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Development of Land–Sea–Air–Space Integrated Information Network

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Abstract: The land–sea–air–space integrated information network is capable of providing globally accessible, safe, and reliable information services for land-, sea-, space-, and air-based users. It is an important infrastructure for China to maintain independence in the information field and become a cyberpower. This study utilized literature research and expert consultations as the main research methods to summarize the development requirements of the land–sea–air–space integrated information network. Following a detailed description of typical domestic and foreign systems, the major weaknesses of China's land–sea–air–space integrated information network are summarized. Additionally, an integrated information network architecture and development routes are proposed. Specifically, we suggest that China should focus on deep integration in terms of network architectures, technical systems, and application services to integrate communication, navigation, and remote sensing systems, promote technical independence and industrial upgrades to space-based networks, and improve its system security protection capabilities.
Keywords: land–sea–air–space integrated information network; space-based information system; network architecture; integrated network; development route

1 Introduction

The continuous progress of information network technology has become the leading force of innovation-driven development, which has a profound impact on politics, military, economy, culture, and other fields, and drives the reformation and remodeling of social systems. As important information infrastructures for supporting social development, space-based information networks and ground information networks have been developed independently for many years, but their limitations are becoming increasingly obvious, making it difficult to meet the requirements of global network coverage, security and autonomous control, and flexible access for all types of users. In recent years, information networks have gradually become increasingly integrated and developed, and the space–ground integrated information network [1–4], as well as an integrated wireless communication network based on sixth-generation mobile communications technology (6G), have been proposed [5]. The technology development ideas for the land–sea–air–space integrated information network (LSASIIN) have gradually become clearer.

The LSASIIN is based on a terrestrial network and extended by a space-based network to cover the space, air, land, and sea. It provides information for various activities performed by space-, air-, land-, and sea-based users. The development and construction of such a network not only reflect comprehensive scientific, technological, and economic strength, but also promote the independent innovation and development of China's relevant fields, meet national strategic needs, and enhance the competitiveness of national cyberspace.

The main difficulty in research on LSASIIN technology is the construction of a global space-based information

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network using satellite-platform-based network nodes to achieve the efficient and deep integration of land-, sea-, air-, and space-based networks at all levels. To this end, this paper analyzes construction requirements, reviews the current development situation, presents existing problems and gaps, and proposes the concept of an integrated network architecture and development route to provide references for the implementation of cyberpower-related major planning and projects.

2 Demand analysis for LSASIIN

China's information industry and its basic research programs are developing rapidly, but the problems of a "strong ground infrastructure with a weak space-based infrastructure," and "strong domestic infrastructure with a weak international infrastructure" still exist. Currently, the space-based information network mainly serves the territory of China and the overseas terrestrial network can not support the application requirements for diplomacy and emergency scenarios based on a lack of safe and controllable conditions. Therefore, the construction of an LSASIIN is important for handling complex international situations. In the civil field, the LSASIIN must meet the public requirements of e-government, energy and water conservancy, production and manufacturing, marine economy, transportation, securities and finance, education and scientific research, cultural tourism, telemedicine, and other industries.

2.1 Global coverage and lunar space extension capabilities

Based on China's economic development and comprehensive strength, national strategic interests have extended significantly, highlighting the need for global diplomacy and emergency activities. Regarding information networks, there is a need to expand the scope of protection from traditional land areas and surrounding areas to the global scene, expand the scope of protection from traditional land users to sea-, air-, and space-based users, and further provide information service capabilities for lunar and deep space exploration.

2.2 Multi-coverage capacity in priority areas and hot spots

To meet China's development and strategic deployment needs in key regions, the information network should cover East Asia, South Asia, countries and regions along the Belt and Road, and the Arctic region as soon as possible. For hot spots such as the South China Sea, multiple coverage capabilities and the on-demand enhancement of security capabilities are required. Compared to other regions, information networks in priority areas and hot spots should have greater coverage, service more users, provide higher data transmission bandwidth, and ensure better voice communication quality.

2.3 Integrated networking capacity

The LSASIIN must guarantee the communication needs of key users in any location and at any time globally. It must have the capabilities of spatial networking to realize effective global random access and backhaul of overseas information, provide multi-network access capabilities for user terminals, support network users accessing the terrestrial Internet and performing mobile Internet services, and support the interoperability of mobile and broadband services.

