# Development Situation of Integrated Space-Terrestrial Network and Investigation on Key Technologies of Space-Based Communication

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**Abstract** Space-based network is a kind of space wireless network system with various types of satellites as network nodes and interconnected by interstellar links. It is applied widely in earth observation, meteorology, communication, and so on. The development status of the integrated space-terrestrial network at home and abroad is analyzed firstly in this paper. Then, the key technologies of space-based communication are discussed in detail. Finally, the future work of the construction of the integrated space-terrestrial network is proposed.

**Keywords** Integrated space-terrestrial network · Space-based communication · Wireless connection

## 1 Introduction

With the development of aerospace technology, the integrated space-terrestrial network has gradually become a research hotspot in various countries of the world. The integrated space-terrestrial network is based on the terrestrial network and extends from the space network to cover natural space such as space, air, land and sea, providing information protection for the activities of various users such as space-based, air-based, land-based, and sea-based [1]. The role of space-based communications in the integrated space-terrestrial network is particularly critical, including the space-based backbone network, the space-based access network, and the satellite-integrated access network [2]. The space-based backbone network provides broadband access, data relay, and route switching functions through the inter-satellite link. Due to the limited communication load and onboard processing capability of a single star, multiple satellites can be connected to form a cluster to complete relatively complex communication tasks. The space-based access network provides seamless

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C.-T. Yang et al. (eds.), *Innovative Computing*,
Lecture Notes in Electrical Engineering 675,
https://doi.org/10.1007/978-981-15-5959-4_44

coverage, emergency communication, mobile access, and other functions through the satellite-to-ground link, satellite-to-space link, and space-to-ground link. The satellite-integrated access network plays a role of coverage supplement and capacity enhancement for system by satellite-to-ground link and ground link [3].

In summary, this paper first discusses the development status of the integrated space-terrestrial network. Then, from the two aspects of the wireless access technology and networking technology of space-based communication, the key technologies around the uplink multiple access technology, multi-beam satellite beamforming technology, inter-satellite communication, routing technology, constellation design, and heterogeneous network resource management are discussed.

## 2 The Development Situation of Integrated Space-Terrestrial Network Domestic

### *2.1 System Construction*

In recent years, the satellite system construction domestic has achieved great results. In addition to the already retired "Dongfanghong" series and the early "Zhongxing" series, the construction of communication satellite system mainly includes the "beacon fire" series, "Shentong" series, and "Tian chain" series. The "Beacon fire" tactical communication satellite is the first satellite mobile communication system in our army. For the first time, the system utilizes synchronous satellite communication to realize the "moving in the middle," "cooperative communication," and "confidential communication" of the multi-regional and multi-services under the unified control of the network management center. The "Shentong" series runs on the synchronous orbit. It can provide timely, safe, and highly confidential communication command support for the combat units under modern war conditions. Besides, it also can provide effective data instruction for UAV. The "Tian chain" series is a relatively complete synchronous orbit relay satellite system in China which can achieve coverage of global spacecraft. It can provide data relay, measurement, and control services for the manned space engineering in China. At the same time, it will provide data relay services for China's medium and low-orbit resource satellites and provide measurement and control support for spacecraft launches [4].

### *2.2 Network Architecture*

At present, three satellite application series including satellite communication, satellite–earth observation, and satellite navigation and positioning have been preliminarily established in China. Although we have actively explored the integrated space-terrestrial network, we have not established a clear and mature program. Academician named SHEN Rong-jun proposed the space Internet concept and proposed the overall objectives, composition, network architecture, and network protocols of space–earth integration space Internet in 2006 [5]. In the same year, Beijing JiaoTong University proposed an integrated trusted network and established a structural model of "four logos and three maps," which can effectively solve the fusion of heterogeneous networks. These preliminary theoretical studies provided the foundation for the study of the integrated space-terrestrial network.

From 2014 to 2016, the Fund Committee released the major research project named as "Basic Theory and Key Technologies of Spatial Information Network," which was undertaken by the Institute of Electronic Science. The Ministry of Science and Technology funded the "Key Technologies and Demonstration of Future Integrated Networks" project in 2015. The project is undertaken by Beijing JiaoTong University. The main goal of the establishment of these two projects is to propose an integrated network architecture solution that satisfies information sharing, resource integration, interconnection, and access to the domain of various user applications such as land, air, space, and ocean.

