Resource Orchestration in a Terrestrial and Non-Terrestrial Framework

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Abstract— **This paper shows how the ITA-NTN project aims to develop a comprehensive orchestration framework that bridges the gap between Terrestrial Network (TN) and Non-Terrestrial Network (NTN), ensuring seamless connectivity, efficient resource utilization, and enhanced network resilience. Novel approaches for management and orchestration are described, taking into account NTN element movements, handover, energy consumption, and power supply. AI-driven mechanisms are shown in the framework of a proposed TN-NTN architecture with an evolution towards a cloud-native approach, also considering the role of IPv6.**

Keywords—Non-Terrestrial Networks, 5G, 6G, handover, IPv6, 3GPP

I. INTRODUCTION

The rapid evolution of communication technologies has increased demand for ubiquitous, high-speed, and reliable connectivity. In this landscape, the integration of Terrestrial Networks (TN) and Non-Terrestrial Networks (NTN) represents a significant milestone in the development of next-generation communication systems [1-3]. This integration is crucial for expanding network coverage, improving resiliency, and optimizing resource utilization. The ITA-NTN project aims to advance research and development efforts to create a unified orchestration framework capable of efficiently managing TN and NTN resources [4]. The orchestration of TN and NTN is a complex challenge due to fundamental differences in their architectures, communication protocols, and operational dynamics. TNs, which include fiber optic backbones and cellular networks, rely on well-established infrastructures with relatively static topologies. NTNs, on the other hand, encompass satellite networks, High Altitude Platform Stations (HAPS), and Unmanned Aerial Vehicles (UAVs), all of which introduce unique mobility, latency, and coverage considerations. This heterogeneity necessitates an intelligent, adaptive orchestration framework that ensures seamless service continuity and efficient resource allocation. In recent years, advancements in Software-Defined Networking (SDN) and Network Function Virtualization (NFV) [5] have paved the way for more flexible and scalable network architectures. These technologies allow dynamic resource management, real-time traffic optimization, and enhanced quality of service (QoS). The ITA-NTN project leverages SDN and NFV principles to develop an orchestration framework that can effectively manage both terrestrial and non-terrestrial resources [6-7].

In this paper, the Authors describe novel approaches for management and orchestration in the integration of TN and NTN, taking into account some specific behaviors of the NTN domains, such as their movements, energy consumption, and power supply. The orchestration framework must incorporate predictive mobility models, AI-driven handover mechanisms, and adaptive routing algorithms to mitigate disruptions and maintain seamless connectivity. Moreover, energy efficiency is a critical factor in NTN operations. Satellites and UAVs are powered by limited energy sources, necessitating intelligent power management strategies. This work shows how the ITA-NTN framework integrates energy-aware resource allocation techniques to optimize network performance while minimizing energy consumption. Furthermore, multi-path routing strategies, network slicing, and AI-driven traffic prediction mechanisms play a pivotal role in achieving this objective. We also illustrate how the ITA-NTN project explores the potential of cloud-native architecture for network orchestration. Furthermore, the role of IPv6 will be analyzed, describing the SRv6 approach.

After this introduction, Section II is dedicated to the aspects of the satellite movements with implications for time constraints and handover processes. Sect. III to energy aspects and Sect. IV to computing and storage, while a TN-

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This work was supported by the European Union under the Italian National Recovery and Resilience Plan (NRRP) of NextGenerationEU, partnership on "Telecommunications of the Future" (PE00000001 - program "RESTART").

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NTN architecture is proposed in Sect. V and the possible role of IPv6 is considered in Sect. VI.

