Technology prospect of 6G mobile communications

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Abstract: To achieve a deeper level of intelligent communication for human beings, the sixth generation mobile communication system (6G) will realize the extension from the real world to the virtual world. To this end, the "human-machine-thing-genie" problem introduced by 6G was presented, and an evolved dual-world architecture for 6G was proposed. The architecture includes the fourth elements of 6G, genie, in the virtual world. The potential key theories and technologies to support the design and implementation of 6G were proposed and analyzed.

Key words: the sixth generation mobile communication system, human-machine-thing-genie, virtual world

1 Introduction

The increasing demand of communication user and the innovation technology of communication system are the driving force behind the evolution of mobile communication systems. To meet the traffic requirements of "connected in motion", 1G (the first generation mobile communication system) achieved the integration of "mobile" and "communication", which becomes a milestone of mobile communication system from scratch, and started the evolution of mobile communication system. Along with the maturity of digital technology, 2G (the second generation mobile communication system) has completed a comprehensive transition from analog system to digital system, and begin expand the supported service dimensions. Driven by increasingly various service requirements, 3G (the third generation mobile communication system) has adopted a novel code division multiple access method to improve the support for mobile multimedia services [1-2]. At that point, high data rate and large bandwidth support have become important indicators for the evolution of mobile communication systems. 4G (the fourth generation mobile communication system) with MIMO (multiple-input multiple-output) and OFDM (orthogonal frequency division multiple access) as the core technology not only obtains the further improvement of spectrum efficiency and the ability to support bandwidth [3-5], It has also become the foundation of the mobile Internet. While 4G has achieved great commercial success, 5G (the fifth generation mobile communication system) has gradually penetrated into vertical industries, extending the traditional eMBB (enhance mobile broadband) scenario to mMTC (massive machine type of communication) scenario and uRLLC (ultra reliable and low latency communication)scenario [6-9]. Based on technologies such as massive MIMO, millimeter wave transmission, and multiple connectivity, 5G achieves all-round improvements in peak rate, user experience data rate, spectrum efficiency, mobility management, latency, connection density, network energy efficiency, and regional service capacity performance. [10-11] 。 Throughout the above-mentioned evolution process, meeting the communication needs of users is the primary purpose of each generation of system evolution, while new communication technologies are the driving force of each generation of system evolution.

So far, the design of 1G to 5G has followed the loosely coupled criterion between the network side and the user side. Driven by technology, the basic needs of users and the network (such as user data rate, delay, network spectral efficiency, energy efficiency, etc.) have been met to a certain extent. However, subject to technological-driven capability, the design of 1G to 5G does not address deeper communication requirements. In the future 6G (the sixth generation mobile communication system), the network and users will be treated as a unified whole. The user's intelligent needs will be further explored and satisfied, and this will form the benchmark for future technology planning and evolution layout. The goal of 5G is to meet the communication needs of large connectivity, high bandwidth, and low latency scenarios. In the later stage of 5G evolution, there will be a huge number of interconnected automation devices across land, sea and sky, and billions of sensors will be distributed throughout the natural environment and living organisms. Various systems based on AI (artificial intelligence) are deployed on edge devices set in cloud platforms and fog platforms, and create a huge number of new applications. The early stage of 6G will be the expansion and deepening of 5G, based on AI, edge computing and the Internet of Things, to achieve deeper integration of intelligent applications with the network, enabling functions such as virtual reality, virtual users, and intelligent networks. Furthermore, the long-term evolution of 6G, driven by AI theory, emerging materials and integrated antenna-related technologies, will yield new breakthroughs and even build a new world. [12-13]。

In this paper, we first analyzes the 6G evolution trend and explore the relationship between artificial intelligence and human users, and then proposes a new communication element——Genie, based on the 6G service requirement framework, and on this basis anticipate the enabling technologies for 6G mobile communication.

