Research on 6G mobile communication system

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Abstract. 6G will have super flexibility in the utilization of time, frequency and space resources. The time slot can be compressed to use the high frequency band more effectively and meet the demand of delay sensitive service. Terahertz frequency band is used to make up for the current shortage of spectrum resources. The 6G system will adopt the technical architecture of multi frequency close integration and no cellular cell communication network in air, sky and ground areas. 6G system will realize the integration of network and intelligence, communication and sensor, and adopt novel discontinuous communication technology, wireless power transmission and energy harvesting technology, so as to access all people, information and goods with ultra real experience, and completely eliminate the restrictions of working place and time.

1. Introduction
Today's society is becoming data-centric. Complete automation of industrial processes will increase productivity. The automatic driving system is emerging in our roads, oceans and air space. Hundreds of millions of sensors will be embedded in cities, homes and production environments. Due to the rapid development of various emerging applications such as artificial intelligence (AI), virtual reality (VR), three-dimensional (3D) media, Internet of everything (IOE) and other emerging applications, massive traffic has been brought. Autonomous systems are becoming more and more popular in various fields of society, such as industry, health, roads, oceans and space[1]. To provide intelligent living and automation systems, hundreds of millions of sensors will be embedded in cities, vehicles, houses, industry, food, toys and other industries. Communication networks need to provide neural systems for these new intelligent systems and transmit more data at a faster rate.

The sixth generation mobile communication system (6G) connection will surpass personalized communication and fully realize the Internet of things (IOT) mode. It will not only connect persons, but also connect computing resources, vehicles, devices, wearable devices, sensors, and even robots. We can realize the intelligent network adaptation and management, and provide advanced services only by using 6G network.

2. 6G characteristic and network architecture
6G will be "digital twin, intelligent ubiquitous". If the 5G era can realize the ubiquitous acquirement of information, then 6G should fully support the digitization of the world on the basis of 5G, and combine with the development of AI and other technologies to realize the ubiquitous acquirement of information and comprehensively enable everything. In the future, it will move towards a "digital twin" world that combines virtual and reality. The world will generate a digital twin virtual world based on the physical world. Information and intelligence can be transmitted among persons, persons and things, and things and things in the physical world through the 6G. The twin virtual world is the simulation and prediction of the physical world, which will accurately reflect and predict the real state of the physical world, help
human beings further emancipate themselves, improve the quality of life, and improve the efficiency of social production and governance, so as to achieve the goal of "creating a new world through digital innovation, and making all things intelligent".

2.1. 6G time-space-frequency characteristics
According to the evolution and innovation direction of mobile network in the past, 6G will have super flexibility in the utilization of time, frequency and space resources, so as to provide faster rate, larger capacity and ultra-low delay than 5G application in the future. The specific characteristics are as follows[^2][^3]:

(a) In the time dimension, the basic time slot in 6G can be compressed to use the high frequency band more effectively and meet the demand of delay sensitive service. The flexibility and versatility of the network will be improved as the time slot becomes shorter.

(b) In the spatial dimension, ultra massive multiple input multiple output (UM-MIMO) for THz communication can support hundreds to thousands of transmit and receive antennas, and further utilize the "multipath" technology.

(c) In the frequency dimension, on the one hand, THz band and even visible light band will be used for 6G transmission; on the other hand, in the future, mobile network can be integrated with satellite system and Internet to build space-ground integrated network. From the perspective of personal mobile communication, this will indeed increase the frequency range for services. As a result, 6G will use higher frequencies than previous generations of mobile communication systems to increase data rates.

2.2. Innovative network architecture
The introduction of new communication technology will generate new 6G network architecture, but it may also need to update the current mobile network design. The wide use of various communication technologies will increase the heterogeneity of the network, which needs to be managed. The main framework innovations to be introduced in 6G are as follows:

