high terahertz frequency band, ultra-high mobility and stability. In addition, through learning, training and evaluation, AI technology can find the best coding and modulation method suitable for the current system transmission environment to provide a solution that is not based on traditional theories.

(b) large scale multi-antenna

6G's large-scale 6G multiple antenna technology can achieve extremely high spectrum efficiency through space division multiplexing (SDM). It will improve energy efficiency and reduce delay by helping to overcome cell boundaries, and its ultra-high spatial resolution will support high-precision positioning and environmental awareness. The application of multi-antennas on a large scale requires a breakthrough in the technology of the antenna itself. Currently, more attention is being paid to the application of smart reflective surfaces in large-scale antennas.

4.2.2 Orbital Angular Momentum (OAM)

Multiplexing OAM technology uses the angular momentum of a series of orthogonal electromagnetic waves to multiplex multiple data streams on the same channel for greater spectrum efficiency and system capacity. OAM has a large number of orthogonal OAM modes that can be multiplexed/demultiplexed together, which provides a new way to expand the capacity of 6G networks. However, the application of OAM in wireless communication is still in the trial phase and still requires some research.

4.3 Innovative basic technology

(a) Blockchain

Blockchain is based on Distributed Ledger Technology (DLT), and its inherent features such as decentralized protection against change and anonymity make blockchain an ideal choice for various applications. It ensures strong security throughout the communication process of 6G network entities. The distributed control mechanism based on the blockchain can establish a direct communication link between network units, thus reducing the management cost.

Blockchain-based spectrum sharing can significantly improve the efficiency and security of traditional spectrum sharing. SM-MIMO and OAM multiplexing can significantly improve spectral efficiency by multiplexing many parallel data streams on the same frequency channel. Quantum communication and computing can improve computational efficiency and provide strong security guarantees for 6G [38].

(b) New materials

The communication system has achieved great success, but the performance of conventional semiconductor materials seems to have reached its limit, and there is an urgent need for materials with better high-frequency and high-temperature properties for ultra-high-speed communication. New materials such as gallium nitride, indium phosphide, silicon germanium, and graphene have been used to develop next-generation communication devices. In addition, liquid materials are being introduced in the design of frequency reconfigurable antennas to achieve greater flexibility. Metamaterials and metasurfaces can be used in a radio-controlled wireless environment. Software-controlled planar metamaterials can reduce interference by deterministically controlling environmental properties.

(c) Energy management

The demand for constant computing power for AI processing and the increasing popularity of IoT devices pose significant challenges to the energy efficiency of communication devices. Considering the expected scale of the 6G network, it is necessary to pay attention to energy consumption when designing the system. One way to do this is to use energy harvesting. This allows devices to power themselves, which is essential for off-grid operation, sustainable IoT devices and sensors, infrequently used devices, and long standby intervals. In addition, symbiotic wireless technology and smart power management technology offer potential solutions.

4.4 New communication technology

(a) Quantum communications and computing

6G must meet higher security requirements in various application scenarios. Quantum communication can provide strong security through quantum keys. In quantum communication, if an eavesdropper wants to observe, measure and replicate, the quantum state will be disturbed and the eavesdropping can be easily detected. Theoretically, quantum communication can achieve absolute security. Moreover, by combining quantum theory and AI, more powerful and efficient AI algorithms can be developed to meet the requirements of 6G. However, the high data transmission rate and demanding application scenarios pose challenges for wireless computing in 6G.

(b) Molecular communication

In biomedicine, bio-nano-IoT (Internet of Bio-Nano Things, IoBNT) can connect nano-devices (such as nano-robots, implantable chips, and bio-sensors) and biological entities. Molecular communication is a foundational technology of IoBNT. It uses biochemical molecules to communicate and transfer information between nano-devices. Moreover, the combination of IoBNT and human digital twins is a short-range wireless network composed of wearable monitoring devices/sensors and sensors in or on the body, which can provide a comprehensive solution for 6G electronic healthcare.

5. RESEARCH ACTIVITIES

Following the successful commercialization of 5G networks on a large scale, industry, universities, and research institutes around the world have officially begun research into the potential requirements for 6G services, network architecture, and potential enabling technologies in 2019.

5.1 European union

In September 2018, the White Paper "Intelligent Networks in the Next Generation Internet" was published. Based on this, the European Union will formulate the Strategic Research and Innovation Agenda (SRIA) for 6G and the Strategic Development Technology (SDA) under the Industry-College Research 2021-2027 Framework Project in the third quarter of 2020 and implement the strategy in the first quarter of 2021.

