C. C. González, S. Pizzi, M. Murroni and G. Araniti, "Multicasting Over 6G Non-Terrestrial Networks: A Softwarization-Based Approach," in IEEE Vehicular Technology Magazine, vol. 18, no. 1, pp. 91-99, March 2023.

The publisher's version is available at:

https://dx.doi.org/10.1109/MVT.2022.3232919

This is the post-print of the following article: C. C. González, S. Pizzi, M. Murroni, and Giuseppe Araniti, "Multicasting over 6G Non-Terrestrial Networks: a Softwarization-based Approach," in IEEE Vehicular Technology Magazine, doi: 10.1109/MVT.2022.3232919.
Article has been published in final form at: https://ieeexplore.ieee.org/document/10015889.

Multicasting over 6G Non-Terrestrial Networks: a Softwarization-based Approach

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***Abstract*—Multicast/broadcast delivery is a critical challenge of future sixth-generation (6G) mobile networks where massive internet of things deployment and extended reality multimedia such as teleportation are target application scenarios. Non-terrestrial networks (NTNs) are considered essential for the success of 6G, which aims to provide true "global" services by extending mobile access worldwide, thus overcoming the coverage limit of current terrestrial networks (TNs). This paper discusses how the main distinguishing features of NTNs can be effectively exploited for 6G multicasting. Furthermore, in line with the evolution of future 6G networks toward softwarized systems, we evaluate the potential of using the softwarization paradigm in the heterogeneous TN/NTN architecture to deliver multicast services.**

I. Introduction

The fifth-generation (5G) mobile system is being adopted worldwide with significant advances in spectrum usage, system capacity, network performance, and reliability [1]. However, 5G falls short in fulfilling future applications' stricter requirements and realizing true global connectivity. For this reason, even though 5G is still at its initial stage, the research community has started to focus on its successor: the sixth-generation (6G) mobile system.

6G, expected to be deployed around 2030 [2], will enable a wide range of advanced applications such as haptic communications, full-sensory digital reality, extremely high-definition (EHD) video, fully automatic driving, deep-sea sightseeing, and massive internet of things (mIoT). These groundbreaking applications envisaged for the incoming decade will be characterized by diverse key performance indicators (KPIs), imposing tight quality of service (QoS) requirements in terms of ultra-high reliability, data rate, energy efficiency, low latency, and scalability.

In diverse 6G scenarios, the same content could be requested by many users simultaneously, which makes imperative the support of point-to-multipoint (PTM) delivery, also called multicast/broadcast, due to its capability to exploit network resources economically and efficiently. Supporting multicast services from the initial 6G design stages is primarily needed to address the requirements of future IoT deployments, such as massive software updates or multimedia data acquisition beyond augmented and virtual reality (AR/VR), which rise severe communication challenges in 6G networks. For instance, for teleportation, the data rate requirement of a 3D holographic display producing a raw color hologram, full parallax, and 30 fps is 4.32 Tbps [1]. Additionally, vehicular applications can be benefited from multicast transmissions, where terminals involved in the same services (e.g., traffic management) or within the same area (e.g., cars close to the position of an accident) can be grouped to disseminate data among interested vehicles [3].

The 3rd Generation Partnership Project (3GPP) defined, starting from 2005, the Multimedia Broadcast and Multicast Service (MBMS) to optimize the distribution of broadcast and multicast services in cellular networks. While the first versions of the 5G New Radio (NR) development (Releases 15 and 16) were only focused on point-to-point (PTP) communications [4], following the increasing interest in PTM delivery, in Release 17 [5], the 5G network architecture has been enhanced to support multicast/broadcast services (MBS).

Among the requirements that 6G is claimed to meet, realizing a fully connected digital world is a key that terrestrial networks (TNs) may fail to fulfill due to limitations in terms of deployment and coverage. In the last years, a booming interest has been devoted to non-terrestrial networks (NTNs), also due to their capability to complement terrestrial infrastructure for achieving continuous, ubiquitous, and global connectivity (e.g., through nano-satellite constellations) [6]. Indeed, NTNs are crucial to cover unserved/unconnected areas, complement the TNs' deployment during overcrowded situations, and serve as backhaul. Thus, the combination of unmanned aerial vehicles (UAVs), high-altitude platforms (HAPSs), satellite constellations, and TNs will constitute the 3D ecosystem of 6G [7]. Consequently, the cooperation of TNs and NTNs must be effectively managed to satisfy the "always best connected" paradigm and dynamically switch among unicast/multicast/broadcast service delivery according to the application types and network conditions.