2 AI—the starting point of 6G evolution trend analysis

Although the application of AI in 6G is the trend of the times, it is incorrect to simply treat AI as a technology in 6G that is simply superimposed on mobile communications. Only by digging into the needs of users and looking at the interrelationship between intelligence, communication and the future of humanity can we reveal the technological trend of 6G mobile communications. In "A Brief History of the Future" [14], Israeli historian Yuval Harari predicted three progressive stages of the relationship between AI and humans: 1) AI is the super oracle of human beings, able to understand and master all the psychological and physiological characteristics of human beings, and make timely and accurate life and work suggestions for humans, but the decision to accept the suggestions is in the hands of humans; 2) AI will evolve into a super-agent of humans, and take over part of the decision-making power from humans. It has full authority to handle affairs on behalf of humans; 3) AI further evolves into the sovereign of mankind, becoming the master of mankind, and all human actions follow the arrangement of AI [15].

Based on the above prediction, 6G should follow the trend of AI-human relationship and reach the first

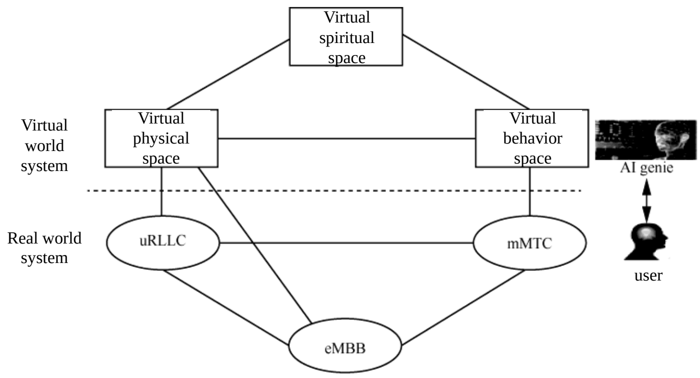

Figure 1 6G service demand framework

stage of relationship evolution, i.e., the oracle stage. Figure 1 illustrates the framework of 6G service requirement. As an important implementation basis for the oracle stage, the services carried by 6G will further evolve into two systems, the real world and the virtual world. The services of the real world system are backward compatible with typical scenarios such as eMBB, mMTC, uRLLC in 5G, to achieve the basic needs of the real world interconnection of all things. The service of the virtual world system is an extension of the real world service and corresponds to the various needs of the virtual world. The virtual world created by 6G is capable of build an AIA (AI assistant) for each user, and capturing, storing and interacting with what users says, sees and thinks. The virtual world system enables the digital abstraction and expression of the various differentiated needs of human users, and establishes an all-round three-dimensional simulation of each user. Specifically, the virtual world system includes three spaces: VPS (virtual physical space), VBS (virtual behavior space), and VSS (virtual spiritual space).

VPS is based on 6G-compatible real-time massive data transmission of typical scenarios, constructs a mirror image of the real physical world (such as geographic environment, buildings, roads, vehicles, indoor structures, etc.) in the virtual world, and provides a virtual digital space for massive users' AIA information interaction. The data in VPS has the characteristics of real-time update and high-precision simulation, which can provide service support for major sports events, major celebrations, rescue and disaster relief, military operations, simulated e-commerce, digital factories, etc.

VBS expands the 5G mMTC scenario. Relying on the 6G human-machine interface and biosensor network, VBS can collect and monitor the physical behavior and physiological functions of human users in real time, and transmit diagnosis and treatment data to AIA in time. Based on the analysis results of the data provided by VBS, AIA predicts the user's health condition and provides timely and effective treatment solutions. The typical application support of VBS is the widespread use of precision medicine.

Based on the massive information interaction and analysis of VPS, VBS and service scenarios, VSS can be constructed. Due to the development of semantic information theory and the improvement of differential demands perception, AIA can capture various psychological states and spiritual needs of users. These perceived needs include not only real needs such as job hunting and social interaction, but also virtual needs such as games and hobbies. Based on the perceived needs captured by VSS, AIA provides complete suggestions and services for users' healthy life and entertainment. For example, with the support of 6G，through information interaction and collaboration, AIA of different users can provide users with in-depth consultation on mate selection and marriage, make accurately analyze users' job hunting and promotion, and help users build, maintain and develop better social interactions relationship.