(a) Multi frequency tight integration and cellular free communication technology architecture
The 6G device will support multiple heterogeneous radio signals, which enables the multi-connection technology to extend the boundaries of the current cell. Users are connected to the whole network instead of a cellular cell. The cellular free process will ensure seamless mobility support, no overhead due to handoff (especially in terahertz systems), and will provide QoS assurance that meets the most challenging mobility requirements envisioned by 6G, such as in vehicle scenarios. These devices can seamlessly handoff between different heterogeneous links without manual configuration. Finally, depending on the specific application, users can also use different network interfaces at the same time to take advantage of their complementary characteristics, such as sub 6 GHz links for control and terahertz links for data planes. In 6G, the full potential of unmanned aerial vehicle (UAV) wireless network or UAV cell will be realized, and its application will be widely extended to mobilize network and realize cellular network without any delay. In order to make full use of the mobile cell formed by UAV, the optimization of resource allocation (including radio, energy and computing resources), trajectory, content cache and user association will be realized jointly. In addition, in 6G, UAV can not only provide wireless coverage as a flight base station, but also serve as a content provider and a computing server. There will be a lot of synergy with other emerging technologies. For example, artificial intelligence will use network usage data to learn and dynamically find the best path for UAVs and optimize their other parameters. This will inevitably lead to dynamic reconfiguration of network topology. As a result, users can move seamlessly from one network to another without any manual configuration in the device. The best network will be selected automatically from the available communication technologies. This will break the limitation of cell concept in wireless communication. Cellular free communication will be achieved through multi-connection and multi-layer hybrid technologies as well as heterogeneous different radios in the equipment.
(b) 3D network architecture

5G and previous generations of networks provide network connectivity with two-dimensional space of ground equipment. Instead, we envision a future 6G heterogeneous architecture that will provide three-dimensional (3D) coverage with air platforms such as UAVs, balloons, and satellites. In addition, these elements can be deployed rapidly to ensure seamless continuity and reliability of services, such as avoiding costly fixed communications infrastructure in rural areas or during activities.

The 6G system will integrate ground and sky networks to provide communication support for vertically expanded users. The 3D base station will be implemented by LEO satellites and UAVs. Adding new dimensions in terms of height and relative degrees of freedom makes 3D connections very different from traditional 2D networks. 6G system can provide any required performance in the air, sky, ground and other areas, provide ultra-high rate and low delay, and meet the requirements of data density and high reliability. The "space-sky-ground" integrated network can be divided into three layers: the space-based network composed of various orbit satellites, the sky-based network composed of aircraft, and the ground network including ground cellular mobile network, satellite ground station and mobile satellite terminal. "Space-sky-ground" integrated network can make full use of the characteristics of large space coverage, large line of sight and low loss transmission to achieve seamless high-rate mobile coverage in the whole 3D space.

In addition, the 6G network will be decentralized and designed based on the integration of ground communications, sky networks and satellite systems to accommodate emerging and urgently needed services (such as disaster prediction) in the future, and achieve global coverage and seamless access, even for ocean and mountain areas. By making full use of the advantages of satellite system, sky network and ground communication system, this multi-dimensional network will bring many benefits to the future 6G wireless communication. In particular, with the increase of the number and type of aircraft, airship and UAV, the dynamic network assisted by flight base station (FBS) can be established to improve the traditional static structure.

(c) User centered network architecture

Machine learning (ML) driven network is still in its infancy, but will become a basic component of a complex 6G system. The 6G system envisages the use of distributed artificial intelligence to implement a completely user-centric network architecture. In this way, the terminal will be able to make independent network decisions based on the previous operation results without the communication overhead between the terminal and the centralized controller. The distributed method can process ML calculation in real time, that is, it has a delay lower than ms level, and can meet the requirements of many 6G services, so as to improve the response ability of network management.

2.3. New network topology

When pursuing ultra-high rate, high capacity (especially uplink) and improving the reliability of wireless communication, it is ideal to communicate in the shortest possible distance and occlusion free environment (low path loss), and generate as many communication paths as possible to increase candidate paths (increase redundancy). Therefore, 6G needs a distributed network topology in the spatial domain. In order to increase the path selection, 6G will pursue the topology of spatial non-orthogonal distribution network by abandoning the concept of "cell".

At the same time, with the rise of smart home, building, city and society, especially with the development of robot and automatic UAV system, 6G will meet the growing demand of human to machine communication and machine to machine (M2M) communication. In order to realize the future IOT, 6G will be a super flexible and super dense network, which can skillfully integrate different technologies to meet different service requirements at the same time. To provide a global mobile complex, 6G is expected to integrate ground, satellite and sky networks into a single wireless system. Through UAV and LEO earth satellite access networks, 3D connectivity will be ubiquitous.

Big buildings, flying cars, airplanes and even space are the natural activity areas of persons and objects. Not only the ground, but also the sky and space are indispensable communication areas. In addition, the demand for maritime and submarine communication areas is increasing. Due to the needs
of various sensor networks, communication areas such as unattended factories and unattended construction sites which without human beings, must also be constructed network. To sum up, the ground, sky and other places will become communication areas.

