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A Survey Non-Terrestrial Networks in 6G/ 7G Smart Network for 2035+ and Beyond

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Abstract: *The Smart Networks and Services (SNS) initiative is currently halfway of its implementation period under the Horizon Europe programmed. Three calls have been launched since the inception of the SNS initiative in 2021, two of them having already delivered significant R&I project work covering the multiple technologies underpinning the 6G vision. This work naturally includes projects covering the Non-Terrestrial Networks (NTN) domain as part of the NTN component of Beyond 6G and future 7G mobile communication systems. Non-Terrestrial Networks (NTN) are considered pivotal for the development of 6G, aiming to provide ubiquitous and continuous mobile broadband coverage. With ongoing standardization efforts by 3GPP, 5G NTN promises seamless connection moving between terrestrial and satellite networks, using existing or next-generation smartphone devices. This paper focuses on the integration of NTN, particularly Low Earth Orbit (LEO) constellations, for 5G NR services. Six-generation (6G) telecommunication systems are expected to meet world market demands of accessing and delivering services anywhere and anytime. Non-Terrestrial Networks (NTN) are able to satisfy requests of anywhere and anytime connection by offering wide-area coverage and ensuring service availability, continuity, and scalability. In this paper, we review 3GPP NTN features and their potential in satisfying user expectations in 6G & beyond networks. State of the art, current 3GPP research activities, and open issues are investigated to highlight the importance of NTN in wireless communication networks. Finally, future research directions are identified to assess the role of NTN in 6G/7G and beyond.*

Keywords: Non-Terrestrial Networks, Smart Networks, SatCom networks, Services Satellite communication, 6G systems, 7G

I. INTRODUCTION

Non-terrestrial networks (NTNs), which include unmanned aerial vehicles (UAVs), high altitude platforms (HAPs), and satellite networks, are traditionally used for certain applications such as disaster management, navigation, television broadcasting, and remote sensing [1]. The uniqueness of NTNs is the capability to offer wide- area coverage by providing connectivity over areas that are expensive or difficult to cover with terrestrial networks (i.e., rural areas, vessels, airplanes). Therefore, the NTN represents a coverage extension for the terrestrial network in a world market where customer needs are radically changing. Indeed.[37] the demand for different services is steadily growing due to the ever-increasing number of devices connected to the internet [2]. Besides delivering service where it is economically challenging to provide [36] coverage with the terrestrial network (i.e., vessels, on board aircrafts, rural and remote areas), 6G NTN ensures service continuity of Machine-to-Machine (M2M)/Internet of Thing (IoT) devices or to people traveling on board moving platforms and service availability in case of both critical communications and future transmissions (i.e., maritime, aeronautical, railway).[38][39] This paper provides a systematical overview and analysis of the evolution of SatCom to empower 6G/7G networks for 2035 and beyond, with a focus on SatCom technologies, international standardization activities, technical challenges, and future directions [3]. The organization of this article is as follows: We first introduce the architecture of integrated satellites with 6G/7G networks. Then, we review the current development and forecast the future development of integrating satellite telecommunication networks with TNs in

6G/7G systems from the perspective of international standards.[40] Finally, we identify key challenges and technologies for further research in SatCom networks.

Non-Terrestrial Networks (NTN)

An NTN may have different deployment options according to the type of NTN platform involved, as listed in NTN platforms are grouped into two main categories: spaceborne and airborne [4].

Geostationary Earth Orbiting (GEO) has a circular and equatorial orbit around the Earth at 35786 km altitude and the orbital period is equal to the Earth rotation period. The GEO appears fixed in the sky to the ground observers. GEO beam footprint size ranges from 200 to 3500 km [5].

Medium Earth Orbiting (MEO) has a circular orbit around the Earth, at an altitude varying from 7000 to 25000 km. MEO beam footprint size ranges from 100 to 1000 km.

Low Earth Orbiting (LEO) has a circular orbit around the Earth, at an altitude between 300 to 1500 km. LEO beam footprint size ranges from 100 to 1000 km.

