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Abbreviations

3GPP	3rd Generation Partnership Project	**ONF**	Open Networking Foundation
5G	Fifth- Generation	**ORAN**	Open RAN
ACTN	Abstraction and Control of Traffic Engineered Networks	**OS**	Operating System
AMF	Access & Mobility Management Function	**OSS**	Operations Support System
API	Application Programming Interface	**PBR**	Policy Based Routing
B2B	Business-to-Business	**PCF**	Policy Control Function
B2B2C	Business-to-Business-to-Consumer	**PE**	Provider Edge
BSS	Business Support System	**PLMN**	Public Landline Mobile Network
CA	Carrier Aggregation	**PNI-NPN**	Public Network Integrated Non-Public Network
CAPIF	Common API Framework for 3GPP Northbound APIs	**PoP**	Point of Presence
CE	Customer Edge	**POP**	Participating Operator
CN	Core Network	**QoS**	Quality of Service
CP	Control Plane	**RAN**	Radio Access Network
CSMF	Communication Service Management Function	**RAT**	Radio Access Technology
CT	Core Network and Terminals	**RF**	Radio Frequency
CU	Central Unit	**RFC**	Request For Comments (IETF normative work)
DC	Dual Connectivity	**RSD**	Route Selection Descriptor
DNN	Data Network Name	**RTT**	Round Trip Time
DSCP	Differentiated Services Code Point	**RU**	Radio Unit
DU	Distributed Unit	**RXX**	Release XX (3GPP)
EGMF	Exposure Governance Management Function	**SA**	Service and System Aspects
eMBB	enhanced Mobile Broadband	**SBI**	South Bound Interface
FSS	Fixed Satellite Service	**SBMA**	Service Based Management Architecture
FTTH	Fibre to the Home	**SD**	Slice Differentiation
GEO	Geosynchronous Equatorial Orbit	**SDN**	Software Defined Network
GSMA	Groupe Speciale Mobile Association	**SDP**	Service Demarcation Points
GST	Generic network Slice Template	**SDTN**	Software Defined Transport Network control
HMTC	High-Performance Machine-Type Communications	**SLA**	Service Level Agreement
HTS	High Throughput Satellites	**SLE**	Service Level Expectations
HW	Hardware	**SLI**	Service Level Indicators
IAB	integrated access and backhaul	**SLO**	Service Level Objectives
IETF	Internet Engineering Task Force	**SLS**	Service Level Specification
IOC	Information Object Class	**SMF**	Session Management Function

IoT	Internet of Things	**SMO**	Service Management and Orchestration
IP	Internet Protocol	**SNPN**	Shared Non-Public Network
ISL	Inter Satellite Link	**S-NSSAI**	Single-Network Slice Selection Assistance Information
IX	Interconnection Point	**SOTM**	Satellite on the move
L2	Layer 2	**SSH**	Secure Socket Shell
L3	Layer 3	**SST**	Slice/Service type
LEO	Low Earth Orbit	**SW**	Software
MDA	Management Data Analytics	**T-API**	Transport Application Programming Interface
MEO	Medium Earth Orbit	**TD**	Traffic Descriptor
mMTC	Massive Machine-Type Communications	**TE**	Traffic Engineering
MNO	Mobile Network Operator	**TeN**	Terrestrial Networks
MOCN	Multi-Operator Core Networks	**TLS**	Transport Layer Security
MOP	Master Operator	**TN**	Terrestrial Network
MPLS	Multiprotocol Label Switching	**TR**	Technical Requirement
MTU	Maximum Transmission Unit	**TS**	Technical Specification
MW	Microwaves	**TSN**	Time Sensitive Networking
NBI	North Bound Interface	**UE**	User Equipment
NEST	Network Slice Type	**UPF**	User Plane Function
NF	Network Functions	**uRLLC**	Ultra-Reliable and Low Latency Communications
NMS	Network Management System	**URSP**	UE Route Selection Policy
NPN	Non-Public Network	**V2X**	Vehicle to everything
NRM	Network Resource Model	**VHTS**	Very High Throughput Satellites
NSaaS	Network Slice as a Service	**VLL**	Virtual Leased Line
NSC	Network Slice Controller	**VNOs**	Virtual Network Operator
NSMF	Network Slice Management Function	**VPLS**	Virtual Private LAN Service
NSSAI	Network Slice Selection Assistance Information	**VPN**	Virtual Private Network
NSSMF	Network Slice Subnet Management Function	**VPRN**	Virtual Private Routed Network
NTN	Non-Terrestrial Network	**WGx**	Working Group x
NWDAF	Network Data Analytics Function	**XR**	Extended Reality
OAM	Orchestration and Management		

1. Introduction

This document focuses on analyzing integration architectures between terrestrial and non-terrestrial networks with specific focus on the framework of the implementation of network slicing in automated end to end network architectures. The content is split in three separate parts, the first being chapter 2 which provides general context information around the implementation of network slicing and this type of management architectures in terrestrial networks, addressing specific key aspects in terms of complexity, architectures and timeline, as well as standardization aspects both in terms of 3GPP definitions and those from other SDOs as IETF, relevant for the implementation of slicing management architectures in the transport domain, outside 3GPP scope, becoming a reference for adoption in the transport network.

The second part, chapter 3, focuses on providing background context around non-terrestrial networks, main use cases, type of systems developing in the industry, evolution of 3GPP work in relation to non-terrestrial network support in their standards, both for backhaul and access services, and also addressing management related specific aspects, with impact on the potential ways to integrate with the terrestrial networks according to the reference architectures under implementation.

Finally, chapter 4 addresses, building on top of the separate aspects elaborated in the previous ones for the terrestrial and non-terrestrial networks, the potential integration architectures for several relevant cases for the integration between networks, targeting the end-to-end slicing orchestration, identifying key challenges and gaps. This section carries out a high-level identification of such aspects, with the main objective of showing the potential variety of cases that the different systems under development open and key factors defining each one, setting the base for further detailed specification in the second stage of the project, for those which might be seen as a priority.

The content in this deliverable constitutes the first deliverable planned for the 6G-INTEGRATION-02 project, **6G-INTEGRATION-02-E5** including results from the work carried out in the three tasks of the project:

- 6G-INTEGRATION-02-A3
- 6G-INTEGRATION-02-A4
- 6G-INTEGRATION-02-A5

The deliverable content covers 100% of the planned scope of the **6G-INTEGRATION-02-E5,** but also includes partial (20%) work related to the detailed specifications targeted within scope of the second planned deliverable **6G-INTEGRATION-02-E6**, especially that related to the detailed analysis of terrestrial impacts of network slicing and IETF/ORAN terrestrial network transport slicing analysis.

