From Ground to Space: Towards an Integrated Management of Terrestrial and Non Terrestrial Networks

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***Abstract*—This paper analyzes the key characteristics of Non Terrestrial Networks (NTNs) which consist of both high-altitude elements as satellites GEO and LEO, and lower-altitude elements as drones and aerial platforms. These elements integrate with Terrestrial Networks (TNs) to create a 3D environment. Managing, orchestrating, and controlling this integrated network requires sophisticated procedures. This complexity primarily stems from the dynamic nature of NTN elements which requires continuous variations of the communication links that could cause strong fluctuations in terms of Quality of Service and overall several troubles with the handover. The paper presents the vision of the Italian ITA-NTN project, detailing all these architectural and dynamical aspects and introducing some guidelines for the management and control of the whole TN-NTN infrastructure considering the main recommendations for cross-domain coming from organizations as 3GPP and ETSI, including also approaches based on Artificial Intelligence, necessary to understand a network behavior with so many elements.**

Keywords—NTN, 5G, 6G, SDN, 3GPP, ETSI

I. INTRODUCTION

In recent years, 3GPP has intensified efforts in defining standards that facilitate efficient integration and collaboration between Terrestrial Networks (TNs) and Non-Terrestrial Networks (NTNs) [1-3]. These endeavors encompass aspects such as the definition of communication protocols, allocation of radio frequencies, resource management, and interoperability between space devices and terrestrial infrastructures. The 3GPP's involvement in standardizing NTN communications reflects the increasing convergence between TN and NTN technologies, enabling greater synergy and cooperation in the era of global connectivity [4-9]. In particular, the NTN segment consists of satellites (Geostationary Earth Orbit, GEO, Medium Earth Orbit, MEO, or Low Earth Orbit, LEO) and airborne devices, including drones and High-Altitude Platform Stations (HAPS), operating at lower altitudes. Different combinations and interconnections among NTN nodes enable a range of possible architectures, defined by the specific role assumed by each device, whether it be a backhaul or access node. Within this context, managing the entire network can be particularly challenging, especially considering the high dynamism of the network in non-GEO systems. This dynamicity necessitates the adoption of advanced solutions, such as Software Defined Networking (SDN) [10] and Network Function Virtualization (NFV), along with approaches like Open Radio Access Network (O-RAN) [11].

Generally, different network domains have been defined and managed through standards perfectly tailored for them. Future heterogeneous networks will necessarily have to integrate various systems that have so far worked independently. In this context, this work deals with the individuation of a possible contact point between these standards, to create layers that can unify different local solutions through a global orchestration. For such an aim it is necessary to clearly understand where this global orchestration must operate including all NTN architectures, Use Cases (UCs), and protocols concerning the multi-accesses and multi-connectivities. All these aspects should be analyzed in a management and control framework proposed for cross-domains by different Standardization organizations, and this is the aim of this paper obtained in the framework of the Italian Project "Integrated Terrestrial And Non-Terrestrial Networks (ITA NTN)", in the context of the "*RESearch and innovation on future Telecommunications systems and networks, to make Italy more smart (RESTART)*" program, funded by the European Union under the Italian

National Recovery and Resilience Plan (NRRP) of Next Generation EU.

Therefore, this paper is structured in the following way. Section II provides an overview of the state of the art about the NTN architectures, while Section III describes the principal UCs of applications of these architectures in different environments. Section IV deals with Satellite handover. Section V describes the main proposals at the standardization level concerning high-level cross-domain management and control operations. Section VI reports our main conclusions.

II. NTN ARCHITECTURES

The ITA-NTN project is focused on a 6G-oriented scenario for 3-dimensional (3D) wireless connectivity and targets the ambitious goal of conceiving novel methodologies and effective solutions to provide pervasive, ubiquitous, and flexible 3D on-demand wireless connectivity and edge computing services through the integration of TN-NTN [12]. By considering that each layer of the 3D networks in the TN/NTN architecture can have different roles, four different architectures are crucial: i) Drone-based Relay Network, ii) Satellite-based Architecture, iii) 3D Single-Connectivity Architecture, and iv) 3D Multi-Connectivity Architecture [8]. In the 3D scenario, the intermediary node and the satellite can operate in transparent and regenerative mode, thus leading to various architecture subcategories.