2.4 Space backbone transmission capacity

The ground backbone network has limited extension to overseas areas, remote areas, sea areas, and airspace, and must have space backbone transmission capabilities. Currently, China's civil sector network users are mainly from the transportation, water conservancy, agriculture, local government, foreign enterprise/media, and mass business fields. By 2025, approximately 1×10^7 public users and 3×10^6 industry users are anticipated and the space backbone network transmission requirements will be approximately 300 Gbps. By 2030, approximately 3×10^7 public users and 4×10^6 industry users are anticipated and the space backbone network transmission requirements will be approximately 1 Tbps. Space backbone transmission capabilities and the ground backbone network should evolve simultaneously and be developed in concert to meet the rapid growth of civilian demand.

2.5 Terminal diversification capabilities

To meet the needs of a variety of scenarios, the LSASIIN must configure handheld, embedded, desktop, and other diversified terminals. Handheld terminals should support a variety of communication systems with

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navigation and positioning, voice communication, and information transmission functions, and should serve as the main application terminals for disaster and emergency response scenarios. Embedded terminals are generally used to provide space-based Internet of Things services through installations such as marine buoys and container monitoring units, and they must have the characteristics of multi-system compatibility, miniaturization, and low power consumption. Desktop terminals are divided into fixed, onboard, ship-borne, airborne, and other types, which require voice communication, data communication, video image transmission, etc. Additionally, as a network node, the ground LAN is connected to a space-based network to provide remote backhaul and broadband multimedia services.

3 Development status of the LSASIIN

3.1 Development status of foreign networks

Since the beginning of the 21st century, developed countries have been actively planning the construction of integrated information networks, competing for the right to control space, air, and sea resources, and promoting the integration of space-based networks with terrestrial interconnection networks and mobile communication networks. Currently, several space-based networks, including geosynchronous orbit (GEO) and low Earth orbit (LEO) constellations, have been formed [6] (Table 1). The positioning and users of different systems have different focuses, including civil systems such as Starlink and OneWeb, military systems such as the Advanced Extremely High Frequency (AEHF) satellite communication system, and converged systems such as Iridium Next.

Table 1. Typical foreign space-based information systems.

Name of system	Type	Features
Transformational Satellite Communications System (TSAT) [7]	GEO constellation	Consists of five GEO satellites based on onboard IP switching and inter-satellite high-speed lasers for direct interconnection to the AEHF and terrestrial grids. The research program for this system was cancelled in 2009.
Integrated Space Infrastructure for Global Communications (ISICOM) [8]	Hybrid constellation	Includes GEO satellites, medium Earth orbit (MEO) satellites, LEO satellites, high altitude platforms, unmanned aerial vehicles, and other space nodes, as well as a variety of ground nodes based on IP switching, and microwave and laser hybrid high-capacity interplanetary Internet, which can connect communication, navigation, Earth observation satellites, and terrestrial networks.
ViaSat	GEO satellite	The deployed ViaSat-2 has a total capacity of 300 Gbps and can provide 25 Mbps broadband services to 2.5 million users. The upcoming ViaSat-3 has a capacity of 1 Tbps.
Iridium Next	LEO constellation	Global coverage via 66 satellites with end-to-end IP technology and Ka inter-satellite links that can achieve global digital communications and provide services to terminals anywhere on the planet without relying on ground transmissions.
Starlink	LEO, very LEO multi-orbit hybrid constellation	Over 40 000 satellites (including interplanetary links) are planned to provide high-speed Internet services worldwide with volume production capability and recoverable rockets. A total of 1145 satellites have been launched as of February 16th, 2021.
OneWeb	LEO multi-orbit hybrid constellation	Over 6000 satellites are planned with no interplanetary links or on-satellite processing. Service data are downloaded to the closest gateway. A total of 110 satellites have been launched.
Telesat	LEO multi-orbit hybrid constellation	Thus far, 298 satellites are planned in polar and inclined orbits with onboard routing and laser inter-satellite links. One test satellite has been launched

3.1.1 Information transmission

Inter-satellite link technology is maturing and its capacity is increasing. For example, Ka-band links have matured and laser links are entering the testing phase. Developed countries are committed to developing the LSASIIN. The United States has strengthened its inter-satellite links and on-satellite routing/exchange capabilities, and is constructing a space communication network based on multi-satellite networks to realize a complete global information grid. Broadband satellite communication technology based on space networking is an important component of the LSASIIN and is of great significance for enhancing communication capacity, coverage capability, system resistance to destructive incidents, and the survival of broadband satellite communication systems. Broadband satellite communication systems are gradually developing in the direction of Ka-band multi-beams and increasing the available bandwidth and capacity of systems through frequency multiplexing and polarization multiplexing technologies.