2. 5G terrestrial networks, slicing and management architectures.

Mobile communication networks need to evolve over time mainly pushed by recurrent traffic growth and the adoption of new services. The progressive adoption of new mobile communication standards and rising penetration of new services requiring higher quality of experience and capacity from the mobile access network drives traffic growth and the evolution of technologies within the networks. In the specific case of 5G, aside growth linked to broadband mobile services and higher capabilities of the 5G NR, new service types opening new business opportunities in different customer segments aside mass market get additional focus, pushing for the further development of technologies and network architecture evolution beyond the pure capacity expansion. Network slicing is one of the key new features within 5G and beyond, which serves as enabler for new services, business models and network development sustainability. In the following, a base context around network slicing implementation in 5G and beyond terrestrial networks will be developed, to later support the analysis of integration scenarios with non-terrestrial ones in a context where slicing support needs to not only extend to the technical capabilities of the deployed devices, but also to an automated orchestration architecture which extends the full service end-to-end.

2.1 5G networks and network slicing

During the first stages of the 5G deployment, the focus was mainly kept on eMBB services, partly because of the limitations coming from the initial NSA deployment models, leveraging 4G mobile cores. The progressive transition, starting in the more advanced 5G markets towards 3GPP R17 with SA mode has opened additional focus on new types of services, including critical services (uRLLC) with specific stringent requirements in terms of latency or availability or machine type, with also relevant service specifics (mMTC). Evolution in eMBB services in parallel to the integration of the new service categories, of high relevance for business segments aside mass market, as industry verticals, is expected to generate new business opportunities, open new service offerings and revenue flows and motivate sustainable growth and development of the 5G networks towards 6G.

In a highly competitive market such as telecommunications, the monetization of typical mobile services (like eMBB) tends to stay flat (unlike investment in network modernization which grows), which decouples revenue from expenditure, and puts pressure on many communication network stakeholders, also impacting the pace of development of the networks. A key expectation for the new wave of 5G services is to open opportunities for new business and revenue streams (driving then network evolution) linked to the implementation of specific differentiated capabilities and SLA enforcement on top of the network infrastructure and systems.

A key enabling feature for this new generation of services is network slicing, which is part of the 3GPP standard definitions from R15. With slicing, network resources are separated into logical (ideally isolated) sub-networks enabling the simultaneous implementation of many different types of services while meeting specific differentiated service requirements and SLAs. This way, slicing support (which extends over the complete network end-to-end) has become a key element and requirement for most communication network devices and technologies, extending also to management systems and business and operation support.

However, supporting slicing in a 5G network is complex, and the process to enable the full service end-to-end support is phased gradually including functionality in the different network domains. The main challenges are typically:

- Network domains are heterogeneous in terms of assets and technologies (and vendors) and slicing needs to be supported in all of them to cover the full service end-to-end.
- The evolution of the technologies in the different network domains is different and the pace of support of new functionalities may differ significantly.
- Network evolution needs to consider typically (unless the focus is on a new deployment or specific standalone private network) in a brownfield scenario where, additionally, penetration of legacy technologies (which in many cases need to be swapped out) is different across all the mobile network domains.
- Slicing implementation goes beyond the pure support of the network underlying technologies and extends to management and OSS/BSS layers. Network management and orchestration architectures also need to evolve and transform to cope to the extra network complexity and rely on automation. Migration to open standard architectures to achieve that brings the complexity of developing standards in the different relevant SDOs, in many cases being a somehow fragmented ecosystem, with many focused in specific network domains.

Solving these issues towards a complete slicing network implementation in a commercial network (especially a large public 5G network) may require years, which motivates that network operators implement workarounds and phased slicing deployment to start commercializing and monetizing network slicing, incorporating progressively new solutions in their portfolio according to the set of slicing capabilities as technologies of the different network domains develop.

The main target of the subsequent sections will be showing some key elements and challenges related to slicing applicable for the different network domains with a focus on management architecture specifics as the latter condition the proposed integration architectures and identification of key challenges which will be elaborated in section 4. It must be also noted that newer 5G satellite mobile access networks (which extend the typical use of satellites as a transport network solution), as it will be covered in more detail in the next 3, constitute complete end to end 5G networks subject to slicing implementation like terrestrial counterparts, so a general high level introduction of the key elements and challenges for slicing implementation will also serve to create a reference for these non-terrestrial access cases.

2.1.1 Slice concept and mobile network domains

A network slice provides service-specific connectivity to one or more service applications hosted by a Data Network (DN). Devices subscribed to one service can establish communication with the service applications through the corresponding network slice, which will provide an enhanced connectivity profile in terms of functionality, performance and/or security. The fact that makes network slicing an E2E concept is that the device-to-application connectivity spans all the technical domains within the operator’s managed network, including the radio access (RAN), mobile core network (CN) and the transport network (TN) domains.

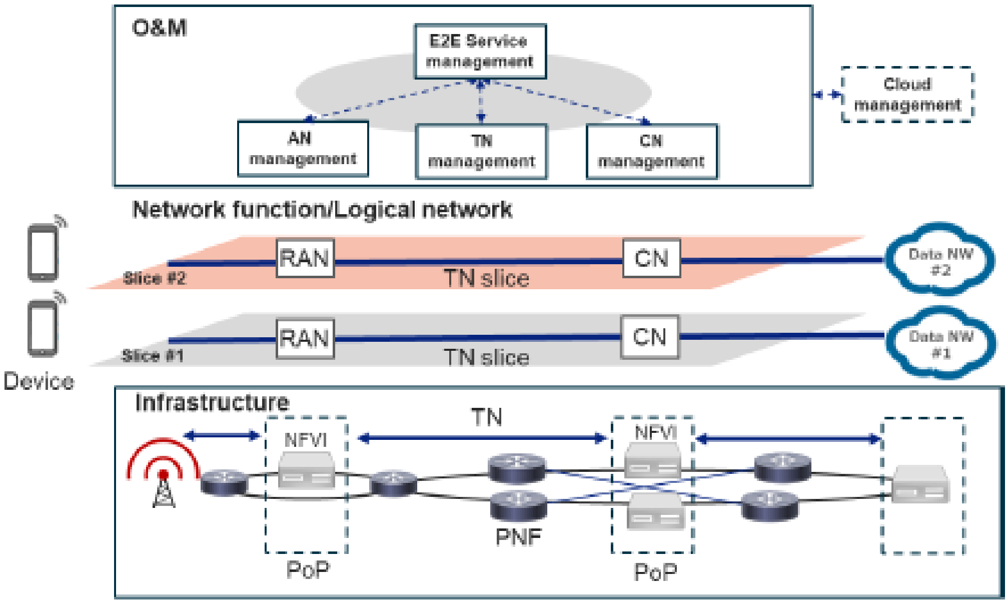


Figure 1. Overall Network Slicing Architecture example for mobile network. [1]