## 3 The Development Situation of Integrated Space-Terrestrial Network Abroad

### *3.1 Network Protocol*

In order to meet the growing demand for spatial information transmission and establish a spatial information network similar to the terrestrial Internet, most countries around the world have strengthened the research on spatial networking technologies and protocols, of which the delay-tolerant networks (DTN) is the focus. The concept of DTN was firstly proposed by the American Jet Propulsion Laboratory in 2003. After that, based on the Star Network Research Group, the Internet Research Task Force formed the Delay/Interrupt Tolerance Network Research Group, which conducted extensive research on DTN and proposed the DTN architecture and parcel protocol in 2007.

The DTN network was initially limited to the exploration of the interstellar Internet. The extensive application of terrestrial DTN greatly promoted the research and development of the interstellar Internet. Since 2008, the National Aeronautics and Space Administration (NASA) has launched a space DTN development plan, conducted a series of DTN flight verification tests, tested the performance of DTN technology in space networks, and promoted the development of DTN technology in space networks.

The Consultative Committee for Space Data System (CCSDS) protocol is a "tailor-made" agreement for space missions. The protocol performance is good. Its own protocol system is perfect, and it is widely used by the international aerospace community. But it cannot be directly interconnected with the terrestrial Internet. So, the protocol conversion is necessary. The DTN-based protocol system is designed for deep space environments, and it is designed for longer-term development. However, it has not yet matured in technology application, and it also needs to solve the problems of reliability, congestion control, routing security, and so on.

### *3.2 System Construction*

Compared with terrestrial networks, space-based communication networks have outstanding features of high, long, and wide-area coverage. They have obvious advantages for remote areas that are difficult to cover at sea, air, and ground systems. It has become an important development field of military application, civil communication support, and commercial application.

In civil satellite systems, the International Maritime Satellite System characterized by high-quality, large-capacity, global and full-time communications is the first global mobile service communication system in the world. The International Telecommunication Satellite System (ITSS) is a series of commercial telecommunication satellites operated by the International Telecommunication Satellite Organization (ITSAT), with hundreds of member countries worldwide. The space-based communication and navigation network of the National Aeronautics and Space Administration (NASA) in America is mainly responsible for providing communication and navigation services for space missions throughout the solar system. The European Integrated Global Communication Space Infrastructure is planned to become an IP-based, large-capacity space communication network combining microwave and optical links.

In the military satellite system, the US Air Force's global broadband satellite communication system plans to launch six satellites to provide broadband services. The US Navy's mobile subscriber target system consists of five satellites and four ground stations for providing narrowband mobile communication services. The highly advanced military communication satellite system in the USA uses millimeter-wave inter-satellite links for spatial networking, which can provide joint, interoperable, and guaranteed connectivity for personnel at various levels of conflict in military operations. The TAST of Transitional Satellite Communication System in the USA plans to realize the interconnection with other satellite communication systems of U.S. Army, forming the spatial part of the US global information grid, which provides a reference for the construction of space–earth integrated network.

From the perspective of the development of foreign satellite systems, the transition from a separate satellite communication system to the heterogeneous network of the world has been developed. Now, it is developing toward the integration of heaven and earth [6, 7]. On one hand, under the demand and market traction, the space-based network is becoming larger and larger, and its application is becoming wider and wider. Various operating companies are emerging one after another. The advantages of space-based and terrestrial networks are combined and complemented, and various applications penetrate into all corners of the land and every aspect of people's lives.

On the other hand, driven by scientific and technological innovation, the space-based network's capacity is rapidly increasing, the rate is significantly improved, services are expanding, and costs are significantly reduced. It is subverting the traditional telecom industry concept as well as leading industrial innovation and business model innovation.

# 4 Key Technologies for Space-Based Communications

## *4.1 Wireless Access Technology*

In order to meet the requirements of low peak-to-average ratio of satellite communication signals, the existing satellite mobile communication usually adopts single-carrier continuous phase, constant envelope/quasi-constant envelope modulation to reduce the peak-to-average ratio of the transmitted waveform and improves the out-of-band spectral roll-off. However, with the development of satellite mobile communication services, the available frequency resources of the system are becoming scarce. The single-carrier modulation can no longer meet the capacity requirements of satellite mobile communication systems. On the other hand, with the development of satellite mobile communication services, the resources of L and S bands are becoming increasingly saturated, and high-band satellite mobile communication has become a key area of concern. However, the problem of limited power of satellites is more prominent in high-band communication, and the efficiency of power amplifiers is more high demand.