II. NTN TIME CONSTRAINTS

In NTN, the propagation delay is significantly higher than in terrestrial systems, resulting in increased latency for the mobility signaling processes. These processes include measurement reporting, receiving handover commands, and the handover request/acknowledgment, especially when the target cell is connected to a different satellite. According to the 3rd Generation Partnership Project (3GPP) TR 36.881, the service interruption time is defined as the interval between when the user stops communicating with the source gNB and when it resumes communication with the target gNB. This interruption time differs for uplink and downlink transmissions. For downlink, the interruption time spans from when the network sends the Radio Resource Control (RRC) Reconfiguration with synchronization until the target gNB receives the RRC Reconfiguration Complete. During this interval, the gNB cannot send data and resumes only after receiving the RRC Reconfiguration Complete. For uplink, the user can continue sending data to the source gNB until it receives the RRC Reconfiguration with sync. Thus, the interruption time for uplink is from the user receiving the RRC Reconfiguration with sync to the target gNB receiving the RRC Reconfiguration Complete. Excluding latencies like RRC processing delay and user frequency retuning (which are shorter than the Round-Trip Time (RTT)), the downlink interruption time is approximately 2 RTT (about 1080 ms), and the uplink interruption time is approximately 1.5 RTT (about 810 ms).

The propagation delay in Geostationary Earth Orbit (GEO) scenarios is significantly higher than in Low Earth Orbit (LEO) scenarios, which also require considering satellite movement. Addressing latency associated with mobility signaling is crucial in both GEO and LEO scenarios to minimize service interruption. Although LEO scenarios experience less propagation delay, the movement of satellites could result in inaccurate measurements due to the significant delay between the transmission of the measurement report and the reception of the handover command. This delay might render the measurements invalid, potentially leading to incorrect mobility actions, such as premature or delayed handovers. Incorporating satellite mobility and location information could help mitigate this issue. In contrast, measurement validity is not expected to be problematic in GEO scenarios due to the large cell sizes, significant cell overlap, minimal signal variation, and relatively low user mobility. In terrestrial systems, a user can detect its proximity to a cell edge by noticing a significant difference in Reference Signal Received Power (RSRP) compared to the cell center. However, in NTN deployments, this difference in signal strength between the two beams in an overlapping region may not be as distinct as shown in Figure 1. Traditional handover mechanisms rely on measurement events, so users might struggle to identify the best cell in NTN networks.

Satellites in Non-Geostationary Orbit (NGSO) move rapidly relative to a fixed position on Earth, necessitating frequent and unavoidable handovers for both stationary and mobile users. This can lead to substantial signaling overhead, increased power consumption, and other mobility-related challenges, such as service interruptions due to signaling delays. For a user moving at a constant speed and direction, the longest time it can stay connected to a cell is roughly the cell diameter divided by the user's speed. In LEO networks, this duration is determined by dividing the cell size by the relative speed between the satellite and the user.

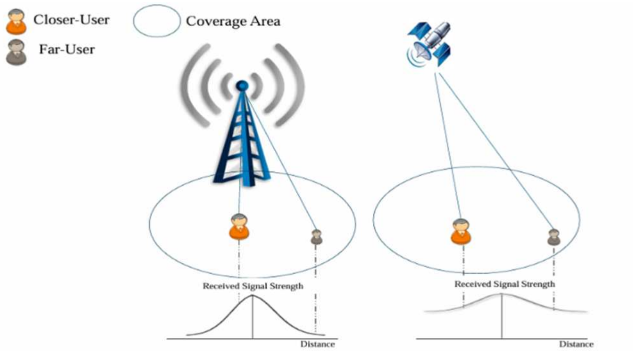

Figure 1: Distance effect on Received Signal Strength in different networks: on the left, Terrestrial Network; on the right, Satellite Network.

According to the 3GPP analysis in TR 38.821, handover frequency in LEO networks can be similar to that experienced by a terrestrial user on a high-speed train. However, this is a worst-case scenario and not typical for regular terrestrial networks. In GEO networks, frequent handovers are not expected due to the large cell sizes, which minimize the effect of user speed. In LEO scenarios, the user speed has a negligible impact on handover frequency because of the higher relative speed of the satellites. This issue mainly arises with moving beams in LEO networks. As communication networks evolve, the demand for robust mobility increases, leading to the Cell Handover Optimization (CHO) proposal and specification in 3GPP Release 16 [8]. CHO aims to reduce connectivity failures in dynamic scenarios by preparing multiple target cells in advance, allowing the user to monitor and select the most suitable target cell, unlike conventional handover, where the switch is made directly to a single target cell [9]. For NTN mobility enhancements, especially in LEO networks, the application of CHO is being explored due to the reduced variations in signal strength. Given the predictable movement of satellites, it makes sense for the user to utilize satellite information (e.g., satellite ID and ephemeris data) to implement a straightforward location-based CHO strategy, monitoring the distance between the user and the satellite as a CHO condition. However, if radio conditions are not monitored, relying solely on location for CHO execution could be problematic, potentially causing the user to switch to a low-quality cell. In NTN, the User-Satellite Service Link (USL) quality is influenced by satellite load, elevation angle, and geographical and meteorological conditions. Therefore, the monitoring conditions for target satellite candidates should incorporate a combination of different resources. Frequent handovers and unstable USL quality during service can result in increased signaling overhead and high handover failure rates, hindering sustainable data services. These challenges in spatial and temporal dimensions complicate the development of CHO solutions and the enhancement of service continuity in NTN. Enhancements to measurement configuration and reporting in NTN can significantly improve mobility management. One proposed enhancement is the conditional triggering of measurement reporting based on the user's location. This can be determined by comparing the user's location to a reference location or using a combination of location and signal metrics, such as RSRP and Reference