Within 5G, two main options exist for the deployment of the **radio access** nodes interfacing the end mobile users:

1. Distributed gNBs including all the hardware and software to implement the full protocol stack of the 5G air interface.
2. Distributed remote radio units (RUs) carrying out the RF transmission deployed at end sites with part (or all) of the baseband functions implementing the radio access becoming centralized at specific larger sites or MNO PoPs. In this case, 3GPP definitions include 3 elements, each implementing a part of the full functions consolidated in a distributed gNB with options to both de-locate physically the individual parts (interfaces are defined in-between) and also consider some flexibility to balance the functions applicable to each (functional splits):
    - **RU**: remote unit, carrying out the radio transmission and (typically) some low level L1 physical layer functions.
    - **DU**: distributed unit, carrying out (typically) the rest of functions of the physical layer not covered by the RU, plus some upper layer functions of the radio protocol stack as MAC and RLC.
    - **CU**: central unit, (typically) implementing the upper layers as PDCP and SDAP in user plane or RRC in control plane

Physical separation between the radio units requires transport connectivity between them (so the transport network becomes interleaved with the access elements in centralization scenarios. In these cases, the link between RU and DU is typically referred to as fronthaul, and the link between DU and CU (which can be separated in user plane and control plane functions, linked by F1-C and F1-U interfaces as defined 3GPP) is referred to as midhaul. From CU to the CN, transport network in a mobile network from the CN to the core typically the term backhaul is used.

RAN centralization can provide some benefits in terms of operational aspects or radio performance. However, the lower (layer) the functionality that is centralized, the higher impact to transport technologies and related requirements (throughput, latency, ports), so low layer splits are difficult to consider by many transport technologies, which extends to satellite communications.

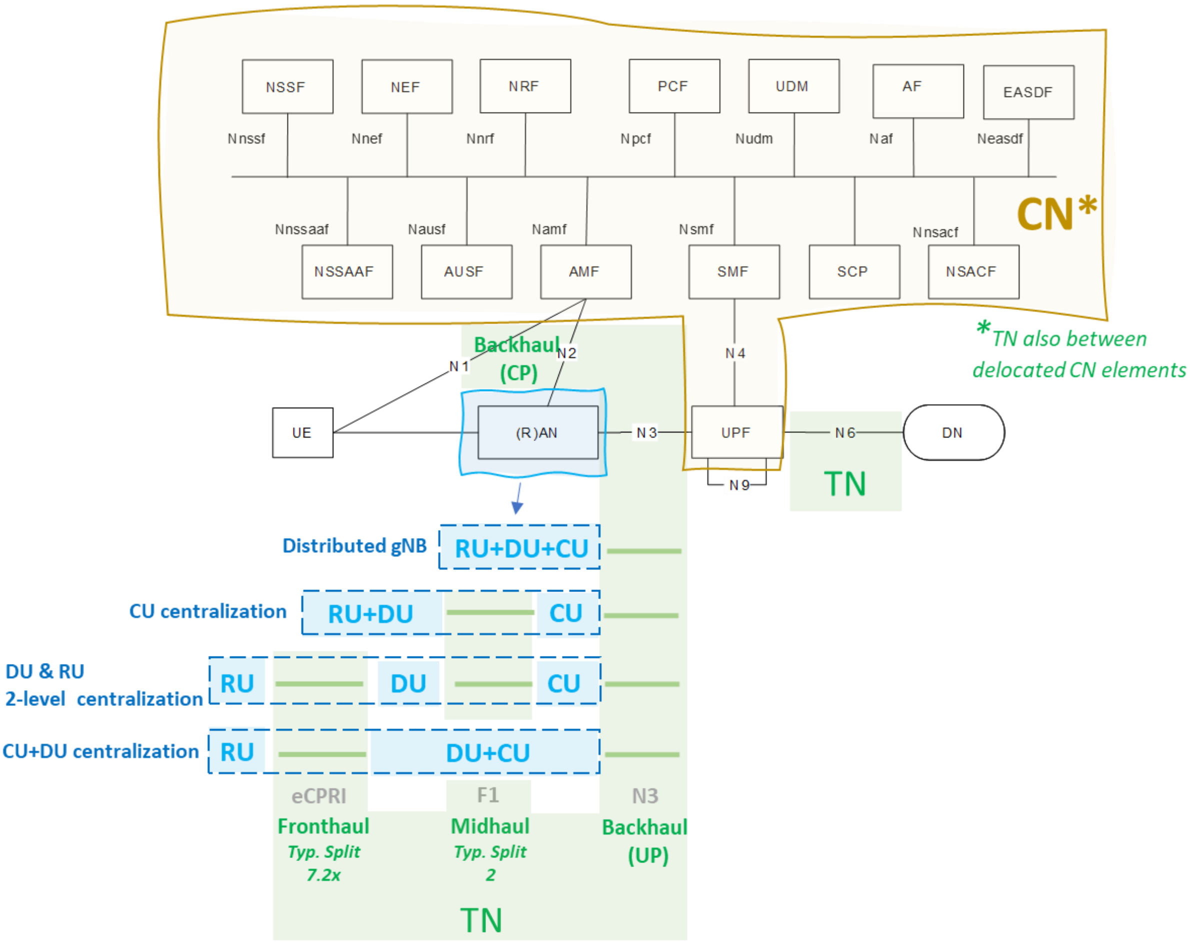


Figure 2. 5G system architecture.

Aside physical separation of functionality, relevant industry groups like O-RAN, leverage this concept by defining these inter-element interfaces to be completely interoperable between different vendors, adding virtualization and cloud implementation options on top, also decoupling the radio access element HW and SW generating a new ecosystem of radio access solutions for 5G.

Transport network nodes are responsible to provide connectivity between the gNB or RU (the entry point to the network for the device) and the core network elements and the data network (DN) where the service applications are hosted. For that, it relies on different forwarding devices, spanning different technologies and implementing different protocols (e.g., IP/MPLS, optical/DWDM and microwave transmission) which form traffic aggregation according to different topologies. As already introduced, the transport network exists not only interconnecting access nodes with the mobile core elements, but also connecting access elements in centralization scenarios, core elements which are physically de-located and interconnecting the core elements with the ultimate data networks.

Finally, **the CN domain** allow user devices to send/receive mobile traffic to/from DN hosted applications or the Internet. The 5G core has a cloud-native design that follows a service-based architecture where network functions are interconnected via a shared bus, fully disaggregated and a modular containerized control plane which is fully decoupled from User Plane Functions (UPFs).

