Standardization Review on Non-Terrestrial Networks

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***Abstract*—As the demand for global connectivity increases, non-terrestrial networks (NTNs), particularly satellite-based systems, have gained significant attention in communication network standardization. The 3rd Generation Partnership Project (3GPP) has been at the forefront of developing standards that incorporate satellite communications into the broader terrestrial network framework. This paper reviews the progression of NTN standardization, focusing on three key stages: (1) the use of satellites as relays or the next generation NodeBs (gNBs), (2) the integration of user plane functions (UPF) within satellites, and (3) the inclusion of control plane network functions (NFs) within satellites. These developments in standardizations reflect a shift from basic relay functions to fully integrated satellite networks.**

***Index Terms*—Non-Terrestrial Networks, 3GPP Standards, Control Plane, Network Functions**

I. Introduction

The rapid advancement in communication technology has led to a growing interest in integrating non-terrestrial networks (NTNs) with terrestrial systems. Specifically, the rapidly expanding LEO satellite constellations [1] is one of the important features in 5G and 5G-Advanced networks. In addition, NTNs' features on connectivity, availability, and scalability are fit into the vision of 6G networks. Recently, by integrating NTNs with 5G, services can be extended to enable service availability and scalability such as public safety (i.e., disaster management), and to provide service continuity such as maritime support.

As part of this evolution, the 3rd Generation Partnership Project (3GPP) has been exploring the standardization of NTNs, specifically leveraging satellite communications and networks to extend the scalability, availability, and reliability of networks [2]–[5]. NTNs are increasingly seen as key enablers in ensuring global connectivity, especially in remote areas where terrestrial infrastructure is limited or infeasible [6].

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Since there are lots of different features on radio access networks, there have been standardization efforts on beamforming, timing, synchronization, radio resource management, and mobility management [2]–[4]. In addition to the radio access network, standardization efforts on architectural development have recently been considered [5]. From the perspective of architectural development, the primary focus of 3GPP's NTN standardization involves several stages of satellite integration, addressing both the user plane (UP) and control plane (CP). These stages represent a shift from basic relay functions to fully integrated network elements that facilitate more sophisticated communication and network services. This paper reviews these stages, examining how satellite-based NTNs evolve from simple relays to entities that integrate both UPF and control plane network functions (NFs).

II. Standardization Review

NTNs are networks that use either satellites or uncrewed aircraft systems in different constellations for relay node or base stations. Satellites include low earth orbit (LEO), medium earth orbit (MEO), geostationary earth orbit (GEO), and highly elliptical orbiting (HEO) [7].

In the initial stages of NTN development, satellites are primarily employed as relays or act as part of the next generation NodeB (gNB) as shown in Figure 1. Generally in NTNs, there are three types of links including the service link between UE and satellites, feeder link between satellite and ground gateway, and inter-satellite link between satellites. In addition, Two modes are generally considered in this context:

In a transparent mode (also called non-generative mode), the satellite acts as a simple relay, forwarding data without on-board processing capability. It essentially amplifies and retransmits signals, ensuring connectivity between ground stations or user equipment and terrestrial networks. This mode is primarily suited for areas where the satellite acts as a mere intermediary to extend terrestrial signals over large distances.

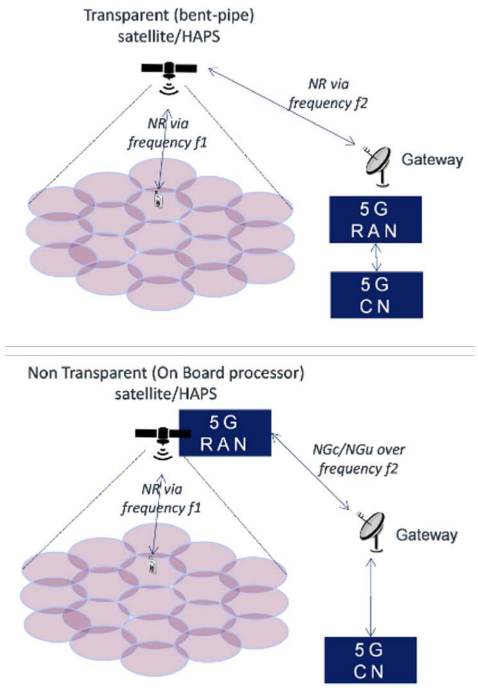

Fig. 1. Transparent and Regenerative Modes in NTNs [3]