5.2 Finland

The Finnish government has taken the lead in establishing the flagship 6G project, which is led and managed by the University of Oulu in Finland in May 2018. The project members are mainly Finnish companies, universities, and research institutes. The College of Oulu in Finland is leading the organization of two 6G mobile summits in March each year. Key manufacturers and operators have given speeches at the 6G technology summit. Based on the technical discussions at the conference, they published the "Facing 6G Summit" and the white paper "Drivers of Ubiquitous Wireless Intelligence and Main Research Challenges" in September 2019. Currently, the 6G Wireless Summit is working to produce white papers on 6G technology on 12 technical topics, including 6G propulsion and the United Nations Sustainable Development Goals, vertical service verification and testing, machine learning in wireless communications, B5G networks, broadband connectivity, radiofrequency technology and spectrum (RF), remote area connectivity, 6G business, 6G edge computing, trust security and privacy, positioning, and sensing.

5.3 United states

In 2018, the U.S. Federal Communications Commission (FCC) initiated research on new services of terahertz spectrum in the frequency range of 95GHz to 3THz. Starting in June 2019, it will issue a 10-year test license for marketable network services. The main content of spectrum research includes:

(i) The 95~275 GHz frequency band is shared by government and non-governmental organizations;

(ii) 275 GHz~3 THz does not affect the use of the existing spectrum;

(iii) The total bandwidth of unlicensed spectrum is 21.2 GHz, including 116~123 GHz, 174.8~182 GHz, 185~190 GHz, 244~246 GHz.

The Alliance for Telecommunications Industry Solutions (ATIS) issued a 6G action proposal on May 19, 2020, recommending that the government invest more research and development resources on breakthrough 6G core technologies, and inviting the government and enterprises to actively participate in the formulation of national spectrum policies.

The future 6G core technologies that the United States currently hopes to dominate include 5G integration and open networks (ION), advanced technologies that support artificial intelligence (AI) networks and services, advanced antennas and radio systems (such as terahertz frequency bands above 95 GHz), Multiple access network services (including terrestrial and non-terrestrial networks, self-sensing support for applications such as ultra-high resolution positioning), medical intelligent network services (including remote diagnosis and surgery, the use of new capabilities, etc. as multi-sensing applications, tactile Internet and Ultra-high resolution 3D imaging) and agriculture 4.0 services (supporting the unified application of water, fertilizer, and pesticides).

5.4 Japan and South Korea

The Japanese government began publishing to release its first research 6G strategy mobile for network 6G research mobile strategy networks in the summer of 2020. The South Korean Government Electronics and Telecommunications Research Institute (ETRI) of the South Korean government signed a research 6G collaboration network for research 6G cooperation networks agreement with the University of Oulu, in Finland in June 2019. Samsung has focused been focusing on 6G, artificial intelligence, and robotics since 2019. LG and South Korea in January 2019, the Korea Institute of Science and Technology (KAIST) cooperated to establish a 6G research center. And SKT and manufacturers the manufacturer jointly researched studied 6G metrics indicators and business requirements.

5.5 China

The Ministry of Industry and Information Technology of China expanded the original IMT-2020 support group to the IMT-2030 support group, and conducted feasibility studies on 6G requirements, vision, key technologies, and global unified standards. The Ministry of Science and Technology of China launched the 6G Technology Development Support Group in November 2019, involving 37 industry-university-research institutions to carry out industry-university cooperation projects on 6G requirements, structures and enabling technologies.

The commercialization of 6G is planned to be realized after 2030, and the future is expected to achieve high speed, low latency, and high connection density. In the 6G society, there will be a world where people no longer realize background communication and communication technology is integrated into society. At present, when 5G is used, we hope to look forward to the realization of 6G while grasping the current problems.

6. CONCLUSION

The growth of wireless data is almost exponential. The rapid popularization of various smart devices, the emergence of various new applications, and the demand for global connectivity of all things have laid the foundation for the next wireless evolution to 6G. It is expected that the 6G wireless network will greatly improve the quality of service and achieve sustainable development in the future. This review article first looks at the vision and requirements of 6G from different angles. Then we discussed technical architectures, potential challenges associated with future 6G technology, and possible solutions to promote 6G development. We also looked at research activities in different countries. Finally, the main contribution of our research is that it shows promising solutions to potential problems and challenges of 6G technology. However, it would be interesting to study these technologies and 6G services in more detail and profoundly determine the actual issues of 6G research.