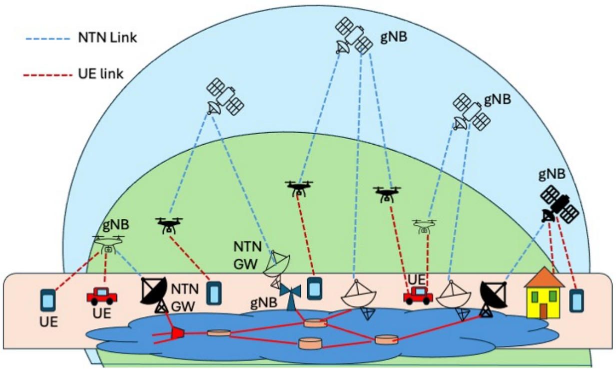


Fig. 1: TN-NTN architectures.

The architecture of a *drone-based relay network* typically consists of three main components: User Equipments (UEs)/Ground Users (GUs), drones, and a ground control station (NTN Gateway, NTN GW), which can be embedded in the gNB (see the drone on the left in Fig. 1). Indeed, drones equipped with communication systems can act as flying base stations or relays, enabling communication between distant locations.

Satellite-based architecture facilitates communications through satellites orbiting the Earth. While communication systems aim for sustained and stable connectivity, satellite-based architectures encounter hurdles like signal latency due to vast satellite-to-ground distances, elevated initial setup and upkeep expenses, and vulnerability to atmospheric conditions. However, unlike drone-based designs, this architecture provides extensive coverage, efficiently linking geographically distant locales, including remote or rural regions. Two different configurations involving satellites can be identified, that are satellite-based access (see Fig.1 satellite on the right) and satellite-based backhauling (i.e., direct and indirect access in 3GPP terminology, respectively). Both configurations allow for connectivity to remote areas where laying terrestrial cables or establishing direct fiber connections is challenging or cost-prohibitive. Note that satellite-based backhauling involves using satellites as a means to connect remote or underserved ground nodes to the core network infrastructure via satellite through the exploitation of Integrated Access and Backhaul (IAB) nodes, introduced in 3GPP Rel. 16.

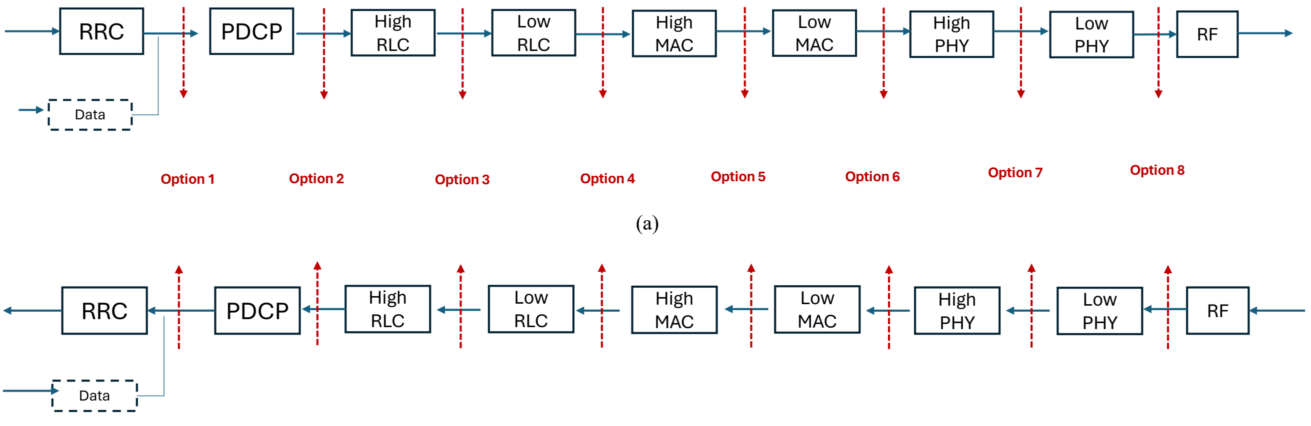
The *3D single-connectivity architecture* combines all the entities of the aforementioned schemes represented in the middle of Fig. 1, but different possibilities can be adopted as a fully transparent option, regenerative satellite (full gNB) and transparent drone, transparent satellite and regenerative drone (full IAB-Donor), and regenerative satellite (full IAB-Donor) and regenerative drone (IAB- node).