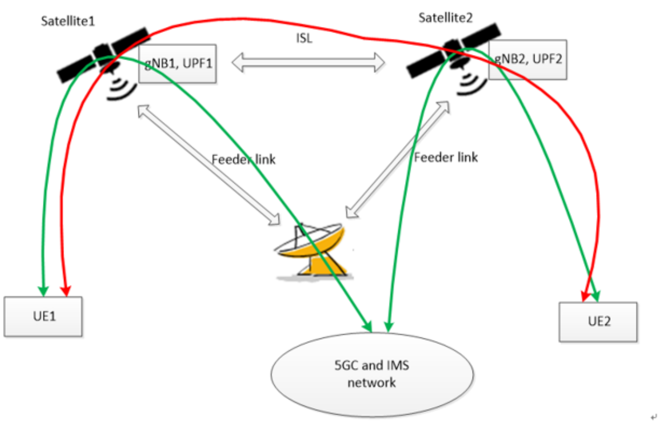

Fig. 2. UPF Integration in NTNs [8]

On the other hand, in a regenerative mode (also called non-transparent mode), the satellite actively processes the data with on-board processing capabilities (for demodulation/decoding, switching and/or routing, coding/modulation), performing functions similar to a terrestrial base station. This gives the satellite more flexibility in managing traffic, reducing latency, and improving data handling, making it a more robust component of the network architecture.

The use of satellites as relays (i.e., transparent mode) or gNBs (i.e., regenerative mode) marks the foundational phase of NTNs and plays a vital role in connecting rural or maritime regions that lack terrestrial infrastructure.

In the next stage, the standardization work introduces the integration of user plane functions (UPF) within satellites [5], [8]. The UPF manages user data traffic, ensuring efficient data routing between the core network and user devices. By incorporating UPF in satellites, edge computing or local switch via UPF on the satellite can be performed [5].

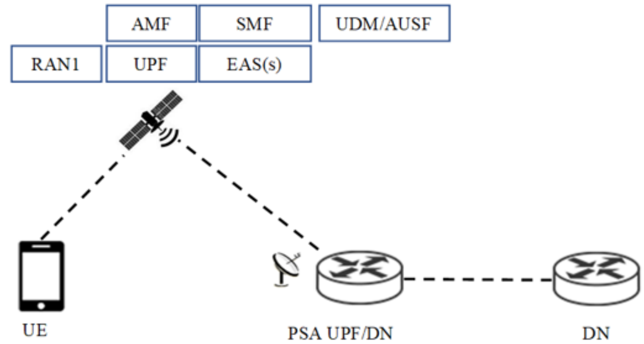

Fig. 3. NFs Integration in NTNs [8]

Specifically, as shown in Figure 2, the UE to UE traffic can be locally switched by UPF(s) deployed on satellite (i.e. through the local switch) to the target UE without traversing back to the satellite gateway on the ground. For the session management, if the session manage function (SMF) selects the UPF deployed on the satellite as a session anchor point of UE's protocol data unit (PDU) session, LAN-type service can be provided for 5G virtual network (VN) group members including unicast or multicast traffic forwarding between VN group members. This development is crucial for applications where low latency is critical, between VN group members.

Recently, in 3GPP technical reports [8], integrating control plane (CP) NFs is considered. This involves having satellites manage control procedures such as for session, mobility, policy, and authentication management. As an example, Figure 3 show that satellite includes access and mobility management function (AMF), session management function (SMF), UPF, and others. A technical report [8] introduces this architecture to enhance the registration and PDU session establishment for UEs under satellite coverage with intermittent/temporary satellite connectivity (e.g. when the satellite is not connected to the ground network).

III. Conclusion

The evolution of non-terrestrial networks, as envisioned by 3GPP, follows a clear trajectory from simple satellite relays to sophisticated systems that integrate both user plane and control plane network functions. By advancing through these stages, NTNs are increasingly capable of supporting a broad array of applications, from remote connectivity to low-latency critical services. As NTNs become fully integrated with 5G and future networks, they will play an indispensable role in bridging the digital divide, extending coverage to remote and underserved areas, and providing resilient, high-performance connectivity. The progression of 3GPP standards in this area marks a significant step toward a future where satellite communications form an essential part of global network infrastructure.

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