3 Genie——The soul of 6G

6G not only contains the three core elements of human society, information space, and physical world (human, machine, and things) involved in 5G, but also includes the fourth-dimensional element defined in this article—Genie. Genie exists in the virtual world system in Figure 1. It enables communication and decision making without human involvement. Genie obtains user intentions and decision-making based on a large amounts of data collected in real time and efficient machine learning technology. Genie can serve as AIA for 6G users, providing powerful proxy functions. Because it is not restricted by the specific physical form of smart terminals, Genie surpasses VPS and includes the complete functions of VBS and BSS, and has the ability to build personalized, autonomous and immersive three-dimensional agents for users. Haddadin et al. [16] proposed the tactile robot network as a multi-dimensional agent of the human virtual world, collecting and recognizing human intentions through various tactile methods. Genie exists on the basis of the omni-directional man-machine-thing integration, and can cover entities in any physical space, including physical entities that can be used as communication and computing nodes, such as smart devices with transmission and computing capabilities, buildings, and plants. Genie perceives multi-dimensional information of users and the environment through physical space resources, and constructs user behavior characteristics, decision-making preference models and other information in virtual spiritual space in real time. Through the collaboration of man-machine-thing-genie, Genie can provide users with real-time virtual service scenarios and implement corresponding needs on behalf of users.

The application scenarios of 6G mainly include virtual reality and virtual users. In virtual reality scenarios, 6G needs to perceive changes in the environment in real time, efficiently process massive amounts of sensor feedback data, and quickly complete information exchange between the terminal and the cloud center. Virtual user scenario refers to the use of artificial intelligence, mobile computing and other technologies to generate virtual objects, and leverage the entire network wireless access and transmission technology to accurately "deploy" Genie in the real environment, providing users with virtual world and physical world integrated application scenarios. Figure 2 illustrates a 6G human-machine-object-spirit collaboration service scenario with a physical flower store in a real environment. A variety of 6G network sensing devices and network devices are deployed in this real environment to collect real-time information such as pictures, odors, temperature, humidity, and light of the items in the store. Genie reconstructs the immersive flower shop scene for users remotely according to user needs. At the same time, users can authorize Genie to make decisions on behalf of users based on their consciousness, needs, goods and other conditions.

The application scenario of 6G has new network characteristics such as virtual and real combination and real-time interaction, which will bring huge transmission pressure to 5G networks. Therefore, there is an urgent need to study the fundamental theories and essential technologies that support 6G evolution. At present, 5G has addressed the problems encountered in eMBB, uRLLC, and mMTC scenarios with industry-specific services, respectively. However, in order to support the fourth element—Genie in the future network, 6G not only needs to be compatible with the three major scenarios in 5G, but also to further enhance the integration of the three major scenarios, reconcile the contradictions of service requirements in different scenarios, and fulfill the deeper intelligent communication needs of the virtual world.

In order to achieve the human-machine-thing-genie collaboration application scenario and meet the all-round spiritual and material needs of human users, both subjective feelings and objective technical performance optimization should be pursued to establish the 6G enabling technology system.

4 6G enabling technology

The network characteristics of virtual world system services, such as the combination of virtual and real, and real-time interaction, have brought great challenges to the current 5G network. In order to support these application requirements of 6G, it is necessary to carry out research on general information theory, personalized transmission technology and idea-driven network technology based on fundamental theories and supporting technologies.