In this complex scenario, the network slicing paradigm arises as a critical piece to introduce flexibility, dynamism, and isolation. Being a significant characteristic of the 5G system [8], it will also be vital for the future 6G deployment [1], together with the software-defined network (SDN) and network function virtualization (NFV) technologies, to efficiently manage network resources in real-time. Additionally, artificial intelligence (AI) will complement SDN, NFV, and slicing technologies to dynamically make proactive decisions regarding network control and resource management [9].

NTNs have been the subject of recent survey papers [10]. However, although some works have recently focused on the integration of TN-NTN and the role of NTNs in the future 6G [11], little attention has been devoted to discussing their potential in delivering multicast/broadcast services. To this aim, after describing the 5G MBS architecture and introducing the basics of NTNs, we motivate why NTNs are an up-and-coming solution for 6G multicasting by discussing how their

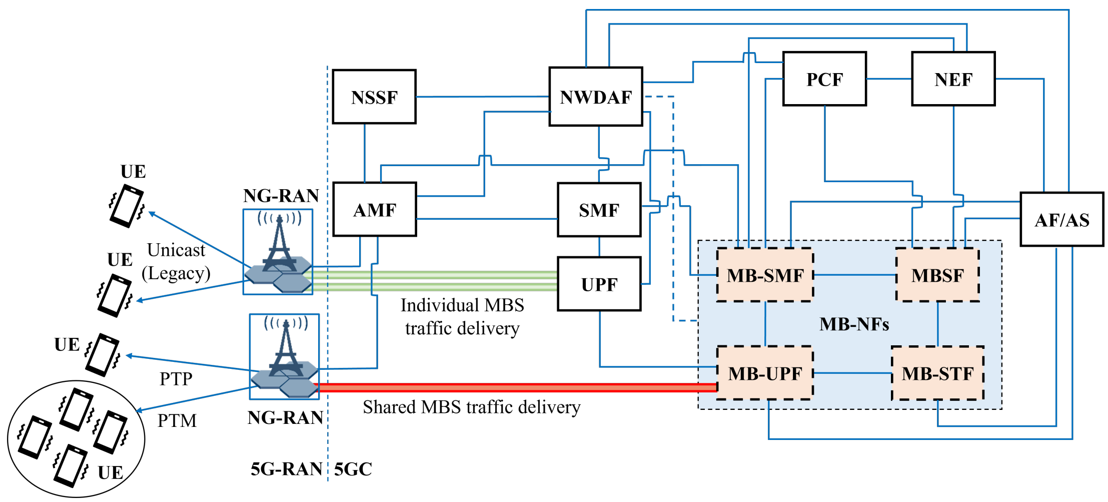

Fig. 1: 5G MBS system architecture.

main distinguishing features can be effective for multicast service delivery. Then, in line with the evolution of future 6G networks toward softwarized systems to fulfilling the strict applications' requirements, constantly changing users' demands, and mobility behavior, we evaluate the potential of exploiting the softwarization paradigm to the heterogeneous TN/NTN architecture in the delivery of multicast services.

The remainder of the paper is organized as follows. Section II describes the MBS architecture and the envisaged development. Sections III and IV summarize the basics of NTNs and discuss benefits, challenges, and enhancements in delivering multicast services over NTNs, respectively. Section V outlines the key enablers that will drive the development of future integrated TN-NTN over a softwarized environment. Conclusions are drawn in section VI.

II. The MBS Architecture in 5G and Beyond

Since the adoption of eMBMS in Release 9, 3GPP has enhanced the PTM capabilities to support multicast and broadcast services efficiently. However, the first 5G NR Release (Release 15) only focused on 5G unicast mode, and Release 16 only included the specifications for 5G broadcast LTE-based [4]. Starting from 5G Release 17, the support of MBSs is being developed over the existing 5G framework, ensuring the smooth introduction of future functionalities and compatibility with legacy MBMS network nodes for service continuity [5].

Fig. 1 shows the 5G MBS system architecture composed of new functional components and other elements that must be updated to support MBS. The new multicast/broadcast network functions (MB-NFs), highlighted in Fig. 1 (dashed blocks), belong to the 5G Core (5GC) and have the following functionalities:

- *Multicast/Broadcast Session Management Function (MB-SMF)* manages multicast/broadcast sessions, including QoS control per each MBS session. It configures the *Multicast/Broadcast User Plane Function (MB-UPF)* based on the policy rules from Policy Control Function (PCF) or local policies.
- MB-UPF is the ingress point to the system and acts as a session anchor. It interacts with MB-SMF for receiving MBS data.
- *Multicast/Broadcast Service Function (MBSF)* has a service level functionality to support MBS and interwork with legacy network nodes (e.g., LTE MBMS). It interacts with the Application Function/Application Server (AF/AS) and MB-SMF for MBS session operations and determines transport parameters. Moreover, it interacts with the *Multicast Broadcast Service Transport Function (MB-STF)* if this component is used.
- MB-STF works as a media anchor for MBS data traffic, if needed. It has generic packet transport functionalities for any IP multicast application, such as multiple flows and framing.