A **network slice**, linked to a specific communication service extends all the domains in the network layer. Each domain includes specific network elements and related resources which support the slice definition. These elements and resources can be split defining logical network partitions, each referred to as a network slice subnet, which support the different slices providing the necessary resources and isolation to guarantee the SLA linked to the target service(s) linked to the slice. The definition of multiple slice subnets within a single domain allows this way to provide differentiated behaviors, in terms of functionality and/or performance. Figure shows the exposed concept for the RAN and CN domains (those within 3GPP scope) which can be extrapolated to the transport network as well. The stitching of slice subnets across the RAN, CN and TN results in the definition of end-to-end network slices.

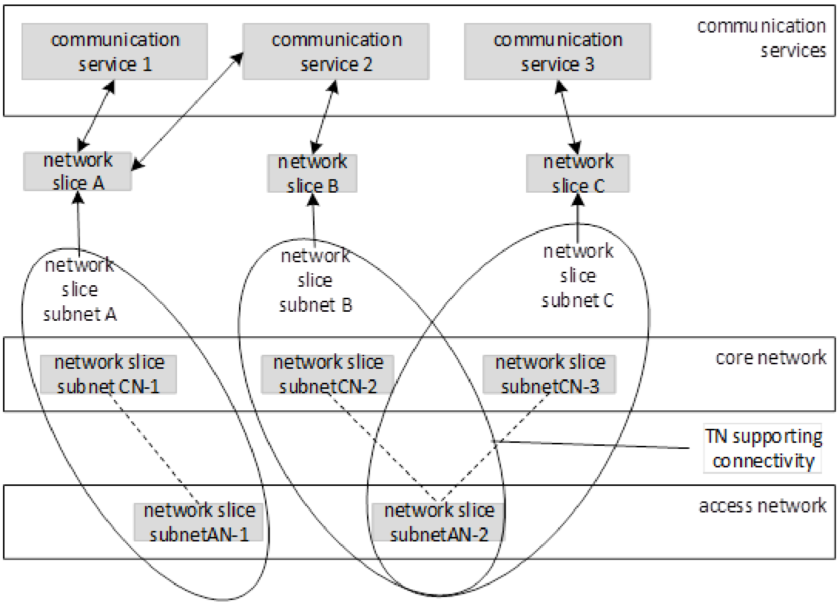


Figure 3. A variety of communications services provided by multiple network slices [2].

The rules for the definition of network slice subnets and their composition into network slices are detailed in the 5G Network Resource Model (NRM) [3], specifically in the Network Slice NRM fragment. Relevant objects within the model defining the slice being:

- **NetworkSlice**: Represents a network slice, linked to one or many ServiceProfile definitions.
- **ServiceProfile**: represents the requirements that the slice needs to support for a particular service.

- **NetworkSliceSubnet**: represents a network slice subnet, with 1:1 mapping to a network slice. Network slice subnets can include other slice subnets.
- **SliceProfile**: requirements applicable to the slice subnet level.
- **ManagedFunction**: represents a 5G network function.
- **EP_Transport**: Object which includes information about the transport, as reachability information, required QoS, etc. This is a relevant object for the stitching between 3GPP (RAN, CN) and TN domains.

For the definition of the service and slice profile requirements, GSMA has developed the GST (Generic Slice Template) concept. It aims at providing a standardized set of attributes to define a type of network slice. GST has been included in 3GPP specifications (e.g. TS 28.541 [4]), and it is used as the way to agree SLA between vertical industry or slice users and the mobile operator or CSP providing the slice. The Service Level Specification (SLS) includes the ServiceProfile information model. A filled GST is referred to as NEST (network slice type) which is translated and used as input to define the ServiceProfile, which is then translated by specific network functions into corresponding requirements applicable for the slice subnet across all the network domains Some of the information in CN SliceProfile is sent to the core network function for the control plane SLA support purpose.

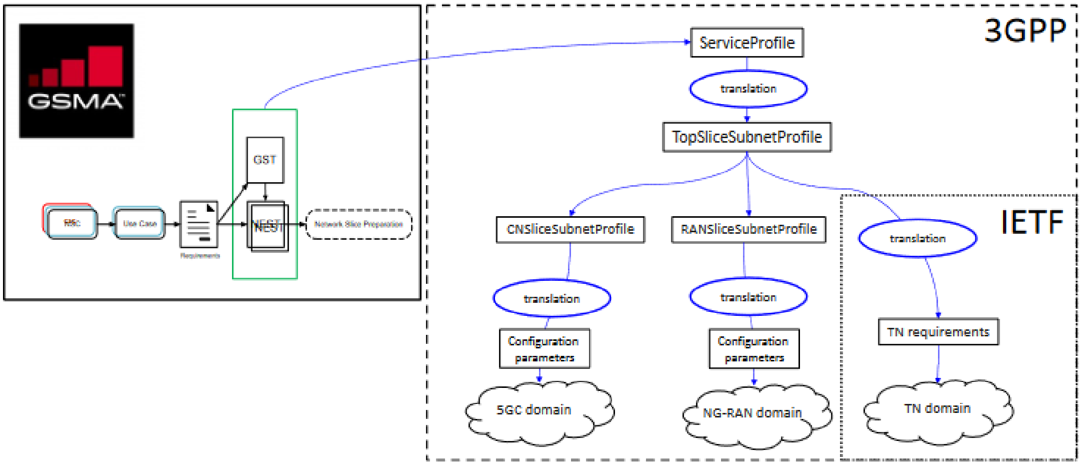


Figure 4.Relation between GST and network slice NRM ServiceProfile [5].

2.1.2 Slicing management and E2E reference orchestration architecture

Aside the support from all the network elements in the different domains of the network layer, network slices need to be managed. Management and orchestration of network slices is key to mobile network operators in support of their communication services. A typical network slice lifecycle includes high level phases as preparation, commissioning, operation and decommissioning, each of them including lower-level procedures, including creation, de-activation or static/dynamic modification.

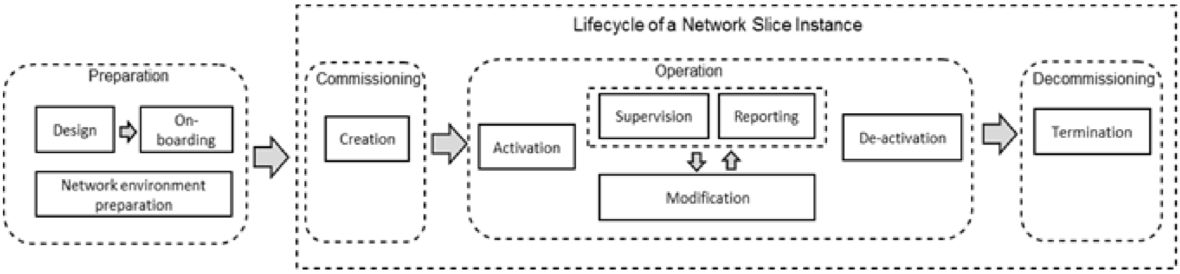


Figure 5. Management aspects of network slicing [2].

