NTN Evolution in 3GPP 5G Advanced

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***Abstract*—Non-Terrestrial Networks (NTNs) have gained increasing attention as a means to overcome the geographical and infrastructural limitations of terrestrial networks. By leveraging satellite and aerial platforms, NTNs offer enhanced connectivity in remote, maritime, and disaster-affected areas where conventional deployment is infeasible. This paper provides a structured overview of the technical background and standardization progress that has shaped NTN development within the 3GPP framework. Beginning with foundational studies in Release 15, and continuing through Releases 16 to 18, this paper outlines key architectural models, protocol enhancements, and deployment challenges. In particular, it highlights the dual track evolution of NR-NTN and IoT-NTN systems tailored for broadband and low-power applications, respectively. The conclusion reflects on current limitations—especially those tied to transparent payload systems—and emphasizes the role of Release 19 in enabling regenerative architectures. Overall, this study underscores the critical importance of NTN as a core enabler of global 5G expansion and a foundational element of the future 6G ecosystem.**

***Index Terms*—Non-Terrestrial Network (NTN), Standardization, Fifth Generation (5G)**

I. Introduction

Non-Terrestrial Networks (NTNs) are defined by 3GPP as communication systems that utilize spaceborne or aerial platforms—such as satellites, unmanned aerial vehicles (UAVs), or high-altitude platforms (HAPs)—to connect terrestrial network components including user terminals and base stations [1]. As mobile networks have evolved from 2G to 5G, connectivity has remained a foundational service. Despite significant advancements in terrestrial infrastructures, such systems remain restricted by geographic inaccessibility and high deployment costs, particularly in remote or disaster-affected areas [2], [3].

NTNs are emerging as a viable complement to terrestrial communication systems, offering extended coverage and increased resilience through the use of Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO) satellites [4]. These platforms enable connectivity in environments where conventional infrastructure is economically or physically unfeasible, such as oceans, mountains, and rural regions.

With the integration of NTNs into 5G systems standardized in 3GPP Release 17 and refined in Release 18 [1], [5], NTNs have evolved beyond a backup solution to become a core component of next-generation mobile networks. This shift has led to extensive studies on technical challenges such as satellite-terrestrial network interoperability, large Doppler shifts, long propagation delays, and the need for optimized hybrid automatic repeat request (HARQ) mechanisms [6], [7].

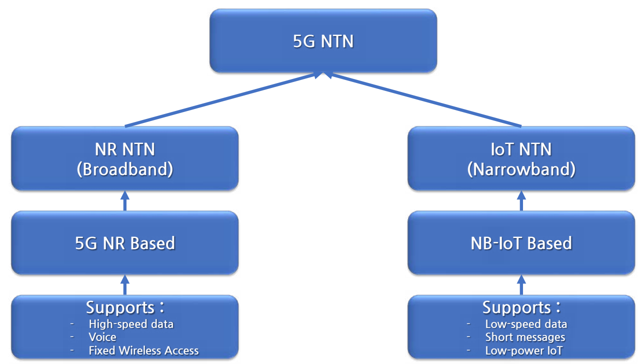

Fig. 1. Comparison between NR-NTN and IoT-NTN

Looking ahead to sixth-generation (6G) networks, NTNs are expected to play a pivotal role in realizing truly global communication systems that support ultra-reliable low-latency communication (URLLC) and massive machine-type communication (mMTC) [8]. Even as terrestrial 5G and fiber-based deployments continue, consistent and universal coverage remains difficult to achieve—especially in the face of natural disasters or infrastructure disruptions [9], [10].

To address these challenges, the NTN domain is branching into two main technological tracks: (i) broadband NR-NTN systems built upon the 5G New Radio standard, designed to support high-speed data, voice, and fixed wireless access services [1]; and (ii) IoT-oriented NTN solutions based on NB-IoT, which are optimized for low-power, low-throughput applications. As illustrated in Fig. 1, these two tracks differ significantly in terms of their target use cases, system complexity, and performance requirements. NR-NTN focuses on delivering enhanced mobile broadband (eMBB) and supports latency-sensitive services, while IoT-NTN emphasizes energy efficiency and massive device connectivity, typically involving delay-tolerant communications.

This paper reviews the 3GPP standardization roadmap for NTNs from Release 15 to 18, examines key architectural and protocol enhancements, and discusses the anticipated transition toward regenerative NTN systems in Release 19 and beyond.

II. NTN Standardization Status

Building upon the growing recognition of NTNs as a vital enabler for extended 5G connectivity, the 3GPP standardization efforts have laid a structured path toward their technical integration. This development has unfolded through successive releases, each contributing foundational insights and capabilities essential for the deployment of NTN-enabled systems.

In the early stages, 3GPP Release 15 initiated a feasibility study that outlined key deployment scenarios and explored the unique propagation and system-level characteristics of satellite communications [1]. This release also emphasized the need to reconsider conventional terrestrial assumptions, particularly in terms of air interface design and link budget constraints.

Release 16 advanced this foundation by establishing formal system requirements and proposing two reference architectures: One based on transparent satellite payloads, and another leveraging onboard signal regeneration [5]. These models provided a framework for analyzing network behaviors and performance trade-offs in space-based environments. In parallel, candidate enhancements for both upper and physical layers were identified to address NTN-specific challenges such as long delays and intermittent link availability [4].

The transition to Release 17 marked a pivotal shift toward full specification. Detailed definitions for both broadband NR-NTN and narrowband IoT-NTN were introduced, along with initial solutions to mitigate large Doppler shifts, latency accumulation, and the dynamics of satellite orbits [6]. This stage signaled the formal inclusion of NTN within the broader 5G ecosystem, setting the groundwork for commercial feasibility [7].

In Release 18, refinement of NTN functionality has continued. Key efforts include extending support to higher frequency bands, improving mobility management and beam tracking, and optimizing uplink reliability under constrained satellite resources. The work also highlights the increasing importance of flexibility and scalability in NTN designs, especially as low-Earth orbit constellations expand [2].

Nonetheless, transparent architectures remain limited by their reliance on terrestrial gateways. As NTN deployments aim for greater autonomy and global reach, 3GPP Release 19 is anticipated to emphasize regenerative payload solutions—capable of local processing onboard satellites—to overcome latency, availability, and scalability bottlenecks [12].

III. Conclusion

NTNs represent a pivotal advancement in extending the global reach of 5G systems. Standardization efforts from 3GPP Releases 15 to 18 have laid the groundwork for both NR-NTN and IoT-NTN, effectively addressing key technical challenges such as Doppler effects, latency, and mobility management. Nevertheless, current reliance on transparent payload architectures highlights the need for further evolution. Release 19 is anticipated to introduce regenerative payload technologies and autonomous networking capabilities, thereby facilitating more scalable and resilient NTN deployments. As NTN technologies mature, they are poised to become an integral component of future 6G communication infrastructures.

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