The *3D multi-connectivity architecture* is a variant of the single-connectivity type where a UE can connect simultaneously to two NTN accesses (the car on the right side of Fig. 1). This scheme offers several benefits. Firstly, it enhances network capacity by leveraging multiple layers or tiers of connectivity, i.e., terrestrial, aerial, and satellite networks. This allows for efficient utilization of available spectrum resources and improved coverage in various environments. Secondly, the architecture improves network reliability and resilience. Within 3GPP, Multi-Radio (MR) Multi-Connectivity (MC), and in particular Dual-Connectivity (DC), was analyzed to simultaneously transmit Protocol Data Unit (PDU) sessions to the same UE over multiple Satellite Access Node (SAN)/ Radio Access Network (RAN) nodes, with more analysis still underway (Rel. 18 and Rel. 19). MC including a non-terrestrial node can be implemented i) between TN and NTN or ii) between two NTN nodes (with the NTN nodes transparent or regenerative).

A fundamental issue in implementing an NTN is reproducing the split functional step defined in 3GPP [13]. With the advent of 5G requirements in terms of throughput and latency, new Functional Split (FS) schemes are introduced to offer a trade-off between throughput, latency, and functional centralization. As in [14], 3GPP defined:

- high layer split point (through F1 Interface): Option 2 (between PDCP and high RLC);
- lower layer split: Option 6 and Option 7.

Fig. 2 gives a representation of the functional split options.



(a)

(b)

Fig. 2: Functional Split options: (a) uplink and (b) downlink.

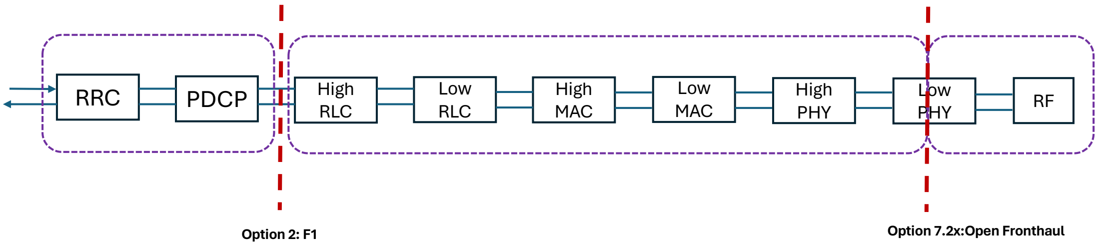


Fig. 3: Functional Split option in O-RAN.

Even the O-RAN model is based on the functional split approach [15-16]. In particular, O-RAN adopts FS Option 2 for the F1 interface between the O-DU (Open-Decentralized Unit) and O-CU (Open Centralized Unit), and Option 7-2x for implementing the fronthaul, the interface between the O-DU and O-RU (Open Radio Unit), as shown in Fig. 3.

According to [17], the optimal functional splitting model in the case of NTN is strongly related to UCs, available resources, and requirements in terms of costs. The functional split is beneficial for simplifying integration with NTNs. Assuming that the satellite radio interface is 5G-NR, the demodulation of the signal can take place in the DU (possibly modified for satellite support), which can be shared between the terrestrial O-RU and the satellite-specific O-RU (if present). In the case of the LEO constellation, the RF subsystem in the O-RU cannot be the same as in the terrestrial one. In fact, referring to modern LEO constellations, the O-RU antenna should be able to follow (even electronically) the satellites, which are assumed to be transparent for the moment. In the case of regenerative satellites, one might think that the satellite definitely hosts both O-RU and O-DU. In this case, the satellite-ground link it boils down to the O-DU-CU link (with the CU in the ground station).