So, on top of the network layer, a complete end-to-end OSS/BSS layer responsible for slicing management and orchestration is required. With mobile networks gaining in scale and complexity and multi-domain orchestration (which each network domain including multiple technologies with disjoint evolutionary paths and many device and technology vendors,) becoming a need to implement slicing, management architectures need to be deeply transformed to enable automation across all domains migrating from constrained architectures including large monolithic platforms to open architectures relying on standard interfaces.

It must be considered that 3GPP management definitions cover RAN and CN network domains but, to provide an end-to-end communication service, the network may use other non-3GPP parts as the TN. To ensure the performance of a communication service according to the business requirements, the 3GPP management system has to coordinate with the management systems of the non-3GPP (e.g., TN) parts when preparing a network slice for this service, which needs to be considered then in the overall orchestration architecture. This coordination may include obtaining capabilities of the TN domain and providing the slice specific requirements and other requirements to the TN domain. The 3GPP management system identifies the requirements involved in all network domains, and the derived requirements need to be sent to lower level per-domain management systems.

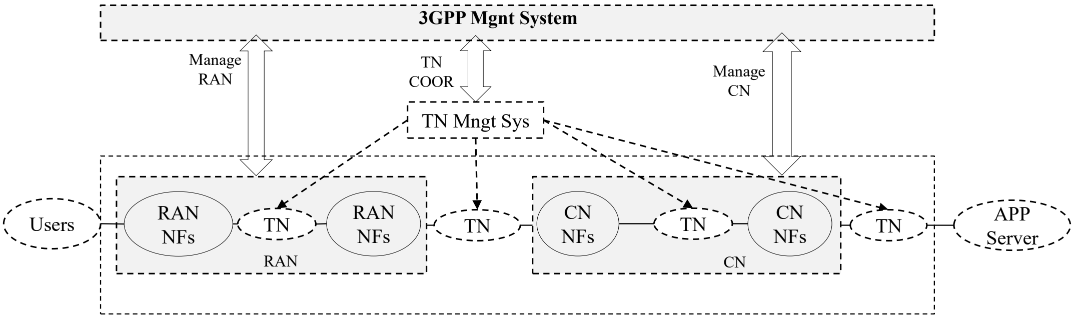


Figure 6. Example of coordination between 3GPP and the TN management systems [2].

Having this as a reference, a service-based paradigm using Application Programming Interfaces (APIs) based on web-based technology (similar in a way to the SBMA adopted by the 5G core network) has been considered as a potential facilitator in this respect and has set the basis for 5G network management and orchestration reference architectures. Here, open standard APIs are a key element to achieve a first key target, which is to achieve independent management of network resources and functions from different technical domains. This facilitates a decoupled evolution of RAN, CN and TN and open selection of technologies and vendors within each network domain. The second key target is to achieve a practical separation between each domain management and the overall end to end network and service orchestration, which is achieved following hierarchical architectures in which higher layer control functions working and systems managing orchestration working with high abstraction that rely on lower-level domain specific control functions and elements which manage the low-level operation and management within each domain. Between them, also standardized interfaces with API definitions gaining in abstraction as higher level within the hierarchy is considered. Integration between all domains is achieved using a service bus.

The next figure summarizes a reference orchestration and management architecture that complements the network layer to implement slicing and operational automation as presented in [6]. It also shows the reference standardization bodies defining the different standard interfaces and models which will be considered as a reference in this project. Note that this architecture (or parts of it for specific network domains has been aligned in relevant industry bodies as GSMA REF GSMA or TIP, in the latter case for example for the transport network management architecture.

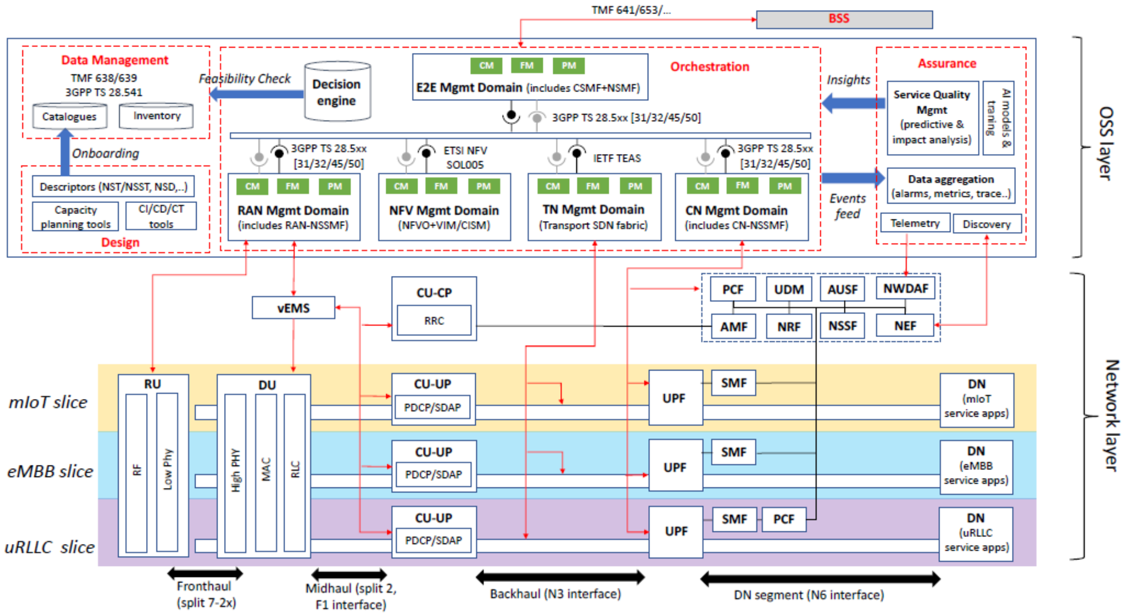


Figure 7.Network slicing system architecture [6].

Prior to zoom in in the transport network SDN management architecture, which requires a more detailed description to support some of the relevant integration architectures (e.g., those focused on satellite systems to support 5G backhauling use cases), some additional aspects will be introduced to serve as a reference for the case of virtualized radio access solution under definition within O-RAN ecosystem.

The general O-RAN architecture is defined in [7], with interfaces, architecture, and terminology consistent with 3GPP definitions, except for those specific aspects which are differential. This extends to network slicing (Slicing specific topics and architectural definitions are addressed in [7]) and the underlying network model as well, which follows the 3GPP NRM, describing additional extensions for specific elements.

