Proceedings of the 5th International Conference on Signal Processing and Machine Learning
DOI: 10.54254/2755-2721/112/2025.17861

Application of 6G Technology in Satellite-Terrestrial Communications

Linglong Li[1,a,*]

[1]Hangzhou Changhe High School, Hangzhou, 310052, China
a. 774344527@qq.com
**corresponding author*

Abstract: In the contemporary digital era, the accelerated dissemination of data and pervasive interconnectivity have emerged as pivotal drivers of social advancement. The increasing demand for high-performance satellite-terrestrial communications systems, which are vital for achieving seamless global coverage, presents a significant challenge. The advent of 6G technology offers a promising avenue for addressing the current limitations of satellite-terrestrial communications. This paper presents a comprehensive review of the potential applications of 6G technology in satellite-terrestrial communication systems, with a particular focus on its capacity to transform these systems. By achieving seamless global connectivity, 6G technology is positioned to address the limitations of current communication technologies and enhance communication speeds, reliability, and efficiency. This research indicates that the integration of satellite and terrestrial communication networks through 6G not only improves the overall efficiency and coverage of the communication network, but also addresses existing challenges such as limited coverage, high latency and scarce spectrum resources. As research and development progresses, it will be essential to facilitate the widespread adoption and evolution of 6G technology in satellite-terrestrial communications through strengthened global cooperation and standardisation.

Keywords: 6G, Satellite-terrestrial communication, Dynamic Spectrum Sharing, RIS, LEO.

1. Introduction

Sixth-generation (6G) technology stands as an emerging and crucial frontier in the realm of wireless communication, poised to revolutionize satellite-terrestrial communication systems in unprecedented ways. As people edge closer to the technological leap of 6G, its potential within integrated satellite-terrestrial networks becomes increasingly apparent. 6G technology aims to achieve seamless global connectivity through the harmonious fusion of satellite and terrestrial communication. This paper delves deeply into the utilization of 6G, examining its capacity to overcome the challenges faced by traditional networks and enhance communication quality and coverage. This study reviews the literature and explores the application of Sixth-generation (6G) technology in satellite-terrestrial communication systems, highlighting its potential to revolutionize these systems in unprecedented ways. Overall, this paper provides a comprehensive overview of the application of 6G technology in satellite-terrestrial communication systems, highlighting its potential benefits and the challenges that need to be addressed to fully harness its capabilities. As technological progress continues and market requirements escalate, satellite-terrestrial communication technology, in synergy with 6G advancements, is poised for an expansive phase of evolution.

2. Shortage of satellite- terrestrial technology

2.1. Technical challenges

(1). Complex Channel Conditions. The open and complex nature of the satellite-terrestrial communication environment makes it susceptible to factors such as rain, snow, and ionospheric loss, leading to signal distortion and transmission instability. This increases the complexity and instability of communication, necessitating the adoption of more advanced channel coding and modulation techniques.

(2). High Latency. Although the deployment of low-earth orbit (LEO) satellite constellations has the potential to mitigate communication latency to some extent, satellite-terrestrial communication still grapples with higher delays in comparison to terrestrial systems. This poses a challenge for applications with high real-time requirements, such as online gaming and HD video calls.

(3). Limited Spectrum Resources. With the rapid development of communication technologies, spectrum resources are becoming increasingly scarce. Satellite-terrestrial communication, as a form of wireless communication, also faces the issue of spectrum resource allocation. Efficient utilization of spectrum resources and prevention of interference between different systems are crucial challenges to overcome.

2.2. Security issues

(1). Vulnerability to Attacks. The open wireless propagation environment of satellite-terrestrial communication increases the risk of eavesdropping. Furthermore, the inherent mobility of wireless terminals engenders a dynamically evolving topology within the satellite-terrestrial communication network, complicating the management of terminal security. This makes satellite-terrestrial communication susceptible to security attacks such as forgery, tampering, and malicious interference from adversaries in military and commercial applications.

(2). Encryption Technology Challenges. With the continuous improvement of modern computing power, traditional encryption schemes face the risk of brute-force cracking. Enhancing the security and reliability of encryption techniques while maintaining communication speed is a difficult problem for satellite-terrestrial communication.

2.3. Economic and cost issues

(1). High Equipment Costs. The capital-intensive nature of satellite development, deployment, and operational maintenance results in elevated costs associated with satellite-terrestrial communication infrastructure. This limits the application of satellite-terrestrial communication in economically underdeveloped regions and remote areas.

(2). Difficult Maintenance and Upgrades. Once satellites are launched into space, their maintenance and upgrade become more challenging and costly than terrestrial equipment. This requires satellite-terrestrial communication systems to be designed with maintainability and scalability in mind to facilitate upgrades and maintenance when necessary.[1]

2.4. Standardization and Interoperability

(1). Low Standardization Level. At the present juncture, there is a lack of unified international standards in the field of satellite-terrestrial communication, leading to differences between systems

DOI: 10.54254/2755-2721/112/2025.17861

in different countries and regions, hindering interconnectivity. This restricts the global application and development of satellite-terrestrial communication.