TABLE 1: Types of NTN Platforms

Platforms	Altitude Range	Orbit	Beam Footprint Size
GEO satellite	35786 km	Fixed position in terms of elevation/azimuth w.r.t. a given point on Earth	200 - 3500 km
MEO satellite	7000 - 25000 km	Circular around Earth	100 - 1000 km
LEO satellite	300 - 1500 km	Circular around Earth	100 - 1000 km

MOTIVATION AND EVOLUTION OF 6G/7G NETWORKS

Several characteristics of the NTNs are different from the terrestrial systems, mainly caused by the altitude and movement of the NT platforms. These features are briefly described in the sequel in a comparative manner Propagation delay and path-loss: The altitude of the NT platforms can cause extra delays in the communication link, especially in the case of GEO satellites reaching round trip latency of 270 ms [6]. This may create a bottleneck for specific services and applications which require ultra-low latency.

Motivation for 6G/7G Network Innovations

The rapid evolution of communication technology has significantly changed how people connect, work, and live [7]. As each generation of mobile networks has introduced new capabilities, the demand for faster, more reliable, and more efficient connectivity continues to grow. With the rise of the Internet of Things (IoT), smart cities, autonomous vehicles, and immersive technologies like Virtual Reality (VR) and Augmented Reality (AR) [8], it is becoming clear that existing networks are struggling to meet the ever-increasing demand. 7G networks aim to address these challenges by providing an advanced infrastructure beyond what 5G and 6G can offer one of the primary motivations for developing 7G is to support the seamless integration of emerging technologies, including AI, robotics, and quantum computing, into everyday life [9]. The need for real-time processing, minimal latency, and massive data handling requires a next-generation network capable of handling the complexities of future technologies. 7G networks are motivated by a more sustainable and efficient communication system [10]. As we move toward a future where billions of devices are interconnected, energy consumption becomes a major concern. 7G networks are expected to incorporate energy-efficient mechanisms to reduce the environmental impact of network operations, supporting global efforts toward green technology [11].

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FIGURE 1: Advancements of 7G network, capabilities and technological integration innovations

Integrating satellites with 6G/7G networks, the structure of SatCom networks is becoming an integral part of future 6G/7G networks, which combine terrestrial and satellite networks [12]. TNs encompass sea areas, rural regions, traffic systems, base stations, and other ground-based infrastructure, while satellite networks include satellites at various orbital altitudes, categorized into GEO satellites, medium-Earth-orbit (MEO) satellites, and LEO satellites [13]. Satellite networks provide broad coverage to meet the demands of 5G/6G networks, with different satellites serving as access, forwarding, and relay nodes, as well as supporting network management and control. The key characteristics of satellites at different orbital altitudes are summarized [14].

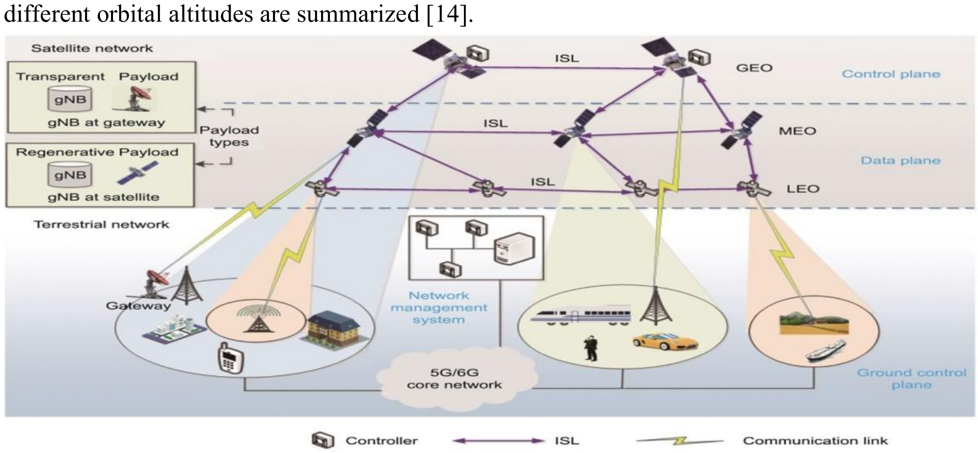

FIGURE 2: Integrating satellites with 5G/6G networks

7G: Evolution Beyond 5G and 6G

While 5G networks are still in the early stages of global deployment, their scalability, spectrum efficiency, and geographic coverage limitations are already becoming apparent [15]. The shift toward 6G is expected to address some of these issues by offering even higher data rates, improved latency, and enhanced integration of AI in managing network functions [16]. The demand for more comprehensive solutions encompassing terrestrial, aerial, and satellite networks will only intensify as communication technologies advance.7G networks power a new era of connectivity by integrating AI, Quantum Computing, Blockchain, IoT, and Terahertz Communication Alongside Edge, Fog, and Space-Based networks [17].