Signal Received Quality (RSRQ). Including location information in measurement reports is another enhancement.

To address propagation delay differences between satellites, the network can compensate within the user measurement window through system information or dedicated signaling tailored to the user. Other solutions to this issue are also possible. Conditional handover mechanisms, which utilize specific triggering parameters, can significantly enhance mobility management.

Several studies have explored the application of Machine Learning (ML) algorithms to optimize handover decisions in NTN. Various research efforts have emphasized the use of reinforcement learning multi-criteria decision-making processes for this purpose. For instance, He et al. [9] introduced a Load-aware Multi-Agent Reinforcement Learning handover approach to limit the number of handovers while considering satellite load. They examined two handover criteria: minimum elevation angle and available satellite channels, achieving a reduced blocking rate compared to load-unaware systems. Similarly, Xu et al. [10] employed a reinforcement learning strategy that considers service time, communication channel resources, and relay overhead for handover execution to maximize User Equipment (UE)'s Quality of Experience (QoE). Traditional methods face limitations in terms of storage for large Q-tables and accuracy loss due to state variable quantization. Hence, more advanced techniques like Deep Q Network (DQN) have been adopted, leveraging neural networks to handle Q-table functions and continuous state variables without quantization, thereby improving decision accuracy and saving storage space. Authors in [11] used reinforcement learning to propose a load-balancing handover strategy to decrease blockage rates and the number of handovers. The effectiveness of training neural networks within the DQN framework significantly influences the overall algorithm convergence performance. Wang et al. [12] proposed a deep reinforcement learning satellite handover scheme targeting the reduction of handovers and minimizing handover failure rates by incorporating carrier-to-noise and interference-to-noise ratios. Furthermore, the authors in [13] utilized deep reinforcement learning to introduce a Load Balancing Energy Aware Satellite handover strategy. This approach effectively manages the constrained energy resources of LEO satellites and accommodates diverse users' performance requirements. Their method successfully eliminates unnecessary handovers, achieves a zero-blocking rate, and evenly distributes the workload among the satellites. From these works and the obtained results, it is evident that incorporating ML techniques in the satellite handover process can effectively address various challenges and ensure improved Quality of Service (QoS). This demonstrates the potential of ML to enhance the efficiency and reliability of satellite communication systems.