3.1.2 Network architectures

The main types of network architectures that are widely used are "space-based nodes with terrestrial networks," "space-based networks," and "space-based networks and terrestrial networks." The technology for the "space-based nodes with terrestrial networks" architecture is relatively mature and widely used, but it is not suitable for application in China. The "space-based network" architecture has advantages in terms of security, anti-destructiveness, and independence, but because it operates independently from the ground, capabilities of on-satellite processing and inter-satellite information transmission are required, increasing the technical complexity and costs for system construction and maintenance, making it difficult for this architecture to be fully promoted and applied at the commercial level. The "space-based networks and terrestrial networks" architecture makes full use of the wide-area coverage capabilities of space-based networks, and powerful transmission and processing capabilities of terrestrial networks, thereby reducing the technical complexity and cost of the entire system.

3.1.3 Services classification

Currently, space-based services are being developed in the direction of IP bearer networking and multiple services on a single system. The evolved versions of systems such as Wideband Global Satcom and Iridium Next are gradually supporting diversified access services such as real-time communication, space target monitoring, navigation, and positioning. The services provided by space-based networks and terrestrial networks are also becoming increasingly similar.

3.2 Development status of networks in China

China is in the initial stages of promoting the comprehensive integration of space-based information networks, the future Internet, and mobile communication networks. In 2016, the Space-Ground Integrated Information Network project was included in the outlines of the 13th Five-Year Plan and the 13th Five-Year Plan for National Science and Technology Innovation. In 2020, the satellite Internet was identified as one of the important information infrastructures in the New Infrastructure Construction. Research institutes and related enterprises are vigorously developing LEO small-satellite constellations such as the Hong Yan Constellation and the Hong Yun Project. Relevant test satellites have completed the verification of key technologies in orbit. In addition to developing space-based networks actively, China continues to develop new generations of high-throughput communication satellites and has launched the SJ-13, Asia-Pacific 6D, and the SJ-20 satellites. High-throughput communication satellites are becoming increasingly powerful in terms of ground coverage and communication capacity, and are gradually becoming an important form of expansion of China's ground network infrastructure. Basic information on relevant space-based information systems is presented in Table 2.

4 Development gap analysis of China's LSASIIN

4.1 Single satellite capacity is relatively low

Satellite capacity is an important indicator of the quality of satellite communication services that determines the number of users that can be served by a satellite and the communication capacity of a single user. The capacity of the Asia-Pacific 6D satellite is 50 Gbps, which is 2.5 times that of the SJ-13 satellite, but is still significantly lower than that of similar satellites launched by the United States. The ViaSat-2 satellite has a capacity of 300 Gbps, which is six times that of the Asia-Pacific 6D. The ViaSat-3 satellite, which is to be launched in 2022, will have a further increase in capacity to 1 Tbps.

4.2 No engineering applications for space laser communication technology

Space laser communication has the advantages of rich bandwidth resources, narrow beam dispersion, and low mass and power consumption, and is an important method for achieving high-capacity transmission between

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satellites and between satellites and ground gateways [9]. In recent years, China's space laser communication technology has made significant progress and has achieved a GEO satellite-to-ground communication rate of 5 Gbps, reaching the international first-class level. However, regarding engineering applications in orbit, there are many problems such as the inability to connect links, amplifier burnout, and low transmission rates. Additionally, the current operation duration is not sufficient to prove overall success. The German European Data Relay System achieved inter-satellite laser communication between GEO and LEO satellites in 2016 with a communication rate of 1.8 Gbps and is still functioning [10].

Table 2. Typical space-based information systems in China.