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FIGURE 3:Future of 7G Networks: Integrating AI, Quantum Computing, IoT.

4G: The Era of High-Speed Connectivity

Fourth-generation (4G) mobile communication systems, introduced in the late 2000s, represent a significant leap forward in wireless technology, focusing on providing high-speed data services and seamless connectivity 4G networks support many multimedia applications, enabling mobile broadband access and enhanced user experiences Technological Foundation: Long-Term Evolution (LTE): The primary technology behind 4G is LTE, which utilizes a flat architecture and Orthogonal Frequency-Division Multiplexing (OFDM) for efficient data transmission [18]. Modulation in 4G: 64-QAM (Quadrature Amplitude Modulation): 4G networks predominantly use 64-QAM to enhance data transmission efficiency, allowing for the transmission of 6 bits per symbol Capacity and Frequency Reuse: 4G networks utilize advanced frequency reuse techniques to maximize capacity [19].

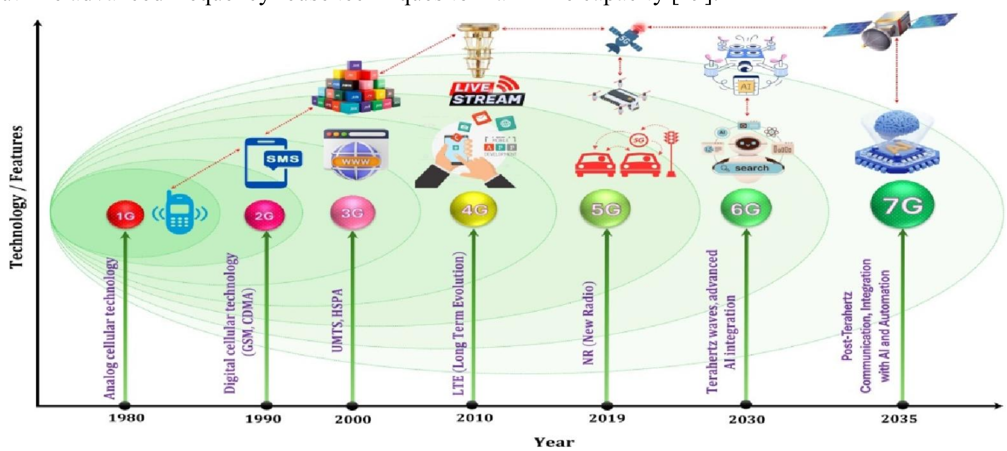

FIGURE 4: Evolution of cellular networks from 1G analog in 1980 to 7G with AI-driven, post-terahertz communication projected by 2035.

Limitations of 4G Systems:

- While 4G technologies significantly improved mobile communication, they also had limitations.
- Coverage Limitations: In rural areas, coverage may be inconsistent due to geographical challenges [20]. High Infrastructure Requirements: Building the necessary infrastructure requires substantial investment [24].

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Limitations of 5G Systems:

Despite its advanced capabilities, 5G technologies face certain challenges: Coverage Challenges: mmWave signals have limited range and penetration capabilities. Infrastructure Costs: The deployment of 5G infrastructure requires significant investment [21].

Limitations of 6G Systems:

Although 6G technologies promise remarkable advancements, they will encounter certain challenges shows a detailed comparison between the specific problems encountered in 6G and 7G networks, such as massive data processing, network latency. Infrastructure Requirements: The deployment of THz infrastructure necessitates significant technological innovations and investments. Regulatory Concerns: Spectrum allocation for THz frequencies may face regulatory hurdles [22] [23].