III. COMPUTER AND STORAGE

Among its many innovations, 6G is expected to revolutionize traditional services by improving Edge Computing (EC), and from a technical perspective, computing and storage resources play a crucial role in Non-Terrestrial Networks (NTN). Integrating EC facilities in space can significantly enhance performance by addressing challenges such as resource limitations and security threats. EC-enabled Low Earth Orbit (LEO) satellite networks can provide high-quality services to ground users in remote areas with limited or no connectivity to terrestrial networks. NTN platforms, including aerial and orbital platforms like Low Altitude Platform Stations (LAPS), HAPS, and various satellite constellations, can boost coverage and capacity, creating sustainable and intelligent systems. Recent LEO constellations are tailored to specific missions and vary in altitude, satellite density, and speed. These constellations can provide EC resources to ground users and act as relay nodes to route requests to other satellites or terrestrial cloud facilities. NTNs face unique challenges such as hardware stability in orbit, energy supply, and heat dissipation. Terrestrial clouds and NFV systems ensure 99.99% reliability through redundancy and periodic migrations, but orbital systems are more complex and dynamic. Ensuring service availability through inter- and intra-satellite links is crucial, even after visibility time. This requires addressing the limited storage and computing resources of satellites, which can only serve a limited number of users and store a limited number of services. TN-based infrastructures are essential for creating a fully functional intelligent network for futuristic applications. However, they alone cannot provide adequate services to dynamic users, who often require extremely low latency and high reliability. Both TN and NTN platforms can enable EC services by placing EC servers within their distributed infrastructures. A multilayered joint TN-NTN framework, consisting of different EC platforms over TN and NTN, can provide heterogeneous services with the required quality. The network reference system includes various elements such as Base Stations (BS), LAPs, HAPs, and LEO satellites. BS elements equipped with EC services can serve larger coverage areas but may experience higher round-trip times for task completion. UAVs deployed as LAPs provide limited EC services with pre-installed EC servers, but their coverage and flight time are restricted. HAPs offer better coverage and computing capacity than UAVs, while LEO satellites provide enhanced coverage and form an extensive NTN-based EC platform for high-quality services and intelligent applications.

Various virtualization techniques (e.g., VMs, containers) can be used for EC resources efficiently. An SDN-based centralized control approach can manage the computation and storage resources of individual EC platforms. Multiple operator-based communication technologies can enable communication between EC nodes of the same and distinct platforms.

IV. THE ENERGY PAY-OFF

In the TN-NTN resource orchestration framework, energy management is a crucial factor affecting network sustainability, efficiency, and operational longevity. Unlike TNs, which have continuous access to the electrical grid and can integrate renewable energy sources such as solar and wind farms, NTNs, which include satellites, HAPS, and UAVs, face severe power constraints due to their reliance on limited onboard energy sources, such as batteries, solar panels, or other energy harvesting mechanisms. These energy limitations impact not only the lifetime of NTN nodes but also their ability to support computationally intensive tasks, high-throughput communication, and prolonged missions in remote or extreme environments. In this context, the integration of TN-NTNs offers high data rates and reliability, which is essential for various applications, including Earth observation, intelligent transportation, and disaster recovery. UAVs provide flexible and dynamic coverage, especially for the Internet of Things (IoT) paradigm, enabling real-time monitoring and automation. However, the energy constraints of IoT devices in harsh environments remain challenging. Wireless Power Transfer (WPT) emerges as a solution, allowing UAVs, equipped with an array antenna, to recharge terrestrial nodes while LEO satellites provide connectivity for data exchange. Despite the advantages, existing literature lacks comprehensive studies on UAV-powered IoT networks integrated with satellite communication. It is possible to bridge this gap by optimizing energy distribution and data transmission in a UAV-IoT-LEO integrated network. To this end, a specific reference scenario is proposed, consisting of a UAV-powered IoT network that integrates satellite communication [14], where the UAV, equipped with a beamforming antenna array, wirelessly recharges IoT terrestrial nodes *T* while ensuring their uplink data transmission to a LEO *CubeSat S*.

V. Management and Orchestration Frameworks

The previous Sessions have shown how many parameters must be considered for a correct management of the entire TN-NTN network and that guarantee adequate sustainability. For such an aim, the ITA-NTN project has explored the applicability of Management and Orchestration (M&O) strategies outlined by primary Standardization bodies for both 5G core and access domains within a TN-NTN context [6-7] following the trend for a final "zero touch" approach [15]. In particular, in [6-7] the main current architectures for Core and RAN 5G domains [15], adopting AI approaches, had already been addressed, where the various proposals from 3GPP, ETSI, and O-RAN [15] had been reviewed for the NTN scenario. In this context, it was highlighted how for the Core segment, with reference to 3GPP, the Service Base Architecture (SBA) was able to exploit AI-based procedures for the optimal management of the network in all its aspects, thanks to the Network Data Analytics Function (NWDAF), a network function dedicated to data analysis.

As regards the RAN part, the O-RAN proposal showed innovative aspects on AI methodologies thanks to the RAN Intelligent Controller (RIC) (near-real-time and non-real-time). Concerning the core management plane, 3GPP SA5 introduced the Management Data Analytics Function (MDAF) to facilitate cross-domain data gathering from sources like OAM systems and intelligent elements within the 5G core and access networks.