REFERENCES

[1] Zhao, Y., Yu, G., Xu, H. (2019). 6G mobile communication network: Vision, challenges and key technologies. arXiv preprint arXiv:1905.04983. https://doi.org/10.1360/n112019-00033

[2] Cave, M. (2018). How disruptive is 5G? Telecommunications Policy, 42(8): 653-658. https://doi.org/10.1016/J.TELPOL.2018.05.005

[3] Zhang, L., Liang, Y.C., Niyato, D. (2019). 6G Visions: Mobile ultra-broadband, super internet-of-things, and artificial intelligence. China Communications, 16(8): 1-14. https://doi.org/10.23919/JCC.2019.08.001

[4] Nayak, S., Patgiri, R. (2020). 6G communication: Envisioning the key issues and challenges. arXiv preprint arXiv:2004.04024. https://doi.org/10.4108/eai.11-11-2020.166959

[5] Jiang, D., Liu, G. (2017). An overview of 5G requirements. 5G Mobile Communications, 3-26. https://doi.org/10.1007/978-3-319-34208-5_1

[6] Gupta, R., Shukla, A., Tanwar, S. (2020). BATS: A blockchain and AI-empowered drone-assisted telesurgery system towards 6G. IEEE Transactions on Network Science and Engineering, 8(4): 2958-2967. https://doi.org/10.1109/TNSE.2020.3043262

[7] Khan, L.U., Yaqoob, I., Imran, M., Han, Z., Hong, C.S. (2020). 6G wireless systems: A vision, architectural elements, and future directions. IEEE Access, 8: 147029-147044. https://doi.org/10.1109/ACCESS.2020.3015289