(2). Poor Interoperability. Owing to the limited degree of standardization, the interoperability between disparate satellite-terrestrial communication systems is notably lacking. This increases the difficulty and cost for users to switch between different systems, limiting the flexibility and scalability of satellite-terrestrial communication.

In summary, satellite-terrestrial communication currently faces deficiencies in technical challenges, security issues, economic and cost considerations, as well as standardization and interoperability. As technological innovations progress and the scope of application scenarios broadens, it is anticipated that these impediments will be incrementally mitigated and resolved.

3. The reasons why the 6G technology can solve these problems

3.1. Enhanced global network coverage

(1). Seamless Global Coverage. 6G technology, through the deep integration of satellites and terrestrial networks, enables network connectivity in every corner of the globe, including remote areas, oceans, mountains, and other regions where terrestrial networks struggle to reach. This advancement marked by the profound integration of satellite and terrestrial networks significantly enhances the accessibility and quality of global communication systems.[2-3]

(2). Multi-layer Heterogeneous Network Integration. The 6G framework is poised to establish an intricate, integrated network architecture that amalgamates space-based multi-layer subnets with terrestrial cellular multi-layer subnets. This integration is designed to provide a more holistic and three-dimensional network coverage, thereby augmenting the overall efficiency and reach of communication networks.

3.2. Improved data transmission speed and efficiency

(1).Low Earth Orbit (LEO) Satellites: 6G heavily relies on LEO satellites, which orbit closer to Earth, significantly reducing signal transmission latency and enhancing data transmission speed and efficiency. Additionally, LEO satellites are relatively cost-effective to manufacture and launch, facilitating large-scale deployment.[4-8]

(2).Satellite-Terrestrial Cooperative Transmission: 6G technology will achieve cooperative transmission between satellites and terrestrial networks, optimizing network architectures and transmission algorithms to further boost data transmission speeds and reliability.

3.3. Strengthened network security and reliability

(1). Backup Network: Satellite communications in 6G serve as a backup for terrestrial networks, ensuring uninterrupted communication continuity in case of terrestrial network disruptions due to attacks or natural disasters.

(2).Dynamic Topology and Routing Algorithms: 6G adopts advanced dynamic topology and routing algorithms to adapt to the dynamic changes in satellite networks, ensuring reliable data transmission and network stability.[2]

3.4. Driving technological innovation and industrial upgrading

(1). Enhanced On-Satellite Processing Capabilities: 6G demands significant advancements in on-satellite processing, including processors, radio frequency subsystems, antennas, and data transmission algorithms, driving overall progress and industrial upgrading in satellite communication technology.

DOI: 10.54254/2755-2721/112/2025.17861

(2). Antenna Technology Innovation: To enable satellite communication on small devices like smartphones, 6G necessitates innovations in antenna design, integrated circuit chip design, and more, catering to the demands of device miniaturization and lightweighting.

3.5. Reduced operating costs and enhanced economics

(1). Cost Reduction: By leveraging LEO satellites and large-scale constellations, 6G significantly reduces the manufacturing and launch costs of satellite communications. Moreover, the refinement of network architectures and transmission algorithms is expected to contribute to a decrease in operational expenditures and an enhancement of the economic viability of satellite communication networks.

(2). Expanded Commercial Applications: The widespread adoption of 6G technology will expand the commercial applications of satellite communications in mobile broadband, IoT, high-precision positioning and navigation, and other fields, fostering new economic growth points globally.[4]

4. Applications

Satellite-ground Integrated Network Architecture: The present study introduces a satellite-ground integrated network architecture underpinned by 6G technological advancements. By optimizing the design of satellite orbits and enhancing interoperability between satellites and ground base stations, it achieves seamless global coverage. This architecture supports the coexistence of multiple services, including voice, data, video, etc., to meet the communication needs of diverse users.[9-10]

Intelligent Reconfigurable Intelligent Surface (RIS) Technology: As one of the key technologies for 6G, RIS enables flexible control over the propagation paths of electromagnetic waves in satellite-ground communication, enhancing signal coverage and communication quality. The introduction of RIS can significantly reduce the complexity and cost of satellite communication while simultaneously boosting the flexibility and scalability of the network.

Dynamic Spectrum Sharing: 6G technology advocates for the adoption of Dynamic Spectrum Sharing (DSS) strategies, which optimize the utilization of spectral resources, thereby augmenting the communicative efficiency of integrated satellite-ground networks. By utilizing advanced technologies such as blockchain, decentralized management and transparent allocation of spectrum resources can be achieved, ensuring fairness and security of resource utilization.