Because the traditional cellular network can not completely cover many important service areas (such as sky, ocean and space), in order to provide services to UAVs, flying cars, ships and space stations, coverage expansion and topology technology are needed. Therefore, The new 6G network topology should be three-dimensional covered horizontally and vertically.

2.4. Integration of network and intelligence
We expect that the number of 6G users and the density of access point deployment will be much more higher. The integration of different technologies and application characteristics makes the network more heterogeneous, and the performance requirements of 6G are more stringent.

(a) Data learning and feature extraction technology
Large amounts of data generated by future networked devices, such as sensors on autopilot, and it cannot guarantee the quality of service required. Therefore, distinguishing the value of information is the basis of maximizing the utility of users. In this case, the machine learning strategy can evaluate the correlation of observations, or extract characteristics from the input vector, and predict the posterior probability of the sequence based on the whole history of the sequence. In 6G, unsupervised reinforcement learning does not need to be labeled and can operate the network autonomously.

(b) Artificial intelligence
Artificial intelligence is partly realized in 5G system, and artificial intelligence will become the core component of 6G. 6G will fully support artificial intelligence. The progress of machine learning will create more intelligent networks for 6G real-time communication. The introduction of artificial intelligence will simplify and improve the transmission of real-time data. Through a lot of analysis, artificial intelligence can determine the execution mode of complex target tasks. Artificial intelligence will improve efficiency and reduce processing delay of communication. Time consuming tasks, such as handoff and network selection, can be quickly completed by artificial intelligence. Artificial intelligence will also play an important role in M2M, machine to person and human to machine communication. It will also communicate in time at the brain computer interface (BCI). Communication systems based on artificial intelligence need to be supported by metamaterials, intelligent structures, intelligent networks, intelligent devices, intelligent cognitive radio, autonomous wireless networks and machine learning. Unsupervised reinforcement learning in networks has a bright future in 6G networks. By combining reinforcement learning with unsupervised learning, it is possible for the network to operate in a truly autonomous way. At present, the most powerful artificial intelligence technology, such as deep learning (DL), is based on deep neural network (DNN).

2.5. 6G technology characteristics
New technologies will be introduced into the 6G mobile communication system as follows:

(a) Novel discontinuous communication technology: When new frequency bands such as millimeter wave and terahertz wave are added to the applied frequency band, 6G will adopt a very wide frequency band compared with the past. Therefore, it seems that there are many related research fields, such as optimizing the selection of multi band according to the application, studying the method of frequency reuse between cells, upgrading the duplex mode in uplink and downlink, and studying the utilization mode of low frequency band.

(b) Ultra high rate, high reliability communication: Wireless communication highly reliable control information is an important requirement of many industrial use cases (such as remote control and factory automation), and 6G is expected to achieve higher reliability and security than 5G. With the popularity of robots, unmanned aerial vehicles, and the expansion of radio coverage to the sky, highly reliable communication is required not only in limited areas such as factories, but also in wider areas, and it is possible to achieve highly reliable communication in various scenarios.
(c) **Network based positioning and sensing:** The 6G network will use a unified positioning and communication interface to improve control operations, which can rely on context information to form beamforming patterns, reduce interference and predict switching, and provide innovative user services, such as vehicle and electronic health services.

(d) **Terahertz communication:** Spectrum efficiency can be achieved by using THz communication (0.1-10THz) and using advanced UM-MIMO technology. RF frequency band has been almost exhausted, and it is not enough to meet the requirement of 6G. THz band will play an important role in 6G communication. THz band will become the next frontier of high data rate communication. The small wavelength of THz signal allows more antenna elements to be integrated into the equipment and base stations operating in frequency band. This allows the use of advanced adaptive array technology, which can overcome the limitations of coverage. Terahertz wave has many characteristics: (1) Terahertz wave is easily absorbed by moisture in the air, which is more suitable for high-rate and short-range wireless communication; (2) The wave beam is narrower and has better directionality, and has stronger anti-interference ability; (3) Terahertz wave has wide bandwidth, which can meet the demand of spectrum bandwidth in wireless broadband transmission. (4) Terahertz wave can be widely used in space communication, especially for the communication between satellites or between satellite and ground; (5) The propagation characteristics of electromagnetic wave show that the free space fading is proportional to the square of frequency, so terahertz has larger decline of free space compared with low frequency band. (6) Terahertz signal is very sensitive to shadow and has great influence on coverage. (7) At the moving rate, the channel coherence time is linearly related to the carrier frequency, which means that the coherent time of terahertz band is very small and the doppler spread is large, which is much faster than the frequency band used in the current cellular system. Terahertz system is a highly spatially oriented signal transmission, which means that the path fading, service beam and cell correlation will change rapidly, and a fast adaptation mechanism is needed to overcome this fast changing intermittent connection problem.