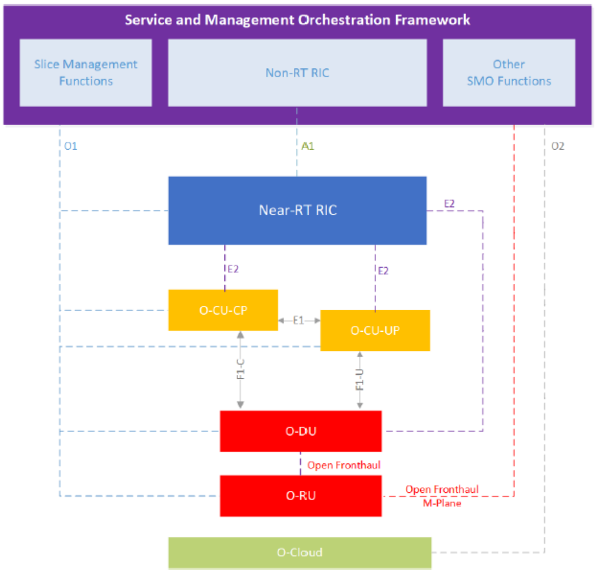


Figure 8. O-RAN Reference slicing architecture [7].

Management and orchestration in the O-RAN is mainly limited so far to the radio access domain. Here, the O-RAN service management and orchestrator (SMO) the component responsible for the RAN domain management, including functions as:

- FCAPS interface to O-RAN Network Functions.
- Non-RT RIC for RAN optimization.
- O-Cloud Management, Orchestration and Workflow Management.
- RAN Slicing management.

Within slicing, some of the key reference cases set for support are full provisioning (slice and slice subnet creation, activation and de-activation, modification, or termination), slice SLA assurance, support of multi-vendor slices (e.g., slices in the radio access domain including HW and SW from different vendors in RU/CU/DU), slice dynamic resource management and cases of extra complexity as those considering RAN-sharing.

Aside radio elements as those already introduced as RU, DU, and CU (in ORAN terminology, O-RU, O-DU and O-CU), Non and Near real time RIC controllers are specific elements of the O-RAN architecture. The fundamental role of the Non-RT RIC in O-RAN slicing architecture is to gather long term slice related data through interaction with the SMO framework and apply AI/ML based approaches interworking with the Near-RT RIC. Near-RT RIC is the component which enables near-real-time RAN slice subnet optimization through execution of slicing related xApps and communicating necessary parameters to O-CU-CP, O-CU-UP and O-DU.

A relevant aspect is that the O-RAN Alliance keeps alignment with the work of other relevant SDOs, which is not only limited to the RAN segment but also is extensible to the transport domain (responsibility of the WG9 group) which is largely aligned so far with IETF work which will be introduced in more detail later. There are existing liaisons between groups and whenever any O-RAN group identifies missing elements in other relevant SDO models, changes are requested to enrich standard definitions and ensure O-RAN system compatibility and integration in the access network domain and end-to-end management architectures. This way, for slicing aspects relevant for the access domain, the considerations in this document will be general, following mainly 3GPP definitions unless identified for any specific case that O-RAN specifics need a more detailed consideration.

2.1.3 Transport network management reference architecture

Because of the relevance for some of the terrestrial and non-terrestrial integration scenarios, the reference transport network SDN architecture to be used within the project scope will be presented in the following. Considering that, within the transport domain devices of different technologies are employed (e.g., optical transmission, routers, microwave and mmWave links, each supporting quite specific technologies), the architecture follows the general principles applicable followed also in the complete network orchestration architecture:

Open architecture relying on standard interfaces and protocols (RESTCONF, NETCONF) and standard network and device models (YANG) as defined and aligned in relevant SDOs.

Separated control elements per key transport domain with a hierarchical end-to-end transport controller on top (Software Defined Transport Network controller or SDTN), working with higher abstraction managing the complete transport domain and interfacing the higher-level network orchestrator.

This reference architecture has been aligned by major network operators and network vendors in relevant industry groups as TIP [8] and will be considered a reference for the project activities.

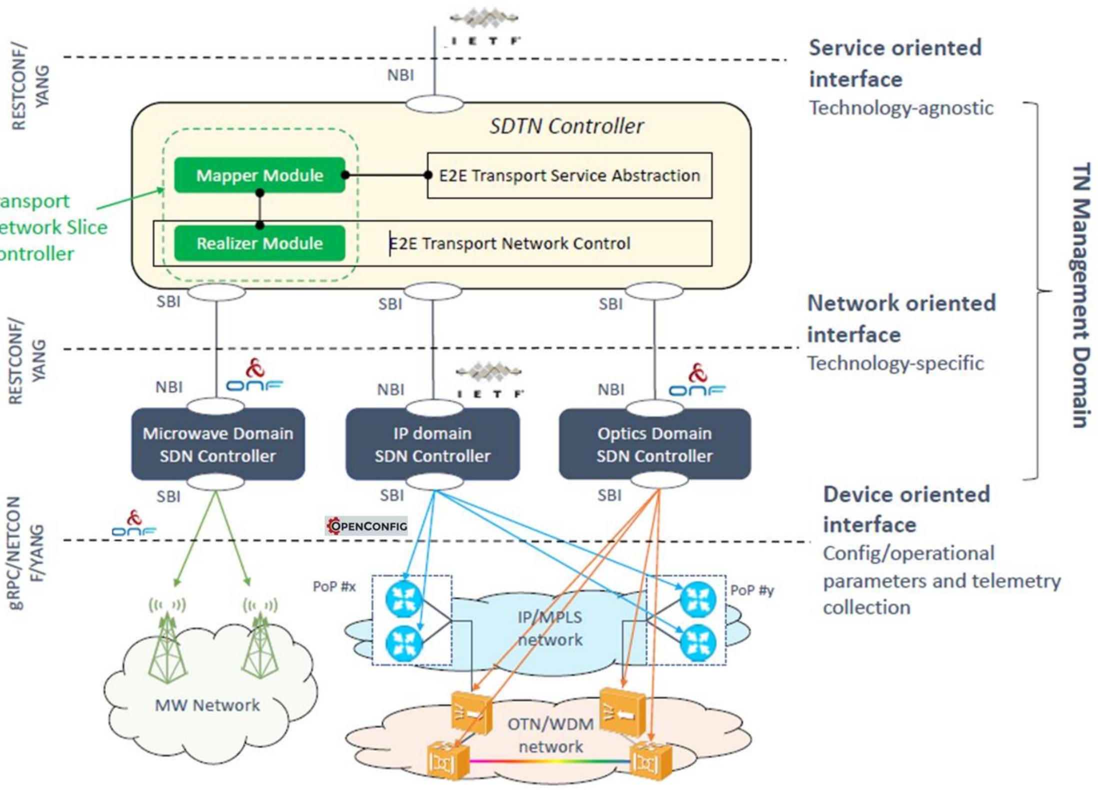


Figure 9. Transport SDN architecture [8].