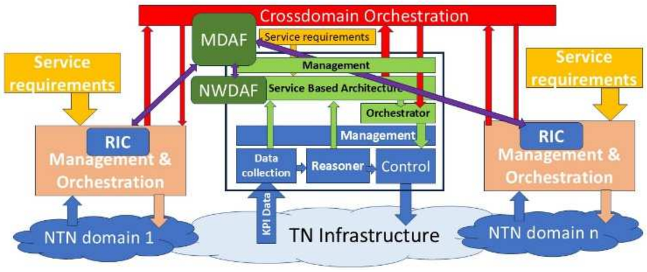

Fig. 2: Functional architecture of integrated network control for TN-NTNs.

Starting with this summary about M&O, the results of the analysis and proposals reported in [6-7] can be represented by the scheme reported in Fig. 2, which, by seamlessly coordinating various network domains, these systems optimize resource allocation and improve overall network efficiency. NTN segments must be controlled by a cross-domain orchestrator. Fig. 2, for the core area, recalls the proposal in [15], inspired by ITU-T Study Group 13, where a two-layer control system is depicted. These two control layers depend on where the AI processes are more efficient in making the network with better performance, and in particular, the blue part regards the case where M&O is carried out by analyzing Key Performance Indicators (KPI) related to the physical layer, while the green part concerns the entire SBA.

However, the specific design of functional components, interfaces, protocols, and algorithms still needs further exploration and standardization, especially in line with ETSI's Zero Touch Network and Service Management (ZSM) vision for AI-driven automation, and in Fig. 3 a typical ZSM is reported, distinguishing between the physical and service management with continuous loops to improve the network behavior [15].

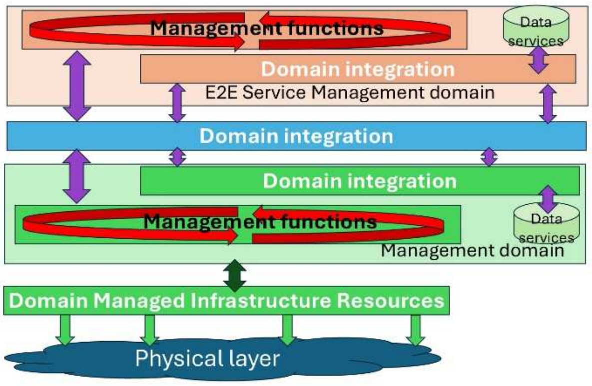

Fig.3: ZSM approach.

VI. Towards Cloud Native

One of the key elements of SDN is the adoption of the NFVs, but it is well known that all the functions of a specific NFV could also be implemented according to a typical "Cloud" approach based on "*containers*" [16]. This advancement has given rise to a new form of containerized network functions known as Cloud-native Network Functions (CNFs). Specifically, Kubernetes (K8s), recognized as the de facto standard for CNFs, has been applied to orchestrate various network functions and manage containerized infrastructure. K8s has enabled scalable microservice-based service architectures by splitting monolithic services into smaller entities, each running on separate containers. Meanwhile, there are efforts to apply AI/ML for the cloud native network. At the moment, we can observe different implementations of cloud native networks either as part of or the entire network, both at the core and RAN domains.

Concerning the 5G Core, several initiatives aimed to find an alternative to existing 5G Core deployment solutions, moving towards a true cloud native approach to be applied rather than a pseudo-cloud native one based on the distribution and hosting of M&O implementations on the cloud. In [16], the use of Kubernetes as an implementation of the M&O standard was proposed and tested, as opposed to other pre-existing solutions. The Authors concluded that Kubernetes cannot just act as a Network Function Virtualization (NFV) Infrastructure but also as an orchestrator and manager of VNFs.

In ITA-NTN as a cloud approach, the TeraFlow controller (https://www.teraflow-h2020.eu/) has recently emerged within ETSI in the context of packet networks and optical networks [17]. TeraFlow is an open-source cloud-native SDN controller, characterized by a modular architecture, where each module or component is responsible for specific functionalities and cooperates with each other through a bus. TeraFlow is based on microservices, which are deployed independently, making use of containers to isolate the functionalities of the components.