The following elements enhance their functionalities to support MBS:

- PCF is enhanced to support QoS treatment for MBS sessions.
- Network Exposure Function (NEF) must be updated to interact with AFs for MBS procedures such as service provisioning and QoS management. Moreover, it must interact with MB-SMF for MBS session operations.
- AF must be evolved to request MBSs from the 5GC, providing service information and QoS constraints.
- Session Management Function (SMF) must be enhanced to interact with MB-SMF to manage multicast session context. It also must interact with the Next-Generation Radio Access Network (NG-RAN) for shared data transmission resource establishment. Moreover, it must authorize a multicast session join operation, if needed.
- User Plane Function (UPF) is enhanced to receive multicast data from MB-UPF and deliver it to user equipment (UE) through Protocol Data Unit (PDU) sessions.
- Access and Mobility Management Function (AMF) is updated to perform signaling for MBS session management. It must select the NG-RANs for broadcast traffic and notify multicast session activation towards UEs.
- Network slice selection function (NSSF) supports the

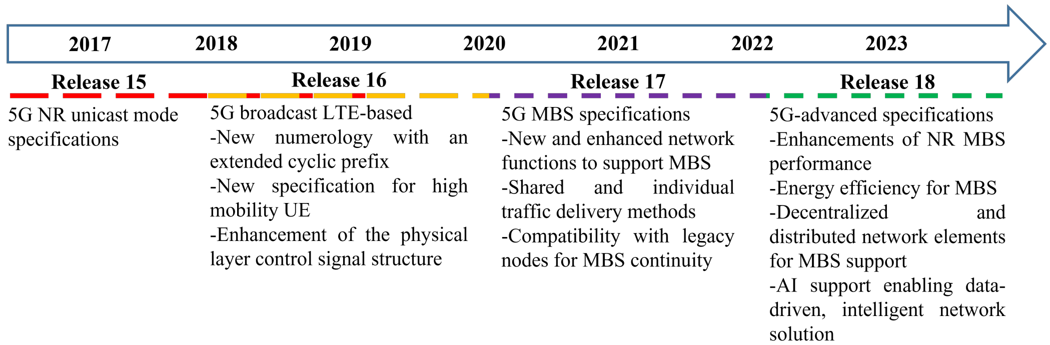

Fig. 2: 5G MBS evolution.

functionality to bind a UE with a specific NS, which could allocate a multicast/broadcast service.

- Network Data Analytics Function (NWDAF) must include new interfaces with the MB-NFs (i.e., dashed line in Fig. 1) and collect QoS KPIs (e.g., throughput, latency), mobility patterns, data usage, or misbehavior from multicast groups. Moreover, it could gather multicast/broadcast slices' status (i.e., load, availability, number of registered users). Above-collected information could be used to train machine learning (ML) models to dynamically adjust the PTM usage and predict traffic and service experience.
- NG-RANs (i.e., TNs and NTNs acting as RANs) must be updated to deliver the MBS data to the UEs using PTM or PTP and support multicast sessions continuity during the handover process.
- UEs must be updated for the reception of the MBS data.

Release 17 details two possible delivery methods to transmit the MBS data between 5GC and NG-RAN:

- 5GC shared MBS traffic delivery: The 5GC receives a single copy of the MBS data packets and delivers a single copy of those MBS packets to an NG-RAN node. Then, the NG-RAN node delivers the packets to one or multiple UEs, guaranteeing dynamic change of service delivery between PTM and PTP according to service coverage area, QoS constraints, and service type. Only NG-RAN nodes with MBS capability can receive data by 5GC shared MBS traffic delivery. This method applies to broadcast and multicast MBS sessions.
- 5GC individual MBS traffic delivery: 5GC receives a single copy of the MBS data packets and delivers separate copies to individual UEs through PDU sessions. This method is essential for NG-RANs without MBS capability but requires transmitting data associated with an MBS session. In NG-RAN deployments with non-homogeneous 5G MBS support, if a user receives MBS data packets and changes to the coverage area of a legacy gNB (without MBS capability), the network switches to the individual delivery method ensuring service continuity. This method only applies to multicast MBS sessions.

Fig. 2 summarizes the evolution in support of multicast/broadcast services from Release 15 to the future Release 18, considered the first 5G-advanced standard that will lay the groundwork for future 6G deployment. In the envisaged MBS architecture, decentralized and distributed caching and edge computing capabilities will be critical in reducing service delay and backhaul data traffic. The new specifications must be oriented to increase energy efficiency for MBS transmission and fulfill successful MBS reception of many users that could be distributed in a scattered and wide area. Moreover, 5G-advanced/6G networks require AI for data-driven and intelligent network solutions in a hierarchical and distributed fashion. Integrating these paradigms is essential to increase MBS resource efficiency and improve each MBS session's QoS in future ultra-dense heterogeneous environments. For example, the RANs can follow a cooperative ML strategy to determine which of them has the best conditions to satisfy the group of users requesting the same content simultaneously.