The architecture considers this way:

- A layer of technology domain controllers separating the low-level management per technology. This separation also facilitates achieving a higher scalability of the architecture.
- A technology agnostic SDTN controller that abstracts the complexity of the different domains below exposing a single-entry point for programmability of the overall transport network. The hierarchical transport controller also enables the end-to-end integration of network slicing features in the transport layer. These are provided by the Transport Network Slice Controller (T-NSC) functionality which is an add-on component to ensure that the SDTN controller can work with slicing and non-slicing services.

In the lower part of the architecture, the device-oriented interfaces (SBI of the domain SDN controller), implementing mainly the NETCONF protocol using standard YANG device data models for device management operations. Complementing NETCONF, other interfaces can be implemented for management cases aside configuration depending on the specific domains, as for example BGP-LS, PCEP or gRPC for topology, traffic engineering and granular monitoring purposes respectively.

As main device models becoming adopted per-domain, Openconfig in IP/MPLS and ONF (TR-512/TR-532) or IETF radio models in microwave networks. In the specific case of the optical domain, in many cases a single domain controller cannot be considered due to the quite specific technology implementations of devices by different vendors. In these cases, multiple optical domain controllers implementing a proprietary interface can be implemented but using the same NBI to the SDTN controller. Disaggregation of optical transceivers opens in any case the way for single domain control.

The interface between each domain controller and the SDTN (NBI of the domain controllers, SBI of the SDTN) needs to offer as a minimum the following capabilities:

- Vendor-agnostic provisioning interface.
- Topology and network inventory information.
- Active monitoring of network status
- Traffic statistics
- Event notifications.

Here, RESTCONF (HTTP-based) protocol with network YANG models is considered for implementation as it permits the reuse of all tooling around the REST interface, industry norm for not device-oriented configuration management operations and to provide abstract representation of relationships between multiple devices, including topology and connectivity services.

Some relevant YANG models applicable for the RESTCONF NBI would be among others [9], [10], [11] for Topology exposure, L2SM, L3SM, L2NM, L3NM for provisioning in the IP/MPLS domain, T-API in the optical one and ONF TR-532 and/or IETF models (REF ETSI for topology and provisioning) for microwave and mmWave networks.

The SDTN will consume these NBIs to orchestrate the domain specific capabilities providing this way real-time control of multi-layer and multi-domain transport network resources. The SDTN carries out control across the different domains via their corresponding SDN domain controllers, constructs and maintains updated E2E topology composition, stateful control of provisioned network services, path computation and service binding to transport resources. It will also be responsible of implementing a domain abstracted NBI towards higher layer orchestration elements exposing transport end to end topology and resources and include the T-NSC, which currently T-NSC is becoming aligned with the IETF Slice Controller developments and definitions within the IETF teas group, which will have the awareness of slicing at the transport layer and manage the workflows for the TN slice provision, as well as for its life cycle. The T-NSC is envisaged this way to include two separate modules: a mapper and a realizer. The mapper module is responsible for collecting the customer-facing view of the TN slice for further processing the TN slice request triggering configuration, control, and management actions. Additionally, the realizer module, would coordinate the different actions on the domain SDN controllers for effectively creating the TN slice, according to the original customer request.

Network operators, to enable automation and programmability capabilities in the transport network in the short and medium term, including allocation and operation of transport slices will need to progressively migrate to a management architecture like the one presented in this section. Not doing so, and without this SDN management architecture, the operator would need to go for static (not scalable) provisioning and management operations, from the E2E management domain to technology-specific management systems, using traditional Command Line Interface (CLI) solutions with ad-hoc extensions to avoid vendor lock-in. This way, although the actual implementation of an architecture like this will follow a phased approach linked to technology availability and standardization (many of these presented components and interfaces are already deployed in live operator networks), the presented transport architecture will be set as a target reference for INTEGRATION2 activities.

2.1.4 Main network features enabling slicing support

In this section, to serve as a high-level reference and especially to identify their phased implementation in commercial networks, the main identified features enabling slicing implementation across all the network domains will be introduced in this section. This will help to identify timeline aspects when considered in parallel to the detailed analysis of the main satellite system use cases and progressive development of new satellite system architectures, to be presented in the next chapter.

Within the **CN domain,** a first need comes related to the slice identity management, where two signaling identifiers become required. These are the Single Network Slice Selection Assistance Information (S-NSSAI), which identifies the slice using a concatenation of two fields, one standard and one for operator specific slice definitions and the Network Slice Selection Assistance Information (NSSAI), which is a set of identifiers to support the procedure to assign an S-NSSAI to a device (and define which AMF serves it) which is managed at tracking and registration area level, including different sets (as configured, requested, subscribed and allowed).

Connectivity at the device level needs also to become slicing-aware. For this, the UE URSP (UE resource selection policy) is introduced, supported by the PCF to inform the device about rules and mappings between applications and network slice information, which will serve to the UE to select PDU sessions for particular applications.

Additionally, CN NFs need of course to incorporate standardized definitions to support slicing. But beyond that, the support of shared or dedicated key core network NFs within slice subnets (as UPF or SMF or even AMF) for slices becomes also relevant.

Within the **RAN domain,** access nodes need to be configured to support several slices. S-NSSAIs are defined at tracking area level (so all the cells serving the same must support the same slices), and PLMN IDs and tracking area codes are used to define and configure the slices supported in the radio nodes, to be then used to map to radio bearers which will be assigned resources as per slice parameters. Radio resource management procedures as admission control and resource scheduling require also specific developments and need to base on the configuration of the per slice quotas as minimum and maximum per radio resource management procedure.

In addition, mobility procedures need to be adapted to support slicing as well, especially when the user moves between tracking areas, where slicing definitions are common. Partial admission control (accepting user handover even some of the S-NSSAIs are not supported by the new access node serving the user, maintaining the PDU sessions where the linked S-NSSAIs are supported) needs to be developed, and other come complex cases like roaming need to develop specific procedures (aside the slicing-level agreements between operators) extending to CN elements.