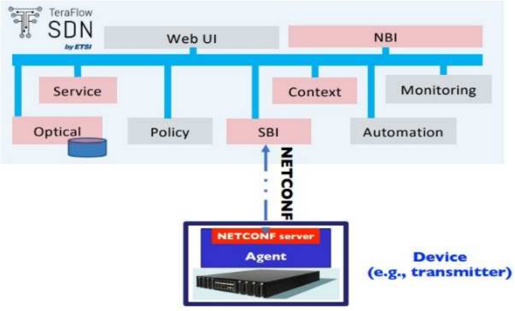

Fig. 4: TeraFlow architecture.

Fig. 4 shows the TeraFlow architecture for an optical SDN controller [17], in which a South Bound Interface (SBI) interfaces TeraFlow with the agent (i.e., local controller) of a device, with the agent holding a NETCONF server storing configuration and state parameters of the device. As an example, the "Monitoring" component collects monitoring information, the "Optical" component is responsible to perform resource allocation (i.e., routing and spectrum assignment) in fiber-optics networks according to traffic requests, while the "SBI" component configures the optical data plane via the NETCONF protocol according to a specific output of the resource allocation done by the "Optical" component. Such architecture can suit the per-domain control system of Fig. 2. Given TeraFlow's modular architecture with isolated functionalities easily extendable, an interesting solution might be to introduce an "NTN" component responsible for the management of NTN (e.g., based on Free Space Optics, FSO, links).

Two other major projects need to be taken into consideration for the transition to cloud native networks: Open Network Automation Platform (ONAP) [18] and µONOS. ONAP is an open-source project hosted by the Linux Foundation that aims to automate the management and orchestration of network services. ONAP is designed to scale, making it suitable for the dynamic and resource-intensive nature of 5G networks, supporting a distributed and federated learning approach and closed-loop automation, and therefore it could appear as an interesting solution for the entire NT and NTN environment. However, implementing and configuring ONAP can be complex, and integration with existing legacy systems and network infrastructure can be challenging. On the other hand, µONOS, a code-name for the next generation architecture of ONOS (https://docs.onosprojecis), is an interesting open-source SDN control and configuration platform since it is natively based on a new generation of control and configuration interfaces and standards. Being a lighter controller than ONOS, it is more suitable for radio access, Edge Computing, and Multi-Access Edge Computing (MEC) environments, and is particularly interesting for O-RAN networks.

Before concluding this paragraph, it would be necessary to analyze the vulnerabilities that could be present when moving to cloud-based structures. As reported in [19], it highlighted the presence of potential vulnerabilities and misconfigurations in the Kubernetes infrastructure supporting the RIC. However, methodologies to minimize these issues and harden the Open RAN virtualization infrastructure are in progress.

VII. INTERNETWORKING AND IPV6

Satellite communications rely on two types of payloads: non-regenerative payload, also known as *transparent mode* or *bent-pipe* which works similarly to an analog RF repeater, lacking on-board processing capabilities, that manages frequency carrier, radio frequency conversions, signal filtering and amplification, and which has been deployed mainly in the last 40 years; regenerative payload, instead, contains base station operations with on-board processing capabilities (for demodulation, decoding, switching, routing, coding, and modulation).

The latter, foreseen in NGSO satellites, best embodies the disaggregated, distributed, and software-defined nature of 5G and can enable the development of a non-terrestrial IP-RAN.

Identifying the RAN topology in the NTN segment is much more challenging than in the terrestrial one due to the continuous update of the available intra-satellite links, whose linkage time is minutes [20]. This variability originates from the so-called snapshots, which represent the periods of time during which the topology of RAN remains invariant and depends on the density of the constellation. 3GPP in Release 16 (ts_138_340) standardized the IAB architecture to densify networks with multiple radio sites. A gNB base station provides NR access to the UE and is connected to 5G. The network functions running on a gNB node can be split between one CU and one or more DUs. The CU controls the DU nodes on the F1 interface(s) through IP forwarding, where the DU node hosts the functional layers for the NR interface to the UE. However, such architecture mainly addresses static configurations that will not easily apply to the non-terrestrial segment. As briefly introduced in [21], a new concept of mobile IAB needs to be studied for both terrestrial and non-terrestrial nodes when the IAB is hosted on a vehicle, a UAV, or an NGSO satellite.