III. NTN USE CASES

To design a complete set of management methodologies for a general NTN environment, it is necessary to take into account all the possible UCs where an NTN can operate and consider all the possible multi-connectivities. The ITA-NTN project has identified six different UCs, by considering that, thanks to their intrinsic ubiquity and broadcasting/multicasting capabilities, NTN and in particular Satellite Communication networks can play multiple roles in 5G, acting as RAN and as backhaul connection for remote 5G deployments:

- *Urban/Suburban area UCs*: an NTN component may be useful for offloading data, with the satellite network that may provide an additional connection aimed at addressing traffic peaks and preserving the performance of specific sensitive flows, and coverage;
- *Rural/Remote area UCs*: Aerial and space platforms can narrow the digital gap by delivering high-speed connectivity to remote regions lacking ground infrastructure. Additionally, HAPs and satellites are pivotal in disaster response, offering resilient emergency communication networks during terrestrial infrastructure disruptions;
- *Transport Systems UCs* that encompass various functionalities, including supporting railway operations and passengers' wireless connectivity during train services [18]. This involves managing signaling and critical voice and data traffic for train movement safety, real-time critical video aiding train operation support, critical and non-critical data concerning train and infrastructure issues affecting passenger safety and travel efficiency [19];
- *Drones for Delivery* in order to revolutionize logistics. The communication between drones and control centers allows updates on parcel location, traffic conditions, and weather, resulting in faster and more efficient deliveries. In addition, drones equipped with high-resolution cameras can transmit live video feeds, enhancing situational awareness, thus allowing operators to identify potential hazards;

- *Internet of Remote Things UCs*, i.e., the network of IoT nodes able to collect data from sensors and send control messages to actuators, by improving situational awareness, the operational efficiency of processes, and paving the way for new revolutionary applications for Smart Agriculture, Environmental Monitoring, Remote Control and Monitoring of Critical Infrastructures, Smart Goods Tracking;
- *Maritime-related UCs*, including Critical Communications like those related to Global Distress and Search&Rescue procedures, which privilege coverage and reliability rather than broadband and real-time features [5].

IV. SATELLITE HANDOVER

Satellite handover is one of the main issues in NTNs and is tackled differently from TNs due to the diverse features of NTNs compared to those of the traditional cellular network. In this section, we will focus on how to manage mobility and investigate the existing solutions to improve the handover procedure.

A. Mobility Management

In recent years, the interest in LEO satellite constellations has grown considerably both from industry and academia up to propose new offers for wide broadband NTN links as in the case of Starlink [20].

Although LEO constellations can guarantee global connectivity, LEO satellites' fast speed around the Earth triggers frequent feeder link switch-over procedures due to the drops of the feeder link between a LEO satellite and an NTN Gateway (GW) and frequent NTN terminal handover procedures from a LEO satellite to the next one. Furthermore, the motion of both the LEO satellites around Earth and the NTN terminals in a certain area leads to a time-varying satellite channel. Therefore, the dynamicity of NGSO satellite links, therefore, implies the execution of handover and paging procedures.

Handover can be: *(i) intra-satellite* when it occurs between satellite beams and is frequent in LEO satellite-based NTN due to the high speeds of the satellite beam footprint; *(ii) inter-satellite* when it occurs between satellites and is due to the limited geographical coverage of LEO satellites, and *(iii) inter-access network* when it occurs either between satellites belonging to different RANs or from the LEO satellite to the gNB (or vice versa) in integrated TN-NTN systems.

Paging mainly depends on the tracking area management. The tracking area is the satellite coverage area that, in LEO satellite-based NTNs, moves together with the LEO satellite. The moving tracking area implies that the network must manage high paging loads. Indeed, since the LEO satellites' beam footprints do not correspond to the terrestrial cells on the ground, it is hard to provide the exact information on the UE tracking area during the initial registration and, therefore, the NTN terminal cannot always establish its location for the procedures of Registration Update and Paging.