III. Non-Terrestrial Networks

According to the definition by the 3GPP [12], an NTN *"refers to a network or segment of networks using RF resources on board a satellite (or UAS platform)."*

The network elements that constitute an NTN are:

- *NTN terminal* served by the satellite (or UAS platform) within the targeted service area;
- One or several *NTN gateways* that connect the NTN to a public data network (e.g., the 5GC network);
- An *NTN platform* which may implement either a *transparent* or a *regenerative* payload;
- A *feeder link* between a satellite gateway and the satellite (or UAS platform);
- A *service link* between the UE and the satellite (or UAS platform);
- *Inter-satellite links (ISL)* to (optionally) provide inter-satellite connectivity.

The NTN terminal can be either a 3GPP UE or a specific satellite terminal. Terminals may operate in the radio frequency of Ka-band (i.e., 30 GHz in the uplink and 20 GHz in the downlink) or S-band (i.e., 2 GHz). ISL, relevant in the case of a constellation of satellites and requiring regenerative payloads on board the satellites, may operate in RF frequency or optical bands.

While the radio interface for the service link is 3GPP-defined New Radio, both 3GPP or non-3GPP-defined radio interfaces may be used for the feeder link and ISL.

TABLE I: Reference scenarios [12].

	Transparent satellite	Regenerative satellite
GEO-based NTN	Scenario A	Scenario B
LEO-based NTN steerable beams	Scenario C1	Scenario D1
LEO-based NTN moving beams	Scenario C2	Scenario D2

NTN platforms are classified as *spaceborne* or *airborne*, depending on their altitude, beam footprint size, and orbit. NTN platforms generate (typically several) beams that can be *steerable* (i.e., generate fixed beam footprint on the ground), or *fixed* (i.e., generate moving beam footprint on the ground). The footprints of the beams are typical of an elliptic shape.

Spaceborne platforms can be distinguished in:

- *Geostationary Earth Orbiting (GEO)* has a circular and equatorial orbit around the Earth, and the orbital period is equal to the Earth's rotation period. The GEO appears fixed in the sky to the ground users.
- *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.

LEO and MEO satellites are also known as Non-GEO (NGSO) satellites for their motion around Earth with a lower period than the Earth's rotation, ranging from 1.5 to 10 hours.

The *airborne* category encompasses Unmanned Aircraft Systems (UAS) platforms, which are typically placed at an altitude between 8 and 50 km and include High Altitude Platform Systems (HAPS) at 20 km altitude. As it happens for the GEO satellite, the UAS position can be kept fixed in the sky concerning a given point on the ground. UAS beam footprint size ranges from 5 to 200 km. Additionally, UAVs represent a particular case with lower altitudes (usually around 100 m). They are more flexible regarding coverage and quick deployment perspective.

NTN platforms may also be distinguished according to the carried payload that may be *transparent* (or bent-pipe) or *regenerative*. While the transparent payload repeats the received waveform signal unchanged, the regenerative payload has onboard processing. Thus, all (or part) of the base station (e.g., gNB) functions are onboard the satellite (or UAS platform).

As a result of the above-discussed classifications regarding the platform type (GEO/LEO) and the carried payload (transparent/regenerative), 3GPP has identified the six macro-scenarios of interest that are reported in Table I. While scenarios A, C2, and D2 have been considered with higher priority, the possibility of implementing steerable beams (scenarios C1 and D1) has recently received increasing attention.

The 3GPP has defined the following options for the NR-enabled NTN architecture to minimize the need for new interfaces and protocols in NG-RAN to support NTNs:

- In *transparent NTN*, the NG-RAN architecture is left unchanged.

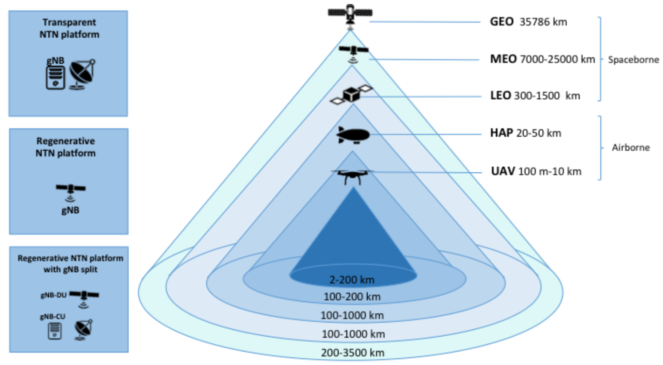

Fig. 3: NTN platform types and architecture options.