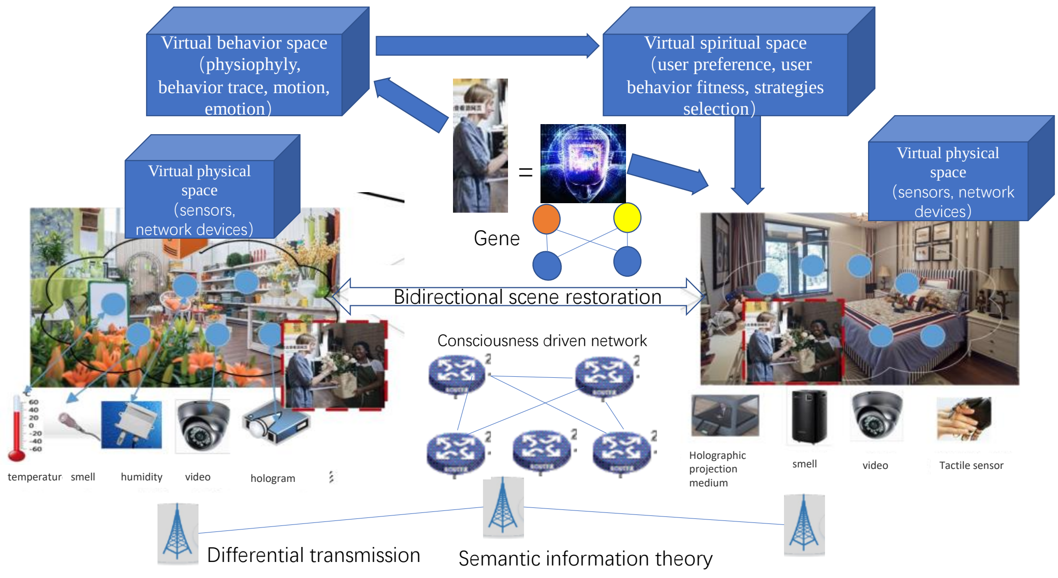

Figure 2 An example of a 6G human-machine-thing-genie collaboration service scenario for florist applications

4.1 General Information Theory

In order to support AI Genie's semantic perception and analysis, 6G must not only collect and transmit digital information, but also process semantic information, which requires that the limitations of classical information theory [17] must be broken through and generalized information theory[18-20] must be developed to construct a comprehensive processing scheme for semantic and grammatical information, his is also the theoretical basis for the realization of human-computer intelligent interaction. The research content of 6G-oriented general information theory includes the following three aspects.

1) Information Quantitative Measurement Theory Integrated Grammatical and Semantic Features

Different from classical information theory based on probability measurement, general information theory requires subjective measurement of semantic information and constructs a joint measurement theory that integrates grammatical and semantic features. First, fuzzy mathematics is used as a tool [19-20]to model and measure the degree of membership affiliation of semantic information such as user experience and experience evaluation of 6G mobile services. Then, further expand the probability measurement method of classical information quantity and establish a joint subjective and objective measurement model of generalized information volume.

2) Information Processing Theory Based on Semantic Recognition

6G mobile communication needs to support various types of human-machine-object communication, and there are significant subjective experience differences in communication quality and effects. On the basis of quantitatively measuring semantic information, the information processing theory based on semantic recognition is studied for the characteristics of the multi-source broadcast service of 6G mobile communication, and it provides guidance for data processing of 6G mobile service.

3) Information Network Optimization Theory Based on Semantic Recognition

6G mobile communication needs to meet network communication in various real and virtual scenarios. Therefore, it is necessary to combine AI theory to study the optimization of communication networks that overlap real and virtual communications.

4.2 Personalized transmission technology

Biodiversity is a universal law of nature, and demand difference is also a universal law of human society. While 1G~5G does not fully meet the personalized needs of human users, 6G mobile communication requires quantitative modeling and analysis of subjective human experience to fulfill the information processing and transmission of differential needs [21], thus to build intelligent communication networks. In this regard, technologies such as polarization coding transmission, massive MIMO, and AI-based signal processing are all competitive cutting-edge technologies.