Name of system	Type	Features
Space-Ground Integrated Information Network	Hybrid constellation	GEO and LEO multi-layer multi-orbit space networking supporting on-demand access for all types of users on land, sea, air, and space, and providing mobile communications, broadband connectivity, space-based IoT, navigation augmentation, maritime/air surveillance (AIS/ADS-B), and other services with two test satellites launched in 2019.
Hong Yan Constellation	LEO multi-orbit hybrid constellation	A total of 324 satellites are planned to be launched to achieve the combination of broadband and narrowband communication capabilities with microwave inter-satellite links for space networking to provide mobile communication, broadband communication, navigation augmentation, aviation/maritime surveillance, and other services with the test satellite "Chongqing" launched in 2018.
Hong Yun Project	LEO multi-orbit hybrid constellation	A total of 156 satellites are planned to be launched to achieve global coverage for broadband communications using laser inter-satellite links with a test satellite launched in 2018.
SJ-13	GEO satellite	China's first high-throughput communication satellite and the first application of a Ka-band communication payload, with a total communication capacity of 20 Gbps.
SJ-20	GEO satellite	Q/V-band payload, broadband flexible transponder with a bandwidth of 5 GHz, and a satellite-to-ground laser communication payload achieving a communication rate of 10 Gbps.
Asia-Pacific 6D	GEO satellite	Ku and Ka carriers with a total capacity of 50 Gbps and up to 1 Gbps in a single beam.

4.3 Significant gaps in satellite bulk production and deployment capabilities

The number of satellites in orbit is an important factor limiting the capacity of the LSASIIN. The United States has been deploying and operating constellations such as Iridium and Globalstar since the 1990s and is currently deploying the Starlink constellation, whereas China has no experience with the engineering construction and operation of large constellations. Starlink and other emerging satellite Internet projects use Internet thinking, which draws on the concepts of car manufacturing, to reduce production costs and improve satellite manufacturing capacity significantly. The weekly output of satellites is as high as 16 and the cost of each small satellite is approximately 500 000 USD. In contrast, China's communications satellites still use the traditional engineering development model and even after a technology matures, it takes two years to develop the entire satellite cycle, which does not provide the ability to deploy satellites rapidly on a large scale.

4.4 Insufficient systematization and difficult integration of space-based networks

China's communication satellites, relay satellites, and broadband constellations under construction are all developed independently and China has not yet formed a unified standards system for combining different technical systems, making it difficult to achieve efficient connectivity between different network users. The uneven development of space-based information networks and terrestrial networks makes it difficult to form a "single network," but the LSASIIN requires deep integration. In contrast, the United States proposed the use of the TSAT system as the basis for converging AEHF and terrestrial grid networks, and Europe proposed constructing a converged ISICOM information infrastructure and has begun the first phase of work. In 2018, the International Telecommunication Union established the Network 2030 Focus Group, which identified satellite access as one of the main features of future networks. In 2019, the Institute of Electrical and Electronics Engineers held the first Global 6G Wireless Summit, prompting a general consensus in the academic and engineering communities for developing integrated networks containing space-, air-, and ground-based components.

5 Infrastructure for the LSASIIN

China urgently needs to construct "globally covering, secure, and self-controllable" information networks. However, based on current national conditions, it is not possible to adopt an architecture of space-based nodes with terrestrial networks to realize information landing and interaction by deploying gateways around the world. Therefore, it is advisable to adopt a space-based network and terrestrial network architecture containing a core layer, access layer, and user side (Fig. 1).