5. Challenges

5.1. Elevated technical complexity

(1).High-Frequency Wireless Transmission: 6G technology will explore the use of higher frequency bands, such as the terahertz range, to achieve even higher data transmission rates. However, high-frequency signals are prone to attenuation and absorption by atmospheric conditions like rain, limiting signal propagation and coverage. Therefore, achieving stable and efficient wireless transmission at these frequencies poses a significant challenge for 6G technology.

(2).Space-Air-Ground-Sea Integrated Network: 6G aims to construct an integrated network spanning space, air, ground, and sea, enabling global seamless coverage. This requires 6G technology to address interoperability issues among diverse network types, including satellite networks, terrestrial cellular networks, and drone networks. Additionally, managing spectrum sharing and interference between these networks to ensure overall network performance and stability is a critical challenge.

5.2. Multidisciplinary technology integration

(1). Deep Integration of AI and Communications Technology: 6G introduces artificial intelligence (AI) algorithms into every aspect of communication networks, including planning, optimization, and operation. However, effectively fusing AI algorithms with communication technology to enhance network intelligence while minimizing algorithmic complexity and computational costs is a key challenge for 6G.[11-14]

(2).Convergence of Sensing and Communication Technologies: 6G explores the integration of sensing and communication technologies to enable joint communication and sensing capabilities. This necessitates 6G technology to coordinate sensing and communication functionalities efficiently, managing the additional load and privacy concerns arising from sensor data.

5.3. Network architecture redesign

(1).Design of Novel Network Architectures: 6G requires the design of a new network architecture capable of supporting space-air-ground-sea integrated transmission. This architecture must address packet loss issues due to high transmission rates and low latency, while ensuring scalability, flexibility, and security. Developing an efficient, reliable, and secure network architecture is a critical challenge for 6G.

(2).Network Slicing and Edge Computing: 6G will extensively utilize network slicing and edge computing to cater to diverse application scenarios. However, flexible deployment and efficient management of network slices, along with achieving low-latency, high-reliability data processing and transmission in edge computing environments, pose technical challenges for 6G.

5.4. Other technical challenges

(1).Low-Power Design: As 6G networks expand their coverage and transmission rates, device power consumption becomes more critical. Thus, reducing device power consumption while maintaining performance is a vital challenge for 6G technology.

(2).Security and Privacy Protection: 6G networks will carry more sensitive data and privacy information, necessitating heightened focus on network security and privacy protection. This includes strengthening network defenses, enhancing data encryption, and refining privacy protection mechanisms.

In conclusion, the technical impediments facing 6G technology span a wide array of dimensions, encompassing heightened levels of technical intricacy, including elevated technical complexity, multidisciplinary technology integration, network architecture redesign, and other challenges such as low-power design and security and privacy protection. Addressing these challenges requires collaborative efforts from researchers and industries worldwide.

6. Discussion

Anticipating future developments, the confluence of continuous technological progress and escalating market requirements suggests that satellite-terrestrial communication technology, in synergy with 6G advancements, is on the cusp of an expansive phase of evolution. On one hand, as 5G technology is being deployed commercially and 6G technology progresses in research and development, satellite-terrestrial communication will achieve higher data transmission rates, lower latency, and wider coverage. On the other hand, with the emergence of new application scenarios such as the Internet of Things (IoT) and smart cities, satellite-terrestrial communication will play a pivotal role in numerous fields. Additionally, strengthened global cooperation and the advancement of standardization will

DOI: 10.54254/2755-2721/112/2025.17861

render satellite-terrestrial communication technology and 6G technology more mature and reliable, infusing fresh momentum into the growth of the global communication industry.

Anticipating future developments, the confluence of continuous technological progress and escalating market requirements suggests that satellite-terrestrial communication technology, in synergy with 6G advancements, is on the cusp of an expansive phase of evolution. On one hand, as 5G technology is being deployed commercially and 6G technology progresses in research and development, satellite-terrestrial communication will achieve higher data transmission rates, lower latency, and wider coverage. On the other hand, with the emergence of new application scenarios such as the Internet of Things (IoT) and smart cities, satellite-terrestrial communication will play a pivotal role in numerous fields. Additionally, strengthened global cooperation and the advancement of standardization will render satellite-terrestrial communication technology and 6G technology more mature and reliable, infusing fresh momentum into the growth of the global communication industry.

7. Conclusion

In conclusion, the paper offers a comprehensive examination of the potential of sixth-generation (6G) technology and its implementation in satellite-terrestrial communications. The article underscores the potential of 6G to transform these systems, ushering in a new era of seamless global connectivity. The integration of satellite and terrestrial communication networks through 6G not only enhances the overall efficiency and coverage of communication networks but also addresses existing challenges such as limited coverage, high latency, and scarce spectrum resources.