B. Handover improvement

The literature provides solutions to better manage frequent handover procedures over LEO satellite-based NTN networks due to the LEO satellites' low altitudes, their limited coverage, and their rapid movement around the Earth.

To minimize the number of handovers, reduce the handover time, and balance the LEO constellation load, the potential game for mobile terminals has been the pillar for a new strategy of inter-beam satellite handover in [21], whereas in [22], a virtual agent cluster has been introduced to manage handovers and construct the home mobile-agent-anchor and the local mobile-agent anchor to allow users to share their location information. In [23], the NTN terminals' velocity has been considered in the formulation of a handover prediction method in LEO satellite networks to avoid handover failures.

Inter-RAN handover has been investigated in [24], where reinforcement learning has been applied to make the decision of vertical handover in an integrated T-NTN system by considering several attributes, such as received signal strength (RSS), speed, network bandwidth utilization, and handover cost. The optimal association matrix between users and base stations has been proposed in [25] with a modified matching algorithm as a solution to vertical handover in integrated TN-NTN networks. A network-flow model of the satellite handover and the handover of NTN terminals has been designed in [26] as a satellite handover strategy for the ultra-dense LEO satellite constellation. In [27], a handover optimization strategy based on a conditional handover (CHO) mechanism has been proposed to enhance service continuity in LEO satellite-based NTNs.

Less investigated is the issue of feeder link switch-over, i.e., the procedure triggered by a moving satellite that is about to leave the visibility area of an NTN-GW and enter that of the next NTN-GW, thus disabling a feeder link with the old NTN-GW and enabling another one with a new NTN-GW. The Third Generation Partnership Project (3GPP) has defined two modalities for feeder link switch-over modalities: the *soft* procedure foresees that two-feeder links with two different NTN-GWs can be active at the same time thus ensuring seamless feeder link switch-over and service continuity; the *hard* procedure foresees that only one feeder link can be kept active at a time thus causing service interruptions and data losses [28]. Two novel feeder link switch-over approaches have been proposed in [29] with the aim of exploiting inter-satellite links (ISLs) between satellites to reduce the feeder link switch-over time when NTN-GWs are located far from each other and, hence, when a LEO satellite cannot see any other NTN-GW for a certain time interval.

V. CROSS-DOMAIN ORCHESTRATION AND MANAGEMENT

Integrating control, orchestration, and management across TNs and NTNs presents a multifaceted challenge. Several high-level specific issues related to cross-domain control plane, orchestration, and management in integrating TN and NTN can be listed:

- Heterogeneous Technology Integration: it includes reconciling differences in network architectures, communication protocols, and transmission mediums; it clearly appears looking for example at satellite, optical fibers, cellular, and IoT technologies.
- Dynamic Resource Management: NTN environments, such as satellite networks, exhibit dynamic characteristics due to factors like satellite mobility, variable propagation conditions, and handovers between different satellites. Coordinating resource allocation and management across these dynamic environments, and taking into account also the connection with NT, while ensuring seamless handovers and QoS provisioning is a challenging task.