- In *regenerative NTN*, the satellite implements all functions of a gNB.
- In *regenerative NTN with functional split*, the distributed unit (DU) of the gNB is on board the satellite, while the central unit (CU) is on the ground.

Fig. 3 illustrates the discussed NTN architectures.

IV. Why and How NTNs for Multicast Services Delivery?

Future 6G networks are claimed to support a wide range of traffic types, among which the demand for video, currently accounting for about 69 percent of all mobile data traffic, will continue to be significant as it is forecasted to increase up to 79 percent in 2027 [13].

A wide range of multicast use cases in various verticals, such as Media & Entertainment, Automotive & Safety, Industrial IoT, and Healthcare, make use of immersive live videos, requiring the delivery of interactive videos together with audio, data transmission, and feedback controls (see Fig. 4). These applications demand a highly reliable delivery and a less strict latency than ultra-reliable low latency communications (URLLC) but are more stringent than traditional enhanced mobile broadband (eMBB) services. Thus, in the future transition from 5G to 6G, the demand for network capabilities in terms of capacity and availability will increase significantly, along with the need to reduce the costs of the provided services. This growth in demand is not feasible to be sustained by systems that only leverage unicast transmissions. This has already become clear in 5G systems, where multicasting and broadcasting have gained increasing attention, but places multicasting as a cornerstone technology of 6G systems for meeting the requirements of future applications.

NTNs represent a key solution for the above-mentioned multicast use cases because of their main distinguishing features:

- *Reliability*: measured by either the error rate of communication links or outage time, represents a key feature for multicast scenarios. NTNs could provide a cooperative multicast transmission to improve the signal-to-interference-plus-noise-ratio (SINR) of users with poor terrestrial channels. Moreover, due to the possible presence of different kinds of NTN platforms at a time, users may be served by more spaceborne/airborne vehicles

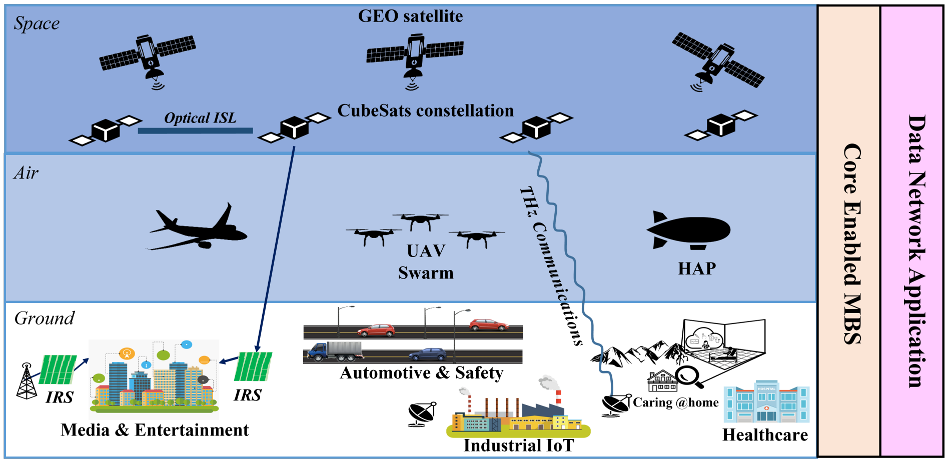

Fig. 4: NTNs for multicast use cases.

simultaneously, with a consequent significant reliability improvement thanks to the spatial diversity gains.

- *Availability*: refers to the probability that a UE is under the coverage of at least one NTN platform. Besides the likely presence of network coverage by the sky/space made available by a vast number of operators, NTN platforms such as HAPSs can be easily deployed when needed. Therefore, NTNs are suitable for providing broadcast/multicast services for widely distributed users, reaching cost-effectively remote areas.
- *Survivability*: unlike the terrestrial infrastructure, NTNs are not affected by natural or man-made disasters that may lead to network paralysis. Thus, aided by the multicast/broadcast capabilities, they can efficiently disseminate early warnings (e.g., earthquakes) to many users. Moreover, NTNs can rather be effectively exploited in emergency situations such as search&rescue operations or post-disaster scenarios by means of, for example, a swarm of UAVs.
- *Cost*: the low dependence of NTNs from terrestrial infrastructures makes them a favorable candidate in rural/remote areas. Indeed, recent developments in space technology manufacturing have done satellite networking affordable thanks to CubeSats, a low-cost small-size solution requiring a short development-to-deployment time. Additionally, UAVs' flexibility and rapid deployment is an economical and effective solution to assist the TNs during a temporary event, multicasting common content to multiple users and relieving congestion.
- *Mobility*: the large footprint of NTN platforms, especially in the case of GEO satellites, eases mobility management, ensuring service continuity, particularly in emergencies. However, LEO satellites fastly moving around the Earth's orbit face paging and handover issues that must be properly tackled.
- *Scalability*: reflects the ability to support an increasing number of mobile terminals. NTNs are intrinsically scalable since multicast/broadcast services can be delivered to groups of terminals located in wide areas on the ground through PTM connections by utilizing the same network resources.