In addition, the frequency offset in satellite mobile communication is affected by factors such as satellite orbit, communication frequency, elevation angle, and terminal moving speed. The range of variation is large. Under normal circumstances, the large-scale frequency offset appears in two aspects. Firstly, the frequency offset of different communication links is quite different. Secondly, the frequency offset of the same link changes at different times. Therefore, the research on anti-frequency offset, high-efficiency waveform design, and large-scale frequency offset suppression technology has great scientific significance and application prospects for the next-generation satellite mobile communication systems.

As a key technology in the communication process, multiple access technology determines the system performances, such as throughput, delay, stability, and resource utilization. The traditional satellite communication system mainly adopts the on-demand allocation multiple access technology, which is suitable for large data volume service transmission. In recent years, with the development of Internet of things applications, some low-power sensors have become the main terminal types in satellite networks. These sensor terminals are large and densely distributed. They are used to collect and monitor information in the surrounding environment, and then, the data collected is transmitted back to the ground via satellite to complete real-time monitoring of the monitoring targets. Such services have the characteristics of small data volume, frequent transmission and low duty cycle. For small packet service transmission, the traditional on-demand allocation efficiency is low.

Multi-beam satellites generate multiple spot beams at the same time, which not only meet the large-capacity requirements of the system, but also meet the requirements of low-power consumption and miniaturization of mobile user equipment. At present, multi-beam satellite systems mainly use digital beamforming technology. In general, digital beamforming can be divided into onboard beamforming and terrestrial beamforming. Due to the limited processing capacity of satellite payloads, on-ground beamforming flexibility is superior to onboard beamforming, but beamforming requires higher feedband bandwidth and RF channel consistency than onboard beamforming.

As the operating bandwidth of the satellite system and the number of satellite-borne antenna feeds increase, the bandwidth of the feeder channel and the complexity of the RF channel required for on-ground beamforming are getting higher and higher, and the difficulty and cost are increased. Therefore, the mixed beam shaping technology that cascades analog beamforming technology and digital beamforming technology has emerged. The number of radio frequency channels on board of the mixed beam shaping for multi-beam satellite is less than the number of feeds. Besides, it can adjust the beam number and direction based on coverage and capacity demand dynamics. It is one of the development trends of multi-beam satellite beamforming technology [8].

The new technology of space-based communication, while bringing personal convenience, also poses a threat to personal information security to a certain extent. The existing research mainly improves the information security in the process of space-based communication from the following aspects. Firstly, space-based communication physical layer encryption—Compared with other communication sub-layer encryption, physical layer encryption has low encryption algorithm complexity characteristic. It can protect the information interaction process and can utilize channel noise to further improve the security of the algorithm. Therefore, the advantages of the physical layer encryption and the characteristics of the physical channel can be utilized to realize one-time and one-secure, ensuring communication security and reliability. Secondly, the space-based communication network access authentication—In order to prevent various spoofing attacks, two-way identity authentication is performed between the terminal and the network before the data access operation is performed. Thirdly, the space-based communication network key management—Space-based communication resources, computing resources, and storage resources are limited. In the case of limited multi-dimensional resources, a well-designed key management mechanism is essential for space-based communication security. Fourthly, space-based communication network encryption algorithm—Encryption algorithms often face a conflict between security and computational complexity. Aiming at the characteristics of space-based communication channels, designing new encryption and decryption algorithms, balancing data security and encryption and decryption speed are the main research direction of space-based communication information security [9].

## *4.2 Network Technology*

The integrated space-terrestrial network will achieve seamless coverage to the world and provide users with high-quality, high-reliability communication services. However, relying solely on the communication link between satellites, satellite networks cannot truly realize global communication services. Inter-satellite links need to be established between satellites to achieve global interconnection through inter-satellite links and routing protocols. Satellites links are mainly divided into three types including in-orbit inter-satellite links, inter-orbital inter-satellite link and inter-layer inter-satellite link. The in-orbit inter-satellite links are communication links between satellites in the same orbital plane. The inter-orbital inter-satellite link is inter-satellite links between different orbital planes in the same layer. The interlayer inter-satellite link is an inter-satellite link between different layers [10].