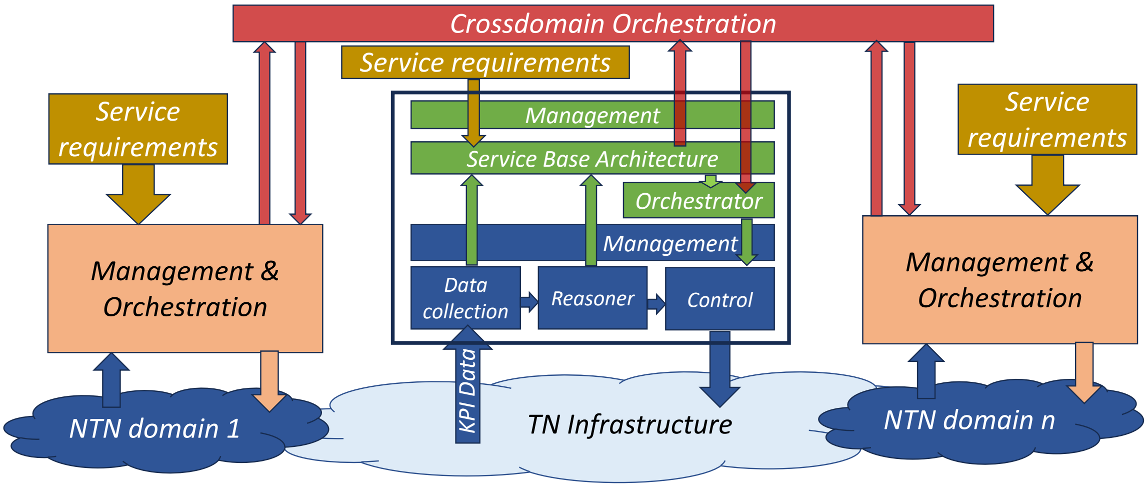


Fig. 4: Functional architecture of integrated network control.

- Service Orchestration and Lifecycle Management: Orchestration platforms must support end-to-end service creation, provisioning, and lifecycle management across TN and NTN domains. This includes dynamic service chaining, policy enforcement, and resource optimization while accommodating the diverse requirements and constraints of each domain.
- Inter-Domain Routing and Traffic Engineering: Efficient routing and traffic engineering across TN and NTN domains require mechanisms to optimize end-to-end path selection, considering factors like latency, bandwidth availability, and network congestion. This involves also developing algorithms and protocols for inter-domain routing and traffic steering.
- Policy and Governance: Establishing consistent and harmonized policies and governance frameworks across TN and NTN domains is crucial and challenging for ensuring compliance, security, and regulatory requirements.
- Monitoring and managing network performance as well as detecting faults and anomalies across TN and NTN domains require unified management platforms capable of aggregating and correlating data from many different sources.
- Spectrum Management: Developing regulations and standards for efficient spectrum allocation and management to accommodate the diverse requirements of TNs and NTNs, ensuring equitable access and optimal utilization.

Recent research and development efforts worldwide have initiated the exploration of novel technologies to enable TN and NTN convergence, as for example in [5] [30-31]. On the other hand, Standards Development Organizations (SDOs) such as ITU- T [32], ETSI [33] and 3GPP [1-3] have proposed different approaches to address various challenges associated with a unified management and control both for TN and NTN. However, no definitive solutions have been addressed yet and convergence and interoperability remain critical gaps to be further investigated.

In principle, the concept of a high-level architecture framework of integrated network control systems for TN-NTN convergence appears clear, as an example the one shown in Fig. 4, that recalls the proposal in [31], inspired to ITU-T Study Group 13.

In Fig. 4 a two-layer control system is depicted. The upper layer oversees an End-to-End (E2E) service, while the lower layer consists of individual network domain control systems. These systems collectively feed data into a central monitoring system, facilitating a comprehensive analysis of the network's status from an E2E perspective. This analysis serves as the foundation for optimizing E2E resource management and control according to service level requirements and user intents. The goal is dynamically and optimally allocating resources to ensure the delivery of high-quality E2E communication services.

The problem is to go into detail about the characteristics of all the devices present with their transmission characteristics and the protocols operating in each domain. Furthermore, we need to understand which processes can remain controlled within each single domain and which instead reside in the integrated network control system, even if the tendency should be to move upward as much as possible. To achieve effective orchestration and management in this context, advanced analytics capabilities are essential and crucial. These capabilities empower control loops and automation, enabling the system to adapt and respond efficiently to changing conditions. The 3rd Generation Partnership Project Service and System Aspect 5 working group (3GPP SA5) has introduced the Management Data Analytics Function (MDAF) to address these needs also in a cross-domain scenario, gathering data from various sources such as Operations And Maintenance (OAM) systems, intelligent elements within the 5G core network (NetWork Data Analytics Function, i.e., NWDAF), and access networks, i.e., RAN DAF, O-RAN Intelligent Controller (RIC) non-RealTime (non-RT), O-RAN RIC RT. Note that RIC is a cloud-native intelligent component of O-RAN using built-in Artificial Intelligence (AI) capability. However, the detailed design of each functional component, interface, protocol, algorithm, and pipeline has to be further studied and discussed in the different standardization organizations and towards the scenario envisaged in ETSI Zero Touch Network and Service Management (ZSM), enabling AI-based Network and Service Automation [34].