[8] Cisco, U. (2020). Cisco Annual Internet Report (2018–2023) White Paper. Cisco: San Jose, CA, USA.
[9] Noohani, M.Z., Magsi, K.U. (2020). A review of 5G technology: Architecture, security and wide applications. International Research Journal of Engineering and Technology (IRJET), 7: 3440-3471. https://doi.org/10.5281/ZENODO.3842353
[10] Letaief, K.B., Chen, W., Shi, Y., Zhang, J., Zhang, Y.J.A. (2019). The roadmap to 6G: AI empowered wireless networks. IEEE Communications Magazine, 57(8): 84-90.
[11] Chen, S., Liang, Y.C., Sun, S., Kang, S., Cheng, W., Peng, M. (2020). Vision, requirements, and technology trend of 6G: How to tackle the challenges of system coverage, capacity, user data-rate and movement speed. IEEE Wireless Communications, 27(2): 218-228. https://doi.org/10.1109/MWC.001.1900333
[12] Yang, P., Xiao, Y., Xiao, M., Li, S. (2019). 6G wireless communications: Vision and potential techniques. IEEE Network, 33(4): 70-75. https://doi.org/10.1109/MNET.2019.1800418
[13] Akhtar, M.W., Hassan, S.A., Ghaffar, R., Jung, H., Garg, S., Hossain, M.S. (2020). The shift to 6G communications: vision and requirements. Human-centric Computing and Information Sciences, 10(1): 1-27. https://doi.org/10.1186/S13673-020-00258-2
[14] Tataria, H., Shafi, M., Molisch, A.F., Dohler, M., Sjöland, H., Tufvesson, F. (2021). 6G wireless systems: Vision, requirements, challenges, insights, and opportunities. Proceedings of the IEEE, 109(7): 1166-1199. https://doi.org/10.1109/JPROC.2021.3061701
[15] Alsharif, M.H., Kelechi, A.H., Albreem, M.A., Chaudhry, S.A., Zia, M.S., Kim, S. (2020). Sixth generation (6G) wireless networks: Vision, research activities, challenges and potential solutions. Symmetry, 12(4): 676. https://doi.org/10.3390/SYM12040676
[16] Zhang, Z., Xiao, Y., Ma, Z., Xiao, M., Ding, Z., Lei, X., Fan, P. (2019). 6G wireless networks: Vision, requirements, architecture, and key technologies. IEEE Vehicular Technology Magazine, 14(3): 28-41. https://doi.org/10.1109/MVT.2019.2921208
[17] David, K., Berndt, H. (2018). 6G vision and requirements: Is there any need for beyond 5G? IEEE Vehicular Technology Magazine, 13(3): 72-80. https://doi.org/10.1109/MVT.2018.2848498
[18] Shahraki, A., Abbasi, M., Piran, M., Taherkordi, A. (2021). A comprehensive survey on 6G networks: Applications, core services, enabling technologies, and future challenges. arXiv preprint arXiv:2101.12475.
[19] You, X., Wang, C.X., Huang, J., Gao, X., Zhang, Z., Wang, M., Liang, Y.C. (2021). Towards 6G wireless communication networks: Vision, enabling technologies, and new paradigm shifts. Science China Information Sciences, 64(1): 1-74. https://doi.org/10.1007/S11432-020-2955-6
[20] Yazar, A., Dogan-Tusha, S., Arslan, H. (2020). 6G vision: An ultra-flexible perspective. ITU Journal on Future and Evolving Technologies, 1(1): 121-140.
[21] Nawaz, F., Ibrahim, J., Awais, M., Junaid, M., Kousar, S., Parveen, T. (2020). A review of vision and challenges of 6G technology. International Journal of Advanced Computer Science and Applications, 11(2): 643-649. https://doi.org/10.14569/IJACSA.2020.0110281
[22] Clemm, A., Vega, M.T., Ravuri, H.K., Wauters, T., De Turck, F. (2020). Toward truly immersive holographic-type communication: Challenges and solutions. IEEE Communications Magazine, 58(1): 93-99. https://doi.org/10.1109/MCOM.001.1900272
[23] Perfecto, C., Elbamby, M.S., Park, J., Del Ser, J., Bennis, M. (2019). Mobile XR over 5G: A way forward with mmWaves and Edge. arXiv preprint arXiv:1905.04599.
[24] Bastug, E., Bennis, M., Médard, M., Debbah, M. (2017). Toward interconnected virtual reality: Opportunities, Challenges, and Enablers. IEEE Communications Magazine, 55(6): 110-117. https://doi.org/10.1109/MCOM.2017.1601089
[25] Yuan, Y., Zhao, Y., Zong, B., Parolari, S. (2020). Potential key technologies for 6G mobile communications. Science China Information Sciences, 63(8): 1-19. https://doi.org/10.1007/s11432-019-2789-y
[26] Latva-aho, M., Leppänen, K., Clazzer, F., Munari, A. (2020). Key drivers and research challenges for 6G ubiquitous wireless intelligence.
[27] Saad, W., Bennis, M., Chen, M. (2019). A vision of 6G wireless systems: Applications, trends, technologies, and open research problems. IEEE Network, 34(3): 134-142. https://doi.org/10.1109/MNET.001.1900287
[28] Huang, T., Yang, W., Wu, J., Ma, J., Zhang, X., Zhang, D. (2019). A survey on green 6G network: Architecture and technologies. IEEE Access, 7: 175758-175768. https://doi.org/10.1109/ACCESS.2019.2957648
[29] Viswanathan, H., Mogensen, P.E. (2020). Communications in the 6G era. IEEE Access, 8: 57063-57074. https://doi.org/10.1109/ACCESS.2020.2981745
[30] Elmeadawy, S., Shubair, R.M. (2020). Enabling technologies for 6G future wireless communications: Opportunities and challenges. arXiv preprint arXiv:2002.06068.
[31] Zong, B., Fan, C., Wang, X., Duan, X., Wang, B., Wang, J. (2019). 6G technologies: Key drivers, core requirements, system architectures, and enabling technologies. IEEE Vehicular Technology Magazine, 14(3): 18-27. https://doi.org/10.1109/MVT.2019.2921398
[32] Giordani, M., Polese, M., Mezzavilla, M., Rangan, S., Zorzi, M. (2020). Toward 6G networks: Use cases and technologies. IEEE Communications Magazine, 58(3): 55-61. https://doi.org/10.1109/MCOM.001.1900411
[33] Dang, S., Amin, O., Shihada, B., Alouini, M.S. (2020). What should 6G be? Nature Electronics, 3(1): 20-29. https://doi.org/10.1038/s41928-019-0355-6
[34] Ziegler, V., Wild, T., Uusitalo, M., Flinck, H., Räisänen, V., Hätönen, K. (2019). Stratification of 5G evolution and Beyond 5G. In 2019 IEEE 2nd 5G World Forum (5GWF), pp. 329-334. https://doi.org/10.1109/5GWF.2019.8911739
[35] You, X., Wang, C.X., Huang, J., Gao, X., Zhang, Z., Wang, M., Liang, Y.C. (2021). Towards 6G wireless communication networks: Vision, enabling technologies, and new paradigm shifts. Science China Information Sciences, 64(1): 1-74. https://doi.org/10.1007/S11432-020-2955-6
[36] Chen, S., Liang, Y.C., Sun, S., Kang, S., Cheng, W., Peng, M. (2020). Vision, requirements, and technology trend of 6G: How to tackle the challenges of system coverage, capacity, user data-rate and movement speed.

IEEE Wireless Communications, 27(2): 218-228. https://doi.org/10.1109/MWC.001.1900333
[37] Shannon, C.E. (1948). A mathematical theory of communication. The Bell System Technical Journal, 27(3): 379-423. https://doi.org/10.1002/J.1538-7305.1948.TB01338.X
[38] Hewa, T., Gür, G., Kalla, A., Ylianttila, M., Bracken, A., Liyanage, M. (2020). The role of blockchain in 6G: challenges, opportunities and research directions. In 2020 2nd 6G Wireless Summit (6G SUMMIT), pp. 1-5. https://doi.org/10.1109/6GSUMMIT49458.2020.9083784