Inter-satellite links generally use microwave communication or laser communication for data interaction to construct an entire space-based network. Different from the terrestrial communication network, the topology of the satellite communication network is complex and changeable. The traditional static routing algorithm is difficult to adapt to the entire satellite network. Therefore, the satellite network needs to adopt a dynamic routing algorithm that can maintain and update the routing table to better adapt the complex and variable satellite network topology.

According to the type of satellite orbit, the satellite constellation can be divided into a polar/near polar orbit constellation, an equatorial orbit constellation, an elliptical orbit constellation, and a tilted circular orbit constellation. The design of the satellite constellation is an important link in the construction of the integrated space-terrestrial network. The satellite constellation design in the integrated space-terrestrial network is affected by the duration of the communication link, communication delay, inter-satellite link interference, coverage and capacity requirements. It is an optimization problem of multi-objective and multi-constrained.

Early satellite communication systems generally used a single-layer satellite constellation to support traditional voice, data transmission, and other communication services. The future of integrated space-terrestrial network will be able to provide users with high-capacity, high-quality, and high-reliability communication service, which requires a more reasonable and optimized constellation design. The integrated space-terrestrial network based on multi-layer satellite constellation can improve the reliability and survivability of satellite networks, and it also can provide more link selection for networks.

The space-based communication network node is complex, and it is a typical heterogeneous network. Heterogeneous network resource management in space-based communication mainly manages spectrum, transmit power, beam, and cache resources. Besides, it allocates and uses limited resources reasonably to maximize resource utilization efficiency. Multiple access technology, handover technology, and transmission technology are three key technologies for air and space heterogeneous network resource management. The multiple access technology can cut the granularity of resources and reduce the collision probability of the terminal. The switching technology ensures the continuous communication of the terminal, and control the switching mode of the terminal at the same layer access point and the heterogeneous access point. The transmission technology mainly acts against the channel fading, enhancing anti-jamming capability, and improving link adaptability.

Compared with the terrestrial communication network, the space-based communication network has the characteristics of high dynamics, large time and space span, which brings great challenges to the network management. At the same time, different satellite load capabilities vary greatly. It is difficult to update and maintain the on-orbit hardware. The space-based communication network based on software-defined network ideas is flexible for deploying and configuring satellite networks, reducing the complexity and operating costs of satellite networks. It is important to improve the overall performance of the network.

In a software-defined satellite network, the network data plane and the control plane are separated. The control plane is responsible for the unified management of the network, while the data plane is only responsible for data forwarding. In addition, the software-defined satellite network can better implement user service customization and satellite–earth integration service based on technologies such as virtualized resource slicing, global resource management, and dynamic routing management.

The satellite–earth fusion networking can better utilize the advantages of space-based networks and ground-based networks. The two networks can complement each other to improve system capacity and service quality. They can improve the utilization of network resources. Due to the differences in access technologies, networking modes, and control mechanisms between mobile satellite networks and terrestrial networks, the satellite–earth fusion networking also faces some problems that need to be solved urgently. Transparency is one of them, that is, how to make user terminals do not aware that they are using ground base stations or satellites to communicate. In the satellite–earth fusion networking, accessing different networks will bring different performance experiences to users. How to access the appropriate network and allocate corresponding resources according to the user's service characteristics and needs and how to guarantee users' access to better service networks are the problems that need to be solved by the integrated space-terrestrial network

## 5 Conclusion

Establishment of an autonomous control, global coverage, and military–civilian sharing of the integrated space-terrestrial information network is to better adapt to the needs of the development of economic globalization and realizing modernization of national defense information. Besides, the construction of integrated space-terrestrial information network is the need of maintaining national security and development interests; is the need of achieving sustainable development and innovation of space application technology; is the need of achieving the great space power toward a powerful space power; and is the need of realizing the Chinese dream of national renaissance.

The core of integrated space-terrestrial information network is space-based network. Its key technologies are also concentrated in space-based networks. In order to meet the needs of our national strategic development and to meet the actual demand of national defense construction and military support capability, we should further strengthen the research and construction of the integrated space-terrestrial information network in order to promote information sharing and comprehensive utilization of resources as well as to bring into full play of the application benefits of aerospace information construction combining the fast development trend of aerospace technology.

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