VI. CONCLUSIONS

In this paper, we analyze the main characteristics of the Non Terrestrial Networks (NTNs), including higher altitude elements such as satellites GEO and LEO, lower altitude elements such as drones and aerial platforms, and their integration with the Terrestrial Networks (TNs) to form a 3D environment. For this 3D network domain, the whole management, orchestration, and control require sophisticated procedures much complex mainly due to the dynamicity of NTN elements that need continuous variations of the communication links that could cause strong fluctuations in terms of Quality of Service and overall, several troubles for handover. Here the vision of the Italian ITA-NTN project has been reported, listing all these architectural and dynamical aspects considered to design some guidelines for management and control of the whole TN-NTN infrastructure considering the main recommendations for cross-domain coming from the organizations as 3GPP and ETSI, including also approaches typical of the Artificial Intelligence, necessary to understand a network behavior with so complex elements.

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REFERENCES

[1] 3GPP, "Study on using Satellite Access in 5G", 3GPP TR 22.822 V16.0.0 (2018-06)

[2] 3GPP, "Study on management aspects of next generation network architecture and features", 3GPP TR 28.802 V15.0.0 (2018-01).

[3] 3GPP, " Study on architecture aspects for using satellite access in 5G", 3GPP TR 23.737 V17.2.0 (2021-03).

[4] V. P. Kafle, M. Sekiguchi, H. Asaeda and H. Harai, "Integrated Network Control Architecture for Terrestrial and Non-Terrestrial Network Convergence In Beyond 5G Systems," *2022 ITU Kaleidoscope- Extended reality – How to boost quality of experience and interoperability*, Accra, Ghana, 2022, pp. 1-9, doi: 10.23919/ITUK56368.2022.10003041.

[5] G. Geraci et al., "Integrating Terrestrial and Non-Terrestrial Networks: 3D Opportunities and Challenges," in *IEEE Communications Magazine*, vol. 61, no. 4, pp. 42-48, April 2023.

[6] ITU-T Study Group 13 – Future Networks and Emerging Network Technologies.

[7] ETSI, “Satellite Earth Stations and Systems (SES); Seamless integration of satellite and/or HAPS (High Altitude Platform Station) systems into 5G and related architecture options", ETSI TR 103 611 V1.1.1 (2020-06).

[8] Simone Morosi et al., “Terrestrial/Non-terrestrial Integrated Networks for Beyond 5G Communications” Chapter in ‘Space Data Management’, Springer book, 2024.

[9] A. Guidotti et al., “Architectures, standardisation, and procedures for 5G Satellite Communications: A survey,” in Computer Networks, vol. 183, 2020.

[10] S. Sezer et al., “Are we ready for SDN? Implementation challenges for software-defined networks, IEEE Communications Magazine, 51, (7), pp. 36 – 43, 2013.

[11] C. Coletti et al., “O-RAN: Towards an open and smart ran white paper,” O-RAN Alliance White Paper, pp. 1–19, 2018.

[12] R. Giuliano, F. Mazzenga and A. Vizzarri, "Integration of Broadcaster and Telco Access Networks for Real Time/Live Events," in IEEE Transactions on Broadcasting, vol. 66, no. 3, pp. 667-675, Sept. 2020.

[13] “Technical specification group radio access network; study on new radio access technology: Radio access architecture and interfaces,” 3GPP, Sophia Antipolis, France, 3GPP Rep. TR 38.801, 2017.

[14] “475 series (ng-RAN; F1 interface), 3GPP Release 15,” 3GPP, Sophia Antipolis, France, 3GPP Rep. TS 38.470, 2017.