However, NTNs' benefits come with some challenges whose severity depends on the NTN platform type, the scenario under investigation, and the considered architecture option. Among the most relevant are the Doppler shift, propagation delay, and round trip time (RTT), which may significantly complicate critical procedures at PHY and MAC levels. In addition, in the case of multicast traffic delivery, the effect of such problems may be very different among UEs belonging to the same multicast group.

To improve the performance of the multicast transmission, the impact of the adverse effects of typical NTN channel impairments on more disadvantaged users should be mitigated to provide benefits to all group members. Possible solutions rely on exploiting a multicast architecture aided by intelligent reflecting surfaces (IRS), in which the channel conditions of the weakest link can be enhanced by carefully tuning the IRS phase shifts. Significant improvements may also be achieved by relying on a multi-layer architecture encompassing ground, air, and space and leveraging multi-connectivity to enhance the user throughput and increase reliability. Finally, network slicing is a crucial feature for NTNs to segment and provide multiple service instances at different altitudes. Therefore, numerous applications can run on different NSs in parallel, receiving differentiated QoS treatment according to the specific traffic performance.

V. Toward a Softwarized Hybrid Terrestrial/Non-Terrestrial–MBS Architecture

Future wireless networks will evolve into highly complex and ultra-dense heterogeneous systems. Integrating TNs and NTNs is crucial to extend the service coverage area, increase capacity, and guarantee the "always best connected" vision, thus paving the way toward the true global connectivity promised by 6G systems. Based on the TN-NTN cooperation, the user can be connected to the most suitable access network at each moment, ensuring service continuity and enhanced transmission performance.

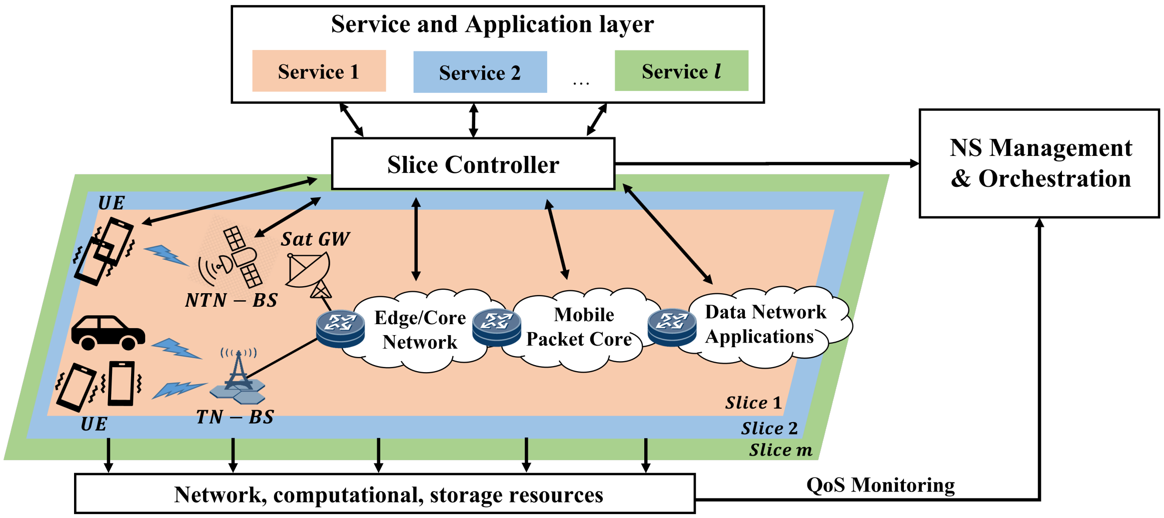

Fig. 5: NS high-level architecture.

In this complex scenario, softwarization and slicing paradigms arise as critical pieces to introduce flexibility, dynamism, and isolation. Fig. 5 shows how, with network softwarization, the heterogeneous TN-NTN infrastructure is abstracted as network, computing, and storage resources. In this environment, the SDN controller enforces intelligent decisions taking complete control of the network. At the same time, NFV guarantees to orchestrate computational and storage resources needed to instantiate network functions.

The end-to-end (E2E) resources and functions are isolated into multiple NSs to flexibly configure resources according to users' demands and heterogeneous network conditions. Critical concerns in NS planning are determining how many NSs to deploy and what functions/features to share across multiple NSs. One NS can allocate multiple service instances, which can be associated with several RANs and core network (CN) segments [14]. Each instance would be activated based on the NS template's specification, which includes the configuration of related network functions and E2E resources.