7G: FUTURE OF CONNECTIVITY

Seventh-generation (7G) mobile communication systems, anticipated to emerge around 2035, are expected to revolutionize the concept of connectivity by integrating advanced technologies such as quantum communication [25], artificial intelligence, and pervasive sensing capabilities [26]. 7G aims to achieve seamless connectivity across multiple domains, facilitating Ultra-Reliable Low-Latency Communications (URLLC) and immersive experiences for users and devices alike highlights essential tools and frameworks for 7G networks, including Quantum Communication Simulators, Edge and Fog Computing Frameworks, Satellite and Next-Generation Network Simulators, AI/ML Modeling Platforms, Blockchain Auditing Tools, and IoT Data Aggregation Platforms, critical for advancing communication, analytics, and security in 7G ecosystems [27] [28].

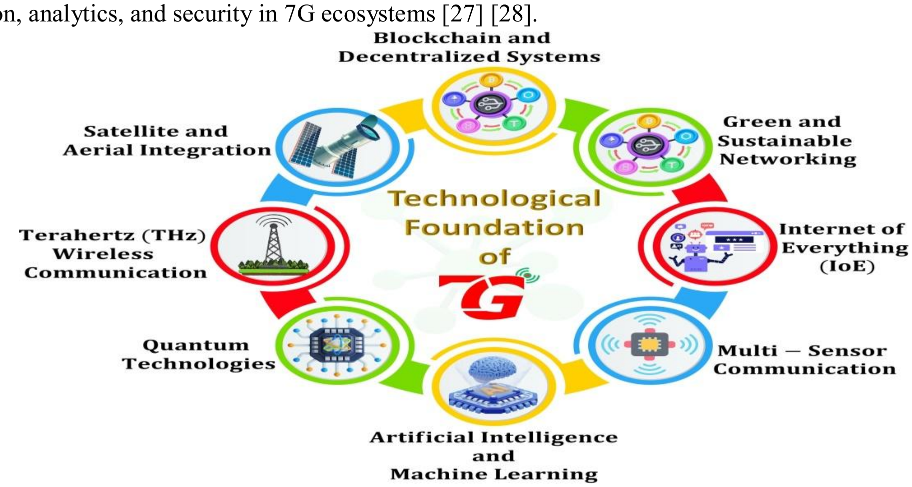

FIGURE 5: Technological Foundation for the Future of Connectivity through Advancements in 7G Networks.

Key challenges and technologies for future research

The integration of satellites with TNs in 5G/6G holds great promise, offering the potential for global, ubiquitous coverage and seamless connectivity for everyone and everything across the world [29]. However, achieving this integration presents several challenges that must be addressed [30]. These challenges include handling the long propagation delays inherent in SatCom, managing satellite mobility and handovers, and optimizing routing and path selection [31].

Long propagation delay of satellites: SatCom experiences significant propagation delays due to the high orbits of satellites, especially in GEO systems. These delays can severely affect the overall communication latency [32]. Strategies such as optimized gateway placement, multi-hop transmission adjustments, and mobile edge computing are required to mitigate latency and improve QoS.

High Doppler shifts: High Doppler shifts in satellite links, particularly for LEO and MEO satellites, lead to signal degradation and unreliable connections. Effective Doppler-compensation techniques and real-time tracking systems are necessary to maintain link stability, ensuring uninterrupted communication in high- speed satellite networks [33].

Resource management: Efficient resource management is essential in satellite–TN integration to ensure optimal utilization of spectrum, bandwidth, and computational resources [34]. Techniques such as spectrum sharing, network slicing, and AI-driven management systems are necessary to balance the demand across satellite networks and TNs while maintaining QoS.

Routing and path selection: In satellite–TN networks, selecting optimal routing paths becomes complex due to varying satellite positions and link qualities. Adaptive routing algorithms that dynamically adjust to changing network conditions are key to ensure efficient data flow and minimize latency, particularly in large-scale constellations [35].

II. CONCLUSION

The last decade of telecommunications has been character- ized by the fast development of smart devices, the important technological advancements, and the exponential growth of demands for new services. These developments have in- creased the interest of both ICT operators and researchers in the NTN as a means to provide ubiquitous services by achieving global network coverage. The relevance of NTN in both design options (i.e., standalone satellite and integrated terrestrial and non-terrestrial architectures) is expected to rise in 5G beyond technologies. The convergence of satellite networks and TNs is widely recognized as a significant trend from 5G to 6G. This article provided an overview of SatCom empowering 5G/6G for seamless communication across different environments.

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