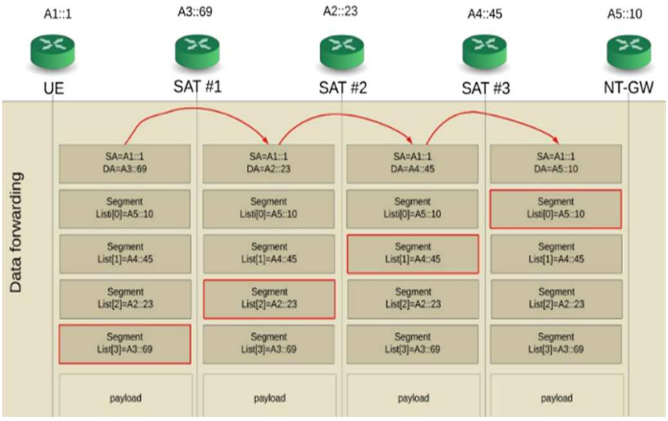

Fig. 5: SRv6 Data Forwarding.

The GTP-U has long been deployed for GSM, UMTS, and 4G LTE. Now, for 5G, SRv6 (Segment Routing over IPv6 dataplane) has been proposed as an alternative user plane protocol to GTP-U in both 3GPP and IETF. SRv6, based on source routing, has many advantages: stateless traffic steering, network programming, etc. Despite the advantages, it is hard to expect to replace GTP-U by SRv6 all at once, even in a 5G deployment, because of many dependencies between 3GPP nodes. Therefore, stateless translation and coexistence with GTP-U have been proposed in IETF with RFC 9433, and its performance has been evaluated in (9012725). SRv6 Traffic Engineering (SRv6-TE) enhances this approach by enabling explicit routing paths based on operator-defined policies. By encoding a sequence of segments, network operators can direct traffic through specific paths, bypassing congestion and ensuring optimal performance. This mechanism can provide fine-grained control over path selection, latency optimization, and resource allocation.

The main advantages of SRv6-TE include:

- Scalability: Uses IPv6 addressing for segment encoding, removing the need for MPLS labels.
- Simplicity: Reduces the dependency on traditional signaling protocols like RSVP-TE.
- Automation and SDN Integration: Works seamlessly with SDN controllers for dynamic path computation.
- Service function chaining: Enables flexible insertion of network functions.

Fig. 5 defines how to encode an ordered segment list as an ordered list of IPv6 addresses by exploiting new IPv6 routing headers known as Segment Routing Header (SRH).

In SRv6, presented in Fig. 5, the active segment is the packet's destination address, and a pointer indicates the next active segment in the SRH. The full list of ordered segments is obtained by visiting all the addresses stored in SRH. The segments list acts as a sequence of SRv6 tunnels that allow carrying mobile, fixed, and enterprise services together, reducing operators' investment and operational and maintenance costs.

VIII. CONCLUSIONS

This paper describes intelligent orchestration frameworks to harmonize TN and NTN networks to take into account resource allocation, mobility management, energy supply, computing, and storage. Concerning mobility management, that remains a critical aspect of TN-NTN integration, the ITA-NTN project proposes innovative solutions to mitigate mobility-induced disruptions. AI-driven handover mechanisms, predictive mobility models, and adaptive routing strategies enhance network continuity, ensuring uninterrupted service delivery across terrestrial and non-terrestrial domains. By implementing energy-aware resource allocation techniques, the framework minimizes power consumption in NTN nodes while maximizing network performance. The project also underscores the importance of inter-domain routing and traffic engineering in TN NTN integration. Cloud-native architectures play a pivotal role in the scalability and interoperability of TN-NTN orchestration. The ITA-NTN project embraces microservices-based network management, edge computing paradigms, and containerized deployment models to ensure seamless integration with emerging 5G and 6G networks. This cloud-native approach fosters rapid innovation, accelerates service deployment, and enhances network resilience. Finally, the role of IPv6 has been analyzed, describing the SRv6 approach.

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