(e) **UAV:** UAV will be an important part of 6G wireless communication. In many cases, UAV technology will be used to provide high data rate wireless connections. The base station entity will be installed on the UAV to provide cellular connectivity. UAVs have some characteristics that are not available in a fixed base station infrastructure, such as ease of deployment, strong LoS links, and degree of freedom with controllable mobility. In emergency situations such as natural disasters, it is not economically feasible to deploy ground communication infrastructure, and sometimes it is impossible to provide any services in unstable environments. UAVs can easily handle these situations. UAV will become a new mode in the field of wireless communication.

(f) **Integration of sensing and communication:** The key driver of autonomous wireless network is to be able to continuously sense the dynamic changes of the environment and exchange information among different nodes. In 6G, sensors will be tightly integrated with communications to support autonomous systems.

(g) **Big data analysis:** Big data analysis is a complex process of analyzing various big data sets. This process discovers information, such as hidden patterns, unknown correlations, and customer preferences, to ensure perfect data management. Big data is collected from a variety of sources, such as videos, social networks, images and sensors. This technology will be widely used in the processing of massive data in 6G system.

(h) **WPT and energy harvesting:** Any IOT device in 6G will consume more power due to the huge computing demands of AI processing. WPT doesn't play a key role in 5G, but in 6G, it will eventually shine. First of all, because the density of wireless network continues to increase, the communication distance will be greatly shortened. In addition, the use of UAV as base station further shortens the distance, which makes WPT more meaningful. UAVs will benefit a lot from wireless power transmission (WPT), which enables UAVs to move all the time. In addition, with the continuous progress of energy harvesting technology, energy harvesting from RF signals may become a feasible power supply for low-power applications.
3. 6G characteristic index

In terms of time delay, the development of mobile communication network is centered on service for people from 2G to 5G. Therefore, the time delay depends on the human response time, such as auditory response time (about 100ms), visual response time (about 10ms), and perceptual response time (about 1ms). For the application of tactile Internet, 5G technology will allow 1 millisecond delay time. However, this is "too long" for the industrial Internet of things (IIOT) and other delay sensitive applications. For example, minimum delay time is essential to reduce the collision rate and improve the safety of autonomous vehicles. Thus 6G aims to achieve a delay less than 1 millisecond that shown in Table 1, because it can enhance the application of autopilot, augmented reality and medical imaging. The demand in 6G network may change, and the frequency width adopted by 6G will be greatly increased. The data rate of 6G uplink and downlink can reach 1Tbps, and the reliability will reach $10^{-9}$. The supported mobile rate ranges from 500 kilometer per hour for 5G to 1000 kilometer per hour for 6G. 6G has ultra-high precision positioning, considering three-dimensional coverage, and integrated with satellite, XR, AI, tactile, automation, etc.

| Delay  | Data rate | Reliability | Mobile rate | Integration                                      |
|--------|-----------|-------------|-------------|--------------------------------------------------|
| <1ms   | 1Tbps     | $10^{-9}$   | 1000 km/h   | Fully integrated with satellite, XR, AI, tactile, automation, etc. |

4. Conclusion

Based on the results and discussions presented above, the conclusions are obtained as follows:

The main development trends of 6G communication system has high bit rate, high reliability, high energy efficiency, high frequency spectrum efficiency, low delay and operate at new spectrum, etc. 6G will be a fully digital and interconnected system. Through the implementation of 6G, everything around us will be very intelligent, which will produce the concept of Internet of things (IOE), with a lot of data and information. Due to the availability of a large number of operational data and the improvement of computing power, artificial intelligence will become an important part of 6G. In 6G, we expect to see that AI run with distributed training at the edge of the network, including microcellular base stations and UEs. It is expected that the world in the 6G era will become a prospect in which all people, information and goods can be accessed in a surreal experience anywhere, and the restrictions on work place and time are completely eliminated. This will greatly eliminate social and cultural differences among urban and rural areas, avoid urban population concentration, and promote local development. It can also make people's lives more convenient.

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