[15] O-RAN, “Building the Next Generation RAN,” 2018, White Paper.

[16] O-RAN Alliance Specification Alliance.

[17] M. Rihan et al., "RAN Functional Split Options for Integrated Terrestrial and Non-Terrestrial 6G Networks," 2023 11th International Japan-Africa Conference on Electronics, Communications, and Computations (JAC-ECC), Alexandria, Egypt, 2023, pp. 152-158.

[18] M. Berbineau et al., "Zero on site testing of railway wireless systems: the Emulradio4Rail platforms," 2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring), Helsinki, Finland, 2021.

[19] A. Vizzarri et al.,”Future Technologies for Train Communication: The Role of LEO HTS Satellites in the Adaptable Communication System”, Sensors 2023, 23, 68.

[20] J. Khalife et al. “The first Carrier Phase Tracking and Positioning Results with Starlink LEO Satellite Signals” Transaction on Aerospace and Electronic Systems, 2022.

[21] Y. Wu et al., “A Satellite Handover Strategy Based on the Potential Game in LEO Satellite Networks,” in *IEEE Access*, Sept. 2019.

[22] X. Zhang, K. Shi, S. Zhang, D. Li, R. Xia, “Virtual Agent Clustering Based Mobility Management Over the Satellite Networks,” in *IEEE Access*, Jul. 2019.

[23] X. Hu, H. Song, S. Liu, W. Wang, “Velocity-aware handover prediction in LEO satellite communication networks,” in *International Journal of Satellite Communications and Networking*, Apr. 2018.

[24] X. Jia et al., “Reinforcement Learning-Based Handover Strategy for Space-Ground Integration Network with Large-Scale Constellations,” in *Journal of Communications and Information Networks*, vol. 7, no. 4, pp. 421-432, Dec. 2022.

[25] H. Zhou, J. Li, K. Yang, H. Zhou, J. An, and Z. Han, “Handover Analysis in Ultra-Dense LEO Satellite Networks With Beamforming Methods,” in *IEEE Transactions on Vehicular Technology*, vol. 72, no. 3, pp. 3676-3690, March 2023.

[26] S. Zhang et al., “A Network-Flows-Based Satellite Handover Strategy for LEO Satellite Networks,” in *IEEE Wireless Communications Letters*, vol. 10, no. 12, pp. 2669-2673, Dec. 2021.

[27] F. Wang et al., “Seamless Handover in LEO Based Non-Terrestrial Networks: Service Continuity and Optimization,” in *IEEE Transactions on Communications*, vol. 71, no. 2, pp. 1008-1023, Feb. 2023.

[28] 3GPP TR 38.821, “Solutions for NR to support non-terrestrial networks (NTN),” Release 16, Mar. 2023.

[29] F. Rinaldi et al., “Delivering Multimedia Services in LEO satellite NTNs Supported by Backward and Frontward ISL during Feeder Link Switch-Over,” in 2023 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Beijing, China, 2023.

[30] X. Zhu and C. Jiang, "Integrated Satellite-Terrestrial Networks Toward 6G: Architectures, Applications, and Challenges," in IEEE Internet of Things Journal, vol. 9, no. 1, pp. 437-461, 1 Jan.1, 2022.

[31] V. P. Kafle et al., "Integrated Network Control Architecture for Terrestrial and Non-Terrestrial Network Convergence In Beyond 5G Systems," 2022 ITU Kaleidoscope- Extended reality – How to boost quality of experience and interoperability, Accra, Ghana, 2022.

[32] ITU-T Study Group 13 – Future Networks and Emerging Network Technologies.

[33] ETSI, "Satellite Earth Stations and Systems (SES); Seamless integration of satellite and/or HAPS (High Altitude Platform Station) systems into 5G and related architecture options", ETSI TR 103 611 V1.1.1 (2020-06).

[34] ETSI, “Zero-touch network and Service Management (ZSM); Cross-domain E2E service lifecycle management”, ETSI GS ZSM 008 V1.1.1 (2022-07).