Furthermore, in diverse 6G scenarios, many users could request the same content (e.g., live video at significant events). Thus, the slicing paradigm must be enhanced to support multicast/broadcast capabilities. Based on the application type, the users' distribution, and network conditions, a common content flow must be dynamically mapped into unicast/multicast/broadcast slice instances, exploiting network and radio resources economically and efficiently. In this context, the cooperation among network operators and content providers is fundamental to managing the E2E system.

In the future ultra-dense heterogeneous environment, the orchestration and management of the network must be conducted by AI techniques combined with slicing and softwarization approaches. The dynamic and intelligent tasks must be oriented to the access network/NSs selection to satisfy the user petition, multicast group formation, and load balancing, including dynamic adjustment between PTP and PTM and a suitable strategy during an overload situation.

In the remainder of this section, we will evaluate the benefits that the application of the softwarization paradigm could bring to the heterogeneous TN/NTN architecture in delivering multicast services.

The applied algorithm for selecting the most suitable combination of access network/NSs to satisfy the user petition is inspired by [15]. Specifically, the resources are dynamically orchestrated considering the RANs in the coverage area, the available resources, the configured NSs, the users' QoS parameters, mobility behavior, and tariff plan. The algorithm assigns resources according to the maximum throughput required by the requested services if enough capacity is available. When the network is overloaded, the RANs/NSs exploit a collaborative approach to balance resources, avoid network performance degradation, and meet users' requirements.

The scenario under analysis comprises a macro-base station (BS), a micro-BS, and a UAV serving as an aerial BS. The network hosts a new user every two seconds. Each user is randomly positioned in the simulated area with a random-way point mobility model. The simulation analyzes the advantage of combining unicast/multicast services in the context of network slicing and softwarization technologies. We consider four services with diverse KPIs, assuming that one out of the four services is multicast. Users can request from one to four services simultaneously, and each NS allocates one of these services (i.e., for a total of four NSs).

Results show that integrating TN-NTNs and exploiting unicast/multicast capabilities (solid lines) in a softwarized context outperforms the other three use cases (TN-NTN unicast, TN unicast/multicast, and TN unicast) in terms of:

- Aggregated data rate (ADR), calculated as the sum of the data rate experienced by the terminals;
- Throughput satisfaction (Th_{sat}), computed as the average ratio between the sum of the assigned throughput and the sum of the maximum throughput supported by the requested services [15].

Fig. 6 and 7 highlight that the scenario where unicast services are delivered via TNs only has the worst performance, reaching the first saturation point for the smallest number of

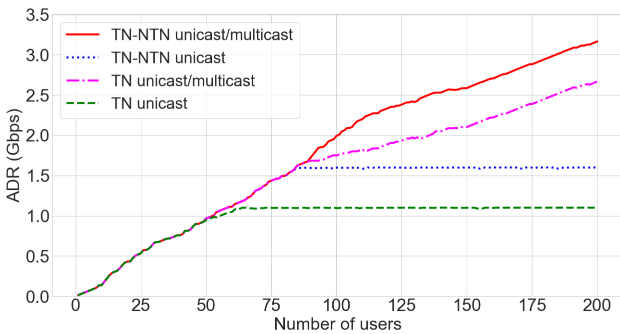

Fig. 6: System ADR with unicast and unicast/multicast capabilities.

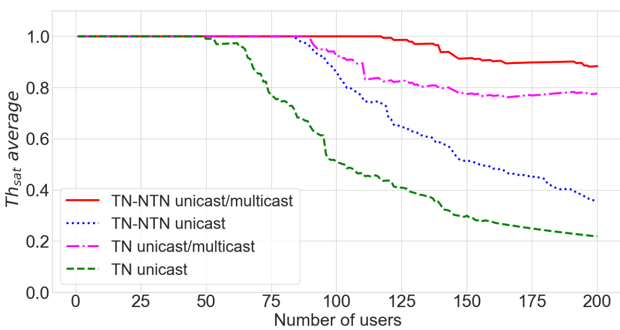

Fig. 7: Th_{sat} average with unicast and unicast/multicast capabilities.

users (equal to 49). Starting from this point, due to the scarcity of resources, the network splits the resources among active users at the expense of affecting the Th_{sat} performance. The load balancing is a gradual and collaborative process until the users in the network receive the minimum throughput according to services' constraints. At this point, it is unfeasible to admit new users until, for example, some terminals leave the network and free up resources.