Furthermore, this paper elucidates the technical challenges, security concerns, economic and cost-related considerations, and standardization and interoperability issues associated with the deployment of 6G technology in satellite-terrestrial communications. The article examines how 6G can address packet loss resulting from high transmission rates and low latency, while ensuring scalability and addressing other challenges, including low-power design, security, and privacy protection. As technology continues to advance, satellite-terrestrial communications will enable higher data rates, lower latency, and wider coverage. With the emergence of new application scenarios such as the Internet of Things (IoT) and smart cities, satellite-terrestrial communications will play a pivotal role in shaping the future of connectivity.

Nevertheless, the aforementioned technological advancements are contingent upon the realization of 6G technology, which remains a theoretical construct. To achieve this, 6G technology must address numerous intricate technical challenges. Existing studies on the physical layer technology for the convergence of 6G technology and satellite-terrestrial communications have not yet fully considered the effects of complex channel environments and multipath fading, resulting in an inaccurate assessment of transmission performance. Most of the studies focus on the improvement of technical performance, while the cost-benefit analysis of 6G technology in satellite-terrestrial communications is not comprehensive enough to provide a strong economic support basis for actual large-scale deployment. Future research should focus more on optimizing physical layer technology based on actual channel environments to improve the transmission reliability and spectral efficiency of 6G technology in satellite ground communication

References

[1] *Zhu X, Jiang C, Kuang L, et al. (2019) Cooperative transmission in integrated terrestrial-satellite networks[J]. IEEE Network, 33(3): 204–210. doi: 10.1109/MNET.2018.1800164.*

[2] *Lin X Q,CIONI S,CHARBIT G,et al. (2021) On the path to 6G:embracing the next wave of low earth orbit satellite access[J]. IEEE Communi-cations Magazine,59(12):36-42.*

DOI: 10.54254/2755-2721/112/2025.17861

[3] *Chen S, Liang Y, Sun S, et al. (2020)Vision, requirements, and technology trend of 6G: How to tackle the challenges of system coverage, capacity, user data-rate and movement speed[J]. IEEE Wireless Communications, 27(2): 218–228. doi: 10.1109/ MWC.001.1900333.*

[4] *3GPP. (2024) Candidate topics for a RAN2 led Rel-19 IoT-NTN-evolution work item:RP-232861[S/OL]. ftp://ftp.3gpp.org/ Specs/.*

[5] *Li Y, Tian B N. (2018) Spaceborne phased array antenna for com- munication systems[C] / / 2018 Cross Strait Quad-Regional Radio Science and Wireless Technology Conference. Xuzhou: Institute of Space : 1-3.*

[6] *Yajima M, Kuroda T, Maeda T, et al. (2007) Active phased array antenna for winds satellite[C] / / The 25th AIAA Inter- national Communications Satellite Systems Conference. Se- oul, South Korea: AIAA Press.1-7.*

[7] *Roper D H, Babiec W E, Hannan D D. (2003) WGS phased arrays support next generation DOD SATCOM capability [C] / / IEEE International Symposium on Phased Array Sys- tems & Technology. Boston: IEEE Press, 82-87.*

[8] *Schuss J J, Upton J, Myers B, et al. (1999) The IRIDIUM main mission antenna concept [J] . IEEE Transactions on Antennas and Propagation, 47(3): 416-424.*

[9] *ITU-T FG-NET-2030. (2019) Network 2030: A Blueprint of Tech- nology,Applications and Market Drivers towards the Year 2030 and Beyond[EB/OL].https: ∥ www. itu. int / en / ITU-T / focusgroups / net2030 / Documents / W h i t e _ P a p e r . p d f ,2 0 1 9 .*

[10] *IEEE Future Networks. (2020) IEEE International Network Gener- ations Roadmap (INGR) [EB/OL]. https: ∥ futurenetworks.ieee.org/roadmap.*

[11] *Yu X, Shen W Q, Zhang R, et al.(2023) Channel estimation for XL-RIS-aided millimeter-wave systems[J]. IEEE Transactions on Communications, 71(9): 5519-5533.*

[12] *Yang S J, Lyu W T, Hu Z Z, et al. (2023) Channel estimation for near-field XL-RIS-aided mmWave hybrid beamforming architectures[J]. IEEE Transactions on Vehicular Technology, 72(8): 11029-11034.*

[13] *Liu W, Pan C H, Ren H, et al. (2023) Low-overhead beam training scheme for extremely large-scale RIS in near field[J]. IEEE Transactions on Communications, 71(8): 4924-4940.*

[14] *Shen D C, Dai L L, Su X, et al. (2023) Multi-beam design for near- field extremely large-scale RIS-aided wireless communications[J]. IEEE Transactions on Green Communications and Networking, 7(3): 1542-1553.*