4.2.1 6G-oriented polarization code transmission theory and technology

1) Personalization-oriented Polarization Code Construction and Optimization

Although the channel coding standard of 5G mobile communication has been determined to employ polar codes [22-23], there is still a lot of room for optimization in the coding construction and decoding algorithms of polar codes. Since the polarization code is coded based on the principle of differentiation, it is ideal for the flexible and variable service requirements of future 6G mobile communications. Therefore, further research on the design and construction theory of the polarization code [24], as well as the high performance and low complexity Research on encoding and decoding algorithms [25-27]is needed.

2) Design and optimization of polarization coding MIMO system

In order to build the VPS space, 6G needs to support ultra-high-speed data transmission, and the polarization-coded MIMO system has significant performance advantages [28] to meet the future data transmission needs. Therefore, it is necessary to investigate the optimization scheme of polarization transmission for the two typical structures of the MIMO system-spatial multiplexing/precoding and spatial modulation.

3) Design and optimization of polarization multiple access system

Multiple access is a landmark technology of mobile communication systems. It is foreseeable that NOMA (non-orthogonal multiple access) will become a representative multiple access technology for 5G/6G mobile communications [29]. Introducing polarization coding into a non-orthogonal multiple access system requires an in-depth analysis of the system structure of NOMA, and optimizing the channel polarization decomposition scheme from the perspective of generalized polarization [30]. According to 6G mobile communication service requirements, the construction criterion of polarization coded multi-user communication will be designed and optimized. Aiming at the multi-user scenario where human-machine-thing-genie coexists, a low-complexity generalized interference cancellation multi-user detection algorithm is designed.

4.2.2 massive MIMO technology

6G will encounter a diversified communication environment where real and virtual coexistence. The range of variations in service rate, system capacity, coverage and mobile speed will be further expanded, and transmission technology will face multiple challenges in performance, complexity and efficiency.

Aiming at the transmission characteristics of 6G wireless signals, massive MIMO [31-32]includes the following research.

1) Multi-domain signal joint modulation and demodulation technology

The introduction of Genie provides an additional signal processing domain, and the service data of human users has a deep correlation with the service data provided by Genie. The multi-dimensional correlation is used to further explore the spatial dimension and design a joint modulation and demodulation scheme for multi-domain signals to improve the link transmission efficiency.

2) Generalized MIMO joint design and optimization technology

With the aid of Genie, we study the deep learning-based MU-MIMO (multiple user MIMO) beamforming technique with generality and universality. Genie can provide accurate and reliable channel estimation and a priori information of service sources, based on which the MU-MIMO beam can be quickly adjusted to improve the link transmission efficiency. In addition, for massive MIMO receivers, Genie can also assist in implementing deep learning-based detection algorithms to optimize the entire receiver performance.

4.2.3 Artificial Intelligence based Signal Processing

6G mobile communication is a complex transmission system with multiple users, multiple cells, multiple antennas, and multiple frequency bands. Signal reception and detection are high-dimensional optimization problems. The optimal ML (maximum likelihood) or MAP (maximum a posteriori) detection is an exponential complexity algorithm, which has superior performance but is difficult to be widely used. Deep learning theory takes another approach, through a large amount of offline training, to obtain a high-performance deep neural network model, thus approaching ML/MAP detection.

Aiming at 6G wireless signal characteristics, signal processing based on deep learning includes the following research contents.

1) Channel estimation technology based on deep learning

Genie explores a new technical approach for applying deep learning in 6G mobile communications [33-34]. Genie can perform big data analysis and intelligent prediction of the wireless channel and propagation environment experienced by human users in the virtual physical space, further investigate the space-time-frequency three-dimensional channel estimation algorithm based on CNN (convolutional neural networks) or LSTM (long short-term memory) model, so as to provide more accurate and reliable channel estimation for the signal detection of mobile terminals' reception.

2) Interference detection and cancellation technology based on deep learning

Facing the complex multi-cell scenarios of future 6G, interference detection and cancellation are critical technologies. In the virtual physical space, Genie can perform big data analysis and intelligent prediction of various interferences in multi-cell scenarios, so as to quickly and accurately estimate and reconstruct interference signals. Further research on classical neural network models such as CNN and LSTM, design an adaptive interference cancellation deep learning algorithm, which can substantially improve the link reception performance.