In contrast, the scenarios with TN and TN-NTN exploiting unicast/multicast capabilities provide a better performance w.r.t. unicasting only. All users of the multicast group efficiently utilize the same NS resources assigned for the multicast service, positively impacting the system ADR performance. Additionally, NTNs play a crucial role as an alternative access network to complement the TNs deployment by increasing the network capacity. Therefore, combining TN-NTN and unicast/multicast allows delivering a higher system ADR and average Th_{sat} w.r.t. the other analyzed cases (i.e., the first saturation point occurs with 117 users).

VI. Conclusions

6G is in the sight of the scientific community with many challenges to be solved to cope with the future advanced applications, impacting the media and entertainment, automotive and safety, industrial IoT, and healthcare. This paper analyzed how multicast/broadcast service delivery aided with NS and softwarization paradigms is suitable for handling a wide range of use cases through economic and efficient resource allocation mechanisms. It delved into the architecture of NTNs and identified how multicast/broadcast could be effectively implemented in 6G scenarios, describing the main features and challenges of NTNs. Moreover, the paper summarized the state-of-the-art multicast/broadcast techniques and their future development. It outlined the key enablers that will drive the growth of future integrated TN-NTN over a softwarized environment. The presented results demonstrated how integrating TN-NTNs and exploiting unicast/multicast capabilities can efficiently allocate network resources.

References

[1] M. Giordani, M. Polese, M. Mezzavilla, S. Rangan and M. Zorzi, "Toward 6G Networks: Use Cases and Technologies," in IEEE Communications Magazine, vol. 58, no. 3, pp. 55-61, March 2020.

[2] Z. Zhang, Y. Xiao, Z. Ma, M. Xiao, Z. Ding, X. Lei, et al., "6G wireless networks: Vision, requirements, architecture, and key technologies," IEEE Vehicular Technology Magazine, vol. 14, pp. 28-41, 2019.

[3] J. Montalban, P. Scopelliti, M. Fadda, E. Iradier, C. Desogus, P. Angueira, M. Murroni, and G. Araniti, "Multimedia multicast services in 5G networks: Subgrouping and non-orthogonal multiple access techniques," IEEE Communications Magazine, vol. 56, no. 3, pp. 91–95, March 2018.

[4] E. Garro, M. Fuentes, J. L. Carcel, H. Chen, D. Mi, F. Tesema, et al., "5G mixed mode: NR multicast-broadcast services," IEEE Transactions on Broadcasting, vol. 66, pp. 390-403, 2020.

[5] 3GPP TS 23.247, "Technical Specification Group Services and System Aspects; Architectural enhancements for 5G multicast-broadcast services; Stage 2 (Release 17)," ed. 2021.

[6] G. Araniti, A. Iera, A. Molinaro, S. Pizzi, and F. Rinaldi, "Opportunistic Federation of CubeSat Constellations: a Game-Changing Paradigm Enabling Enhanced IoT Services in the Sky," IEEE Internet of Things Journal, vol. 9, no. 16, pp. 14876-14890, 15 August 2022.

[7] G. Araniti, A. Iera, S. Pizzi, and F. Rinaldi, "Toward 6G Non-Terrestrial Networks," IEEE Network, vol. 36, no. 1, pp. 113-120, January/February 2022.

[8] A. A. Barakabitze, A. Ahmad, R. Mijumbi, and A. Hines, "5G network slicing using SDN and NFV: A survey of taxonomy, architectures and future challenges," Computer Networks, vol. 167, 106984, 2020.

[9] M. K. Shehzad, L. Rose, M. M. Butt, I. Z. Kovács, M. Assaad and M. Guizani, "Artificial Intelligence for 6G Networks: Technology Advancement and Standardization," in IEEE Vehicular Technology Magazine, vol. 17, no. 3, pp. 16-25, Sept. 2022.

[10] M. M. Azari et al., "Evolution of Non-Terrestrial Networks from 5G to 6G: A Survey," in IEEE Communications Surveys & Tutorials, 2022.

[11] Z. Xiangming, and C. Jiang, "Integrated satellite-terrestrial networks toward 6g: Architectures, applications, and challenges," IEEE Internet of Things Journal, vol. 9, no. 1, pp. 437-461, Jan. 2022.

[12] 3GPP TR 38.821, "Solutions for NR to support non-terrestrial networks (NTN)," Release 16, Jan. 2020. Available at: https://www.3gpp.org/.

[13] Ericsson Mobility Report, June 2022. Available at: https://www.ericsson.com/en/reports-and-papers/mobility-report/reports/june-2022.

[14] 3GPP TS 22.261, "Technical Specification Group Services and System Aspects; Service requirements for the 5G system; Stage 1," Release 18, March 2022. Available at: https://www.3gpp.org/.

[15] C. C. González, E. F. Pupo, L. Atzori, M. Murroni, "Dynamic Radio Access Selection and Slice Allocation for Differentiated Traffic Management on Future Mobile Networks," IEEE Transactions on Network and Service Management, Feb. 2022.

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