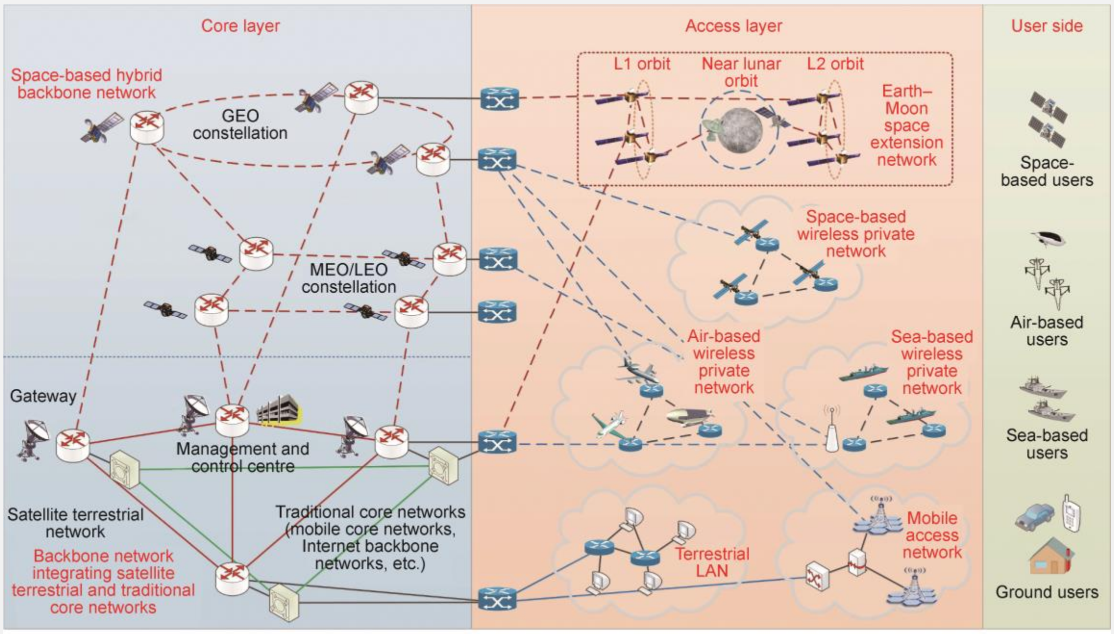

Fig. 1. Physical architecture of the LSASIIN.

5.1 Core layer

The core layer of the LSASIIN adopts a dual-backbone architecture. The terrestrial part consists of traditional core networks (such as ground fiber networks and submarine fiber networks) and a satellite terrestrial network (i.e. satellite terrestrial and traditional core networks with an integrated backbone network referred to as a "terrestrial backbone"), which is the core component of the entire network. This component realizes network control, resource management, protocol transition, information processing, integration sharing, and other functions. It is responsible for the management, control, and operation of the entire network. The space-based component refers to the space-based hybrid backbone network (referred to as the "space-based backbone"), which consists of GEO constellations, MEO constellations, and LEO constellations, which have certain access control, user management, information processing, and service bearing capabilities, and provides a variety of services such as broadband access, backbone interconnection, relay transmission, space-based telemetry, and control, and can also be expanded to provide navigation enhancement, satellite-based surveillance, and other services. The LSASIIN should provide services anywhere, including the seabed, sea surface, land, air, near-Earth space, Earth space, Earth–Moon space, and deep space, with a wide range of corresponding users. The core layer is constructed with a dual backbone that fully benefits from the complementary advantages of both space-based and terrestrial networks, forming an integrated information network core layer with an integrated design for the network architecture, coordinated use of frequency resources, seamless integration of service applications, and collaborative protection of user services. This effectively enhances user access and heterogeneous network integration, and optimizes system service performance.

5.2 Access layer

The access layer of the LSASIIN is an extension of the core layer and is responsible for user access, including

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the Earth–Moon space extension network, space-based wireless private network, air-based wireless private network, sea-based wireless private network, terrestrial local area network, and mobile communication access network. (1) The Earth–Moon space extension network is an extension of the Earth–Moon space information service consisting of a full-time, large-scale, broadband, and high-speed Earth–Moon space communication network that provides uninterrupted communication guarantees and realizes efficient and reliable information interactions between the Earth and Moon. (2) The space-based wireless private network consists of multiple satellites or constellations and serves as the user network for the core layer to receive information from all types of users. (3) The air-based wireless private network is typically composed of aircraft, near-space aircraft, unmanned aerial vehicles, and other platforms, and serves as the user network for the core layer to receive information from all types of users. (4) The sea-based wireless private network is typically composed of various types of surface ships, offshore platforms, and other platforms, and serves as the user network for the core layer to receive information from all types of users. (5) The terrestrial local area network combines traditional core networks and ground users, representing the current terrestrial Internet. (6) The mobile communication access network combines traditional core networks and ground users, representing the current terrestrial mobile network.

5.3 User side

The LSASIIN will provide services to governments, the military, enterprises, and other public users. To extend the functions of transmission, networking, applications, security protection, operations, and maintenance to the user side and integrate them with user applications, it must provide application systems that meet the needs of different users, such as ground-, sea-, air-, and space-based users.

6 Development proposals

6.1 Strengthen the in-depth integration of the network architecture, technical system, and application service support system

(1) Regarding network architecture integration, we suggest breaking from the closed development process of traditional satellite and terrestrial networks, and designing a multi-dimensional integrated shared network from three dimensions—logical functions, functional deployment, and collaborative service—to make network system components more universal, interfaces more standardized, and operations more centralized. (2) Regarding technology system integration, we suggest adopting a unified core network to support the co-management and sharing mechanisms of the space-based Internet and terrestrial mobile communication networks, and designing an integrated air interface access technology system with variable parameter sets according to the concepts of software definition and unification of GEO and LEO networks. (3) Regarding application service support system integration, we suggest adopting the concept of cloud–network integration and deploying space-based information ports and lightweight space-based edge computing platforms to realize in-orbit cloud–edge collaborative processing. This system should be integrated with ground information ports and provide an application service support platform with extensibility, high efficiency, wide coverage, and time sensitivity for various vertical industries and integrated applications.