4.3 Idea-driven network

The establishment and development of artificial intelligence assistants need to rely on on-demand intelligent networks.

In view of the technological development trend of 6G mobile communications, it is necessary to carry out prospective research on theories and core technologies such as a new 6G network architecture that supports the integration of human-machine-thing-genie, distributed edge network intelligence, and intelligently defined networks for cognitive enhancement and decision-making deduction.

4.3.1 A new 6G network architecture for the integration of human-machine-thing-genie

Study the semantic connection, service adaptation, and collaborative orchestration of human-machine-thing-genie quaternary space [35-37], Build a set of 6G network architecture for information transmission, edge intelligence [38-40], and collaborative computing for the four-element space of human-machine-thing-spirit, support the cross-border integration of the four elements of human-machine-thing-genie. Research on key technologies such as collaborative communication, collaborative computing, collaborative storage and collaborative energy supply of terminals, support the full collaboration of terminals to wireless networks, and achieve distributed services of decentralized communication, computing, storage and energy supply; research on network-based multidimensional programmable human-computer-object-spirit fusion assembly method; research on the state monitoring, synchronization control, consistency check and other network fault-tolerant mechanisms of human-machine-thing-genie fusion; research the four-element fusion of human-machine-thing-genie Network collaborative management technology, supporting edge intelligence and adaptation optimization, and enabling multi-level collaborative scheduling of network-wide resources.

4.3.2 Critical technologies for intelligently defined networks with cognitive enhancement and decision-making Inference

Artificial intelligence technology provides new approaches for addressing the complex and dynamic future 6G network services by self-learning states and features and thus continuously iterating and optimizing the output results [41-43]. In view of the lack of the current edge network autonomy and the difficulty of the heterogeneity equipment normalization, construct a hierarchical and domain-specific functional architecture with service requirements as the core; in view of the dynamic and complex characteristics of the future network environment, artificial intelligence technology is used to monitor，model and analyze the pattern of network resource distribution and changes as well as service quality of service, combined with the idea of centralized management and control to enable adaptive deduction as well as automated operation and maintenance of strategies such as routing, transmission, caching, and resource allocation in the network [44-49].

4.3.3 Secure and reliable network transmission technology

Based on a comprehensive perception of the needs of 6G mobile services, aiming at large-scale, low-latency streaming media services[50-51]， the streaming content is converted into coded data by block for transmission and caching through network coding technology[52-54], which improves the efficiency of data transmission while ensuring the privacy of user services and the security of content. In addition, for high-security user services, artificial intelligence and edge computing technologies are employed to extract feature information from the service content and transmit the extracted feature information and return it to the cloud computing center, which ensures user information security while reducing the pressure on the 6G backhaul network and improving user service quality.

5 Conclusion

The communication performance of the network and users is not the only issue in the evolution of post-5G networks. To achieve a deeper level of intelligence communication needs of human beings, 6G will enable the extension from the real world system to the virtual world system. The virtual world system originates from the sampling, transmission, analysis and reconstruction of the real world system. In order to accomplish 6G, it is necessary to make theoretical and technological breakthroughs in information theory, transmission and networking.

Among them, in terms of fundamental information theory, 6G will expand conventional information theory and theoretically ensure the optimization of semantic information measurement, compression, transmission and network; in terms of key transmission technologies, 6G will further explore polarization-related theories to obtain polarization. Breakthroughs in critical technologies such as encoding and decoding, polarization MIMO, polarization multiple access, and polarization relay to achieve differentiated transmission. In terms of networking technology, 6G will employ a new network architecture of man-machine-thing-spirit to fulfill the needs of intelligently defined networks for cognitive enhancement and decision-making deduction, ensure secure and reliable network transmission, and make the idea-driven network come true.

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