6.2 Promote the integration of communication, navigation, and remote sensing systems, and establish a space-based information network with integrated services

The integration and application of a variety of space-based service capabilities will help to improve emergency response capabilities for global emergencies and promote the development of the space-based information commercialization service industry, which is the basis for supporting the realization of information superiority for China. We suggest that “multiple purposes for a single satellite, multi-satellite networking, multi-network integration, and real-time services” should be developed and that multi-type, high-quality, stable, reliable, and large-scale integrated services such as data, communication, navigation, and remote sensing services should be provided based on scientific, reasonable, and on-demand task planning, as well as multi-center collaborative service modes, to support the comprehensive application of various industries.

6.3 Promote the independent control of space-based network technology and upgrading of high-end industries

The LSASIIN is an important infrastructure for China to avoid being controlled by other nations and become a cyberpower. It should be ensured that its design, development, construction, and operation processes can be controlled independently. We suggest maintaining investments in the independent research and development of standards systems, research and industrialization of basic components in the fields of space-based traffic information management, sensing networks, and space communication, and changing the current scenario in which standards depend on foreign countries, technology depends on introduction processes, and industry is restricted as soon as possible. We also suggest improving the level of localization substitution in related application fields, stimulating domestic demand through product substitution and upgrading, and promoting the circular development of the national economy.

6.4 Strengthen the capacity for constructing system security protection

The LSASIIN has the characteristics of exposed nodes, open channels, interconnection of heterogeneous networks, a highly dynamic topology, and limited onboard processing capacity. Additionally, it can be easily attacked through external networks, particularly in the aspects of measurement and control links, satellite-to-ground networking, application service systems and information supervision, owing to its integration with the Internet. We suggest strengthening the integrated design of communication and security protection according to the concept of a flexible system, endogenous security, and dynamic empowerment. New anti-interference waveforms, spectrum cognitive radio, networking authentication and access authentication, differentiated network security interconnection and isolation with multiple security levels, and the dynamic reconfiguration of security protection equipment should be adopted to ensure the security and reliability of the integrated network.

References

[1] Shen R J. Some thoughts of Chinese integrated space-ground network system [J]. Strategic Study of CAE, 2006, 8(10): 19–30. Chinese.

[2] Zhang N T, Zhao K L, Liu G L. Thought on constructing the integrated space-terrestrial information network [J]. Journal of China Academy of Electronics and Information Technology, 2015, 10(3): 223–230. Chinese.

[3] Yao H P, Wang L Y, Wang X D, et al. The space-terrestrial integrated network (STIN): An overview [J]. IEEE Communications Magazine, 2018, 56(4): 2–9.

[4] Wu W. Survey on the development of space-integrated-ground information network [J]. Space-Integrated-Ground Information Networks, 2020, 1(1): 1–16. Chinese.

[5] You X H, Wang C X, Huang J, et al. Towards 6G wireless communication networks: Vision, enabling technologies, and new paradigm shifts [J]. Science China Information Sciences, 2021, 64: 1–76.

[6] Wang C T, Zhai L J, Xu X F. Development and prospects of space-terrestrial integrated information network [J]. Radio Communications Technology, 2020, 46(5): 491–504. Chinese.

[7] Pulliam J, Zambre Y, Karmarkar A, et al. TSAT network architecture [C]. San Diego: Military Communications Conference, 2008.

[8] Vanelli-Coralli A, Corazza G E, Luglio M, et al. The ISICOM architecture [C]. Siena: 2009 International Workshop on Satellite and Space Communications, 2009.

[9] Kaushal H, Kaddoum G. Optical communication in space: Challenges and mitigation techniques [J]. IEEE Communications Surveys & Tutorials, 2017, 19(1): 57–96.

[10] Xu X F, Lu Z. Research status of mitigation techniques to assure the reliability of satellite-to-ground laser communications [J]. Journal of China Academy of Electronics and Information Technology, 2018, 13(6): 650–657. Chinese.