Finally, **within the TN domain**, which is outside 3GPP definitions, aside technology developments to support slicing in the different transport domains (although transport technologies are not slicing native, resources, capabilities and technologies are totally able to support it via proper configuration), there is a need to define transport requirements according to slice definitions, segregate and handle traffic coming from the different slices (using S-NSSAIs or other indirect options) as well as procedures to stitch radio and core domains to the transport network which requires topology and reachability information accessible to the TN. The EP_Transport object within the 5G NRM model has been defined to allow the TN to receive this type of necessary details from the overall 3GPP orchestration system.

Transport technologies allow for implementing slicing isolation in two ways. First, dedicating physical resources for a given slice, which is referred to as hard slicing, or use packet based forwarding technologies and QoS and traffic management on shared resourced to achieve isolation meeting the final slice service SLAs. Aside current technologies as segment routing, DSCP marking, future ones as Flex-e (or Flex-O in optical domain), Det-Net and TSN will be incorporated on the networks opening the potential to flexibly supporting both options.

2.1.5 Timeline considerations

As already presented, network slicing has been part of 3GPP definitions since R15, with new studies and derived specifications since then in subsequent releases. Slicing implementation in mobile networks extends to all the network domains and the OSS and management and orchestration layer on top of the network, with many different technologies evolving at a different pace, standardization bodies advancing in the different definitions and with operators bringing new devices and functionality to their networks following different timelines dependent on strategic or business-related aspects. In this section, to complete the general context around slicing implementation in terrestrial networks, those aspects expected to generally consolidate in a longer term will be presented, to be taken as a reference also for the cases where integration with satellite systems is envisaged. The focus here will be on standalone networks (most of the 5G networks deployed started with non-standalone mode leveraging EPC), with native slicing support.

In **the core network,** one of the first relevant developments for the flexible support of slicing is the multi-slice support in AMF/SMF (which early commercial cores did not support). The ability of having multiple 5GC slices (CN slice subnets) running in parallel provides possibilities to develop slicing implementations and commercial offerings targeting both public network users and industry verticals. Then, depending on the developments on some key CN NFs as UPF and NFV and edge technologies, different cases sharing or dedicating functions and implementing farther or closer to the final customer can be developed to unleash the full potential of network slicing.

Short term, dedicated UPFs for specific slices can be a simpler option to implement for example in B2C segment but will be limited in terms of scalability. Developments in UPFs to support multiple slices with reasonable scalability open additional possibilities beyond R17. For the specific case of B2B market and in the case of PNI-NPNs (with many R16+ definitions to cover private network implementations in the 3GPP standard), there are also several options for implementation to achieve better performance (e.g., deploying UPF on premises) and higher or lower isolation depending on the client needs, dedicating typically CN NFs as UPF and SMF, but with the additional possibility of dedicating as well PCF or even AMF. Implementations rely on the progressive evolution of edge computing technology to achieve full flexibility.

As progressive developments identified to bring progressively new slicing functionality, analytics focused NFs to bring enhance dynamic management of network slices, unconstrained flexible support of multi-slice support per UE (based on URSP), slice specific authentication and access control features or support of slice roaming (which not only includes technical aspects but also inter-operator commercial agreements) are some of the main features. In the case of roaming, it can be relevant considering some of the satellite access solutions under development in the industry, as will be presented in the next chapter 3.1.

In the **radio access network**, there is an expected progressive migration from distributed gNB deployments to RU/DU/CU centralized deployments linked also to the progressive development of the O-RAN ecosystem. As already introduced in Figure 8, there are several options for centralization, that also will develop progressively linked to technology developments not only in the access network unit but also in supporting transport technologies, highly impacted in terms of requirements by some of the potential centralization options (mainly RU-DU separation). Practical implementation in networks of DU-CU disaggregation is expected in shorter term, also decoupling SW implemented CUs in separate CU control and user plane instances. On evolution, implementation of per-slice CU-UP function and development of virtual DUs as an enabler of RU-DU separation, and longer term, addition of radio access control functions as RICs leveraging specific applications for slicing-based radio management optimization.

Aside access node functions and their implementation aspects, functionality related to radio resource management is following also a progressive development, especially moving from priority more basic scheduling mechanisms to higher complexity ones (5QI, relative and controller priority) and integration of radio resource partitioning mechanisms (which are based on PRB reservation and quotas and allow segregation of cell resources among slices), in this case moving from static to dynamic ones (leveraging on AI, RAN -e.g., RIC- controllers,…).

In practice, all this means a progressive evolution from basic slicing support, with resource management based on 5QI and no or basic mobility support, to large scale multiple slice implementation with full mobility support (inc. roaming), SLA strict guarantees leveraging on advanced radio resource management functionality. Progressive smaller scale private network implementations are seen as an intermediate step to gain maturity and develop technologies to then move to large scale public network implementations.

In the **transport network** includes all the Layer 1/2/3 solutions that allow segregating connectivity resources and enforcing traffic separation in this network segment, enabling TN slicing realization. To develop dynamic provision and management, these solutions need the implementation of programmability and automation capabilities following the SDN architecture already introduced in 2.1.3. multiple networking solutions that can be used for the provision of these capabilities, ranging from soft slicing to hard slicing, with some trade-off solutions in between. Early implementations rely on traditional solutions at layers 2 and 3 as VPNs (e.g., VPLS, VLL, VPRN), DSCP / packet marking at RAN/CN NFs (as first option to segregate traffic corresponding to different S-NSSAIs -not visible being within the GTP tunnels and/or segment routing. As slicing implementation in the networks evolve, evolution is expected towards SD-WAN, hard slicing (relying on technologies in the transport to support that as Flex-E/O and deterministic transport techniques (as TSN or DetNet), important for scenarios where uRLLC services or real-time dynamic management gain in relevance. In the longer term, this being in line with O-RAN ecosystem phased approach, achieving slicing aware transport for the RU-DU fronthauling interface (based now on eCPRI, outside 3GPP specifications).

At the management level, as already introduced, current transport networks are already implementing domain controllers and SDN interfaces, with next steps being integration of E2E transport controllers (SDTN) supporting NBI specifications to interface the upper layer 3GPP management systems, for seamless integration of the transport network into the end to end slicing aware service orchestration.

Finally, in the upper **OSS layer**, end-to-end full slice lifecycle management and capability exposure implementing flexible (to enable NSaaS) are the key drivers of the systems evolution. Current networks are already migrating from monolithic systems with ad-hoc integrations towards open management and orchestration architectures integrating MANO stacks in the operator OSS layer and early implementations include already slice and subnet template management, partial -key classes and selected relations and parameters within them- NRM implementation or feasibility check engines, integrating progressively new functionalities, complete NRM support, gaining in complexity and management scale and extension to assurance capabilities. The latter come linked to the necessary developments also in the network domains as CN and RAN (NWDAF analytics NF, RIC controllers, …).

Capability exposure represents the ability of a network slice provider to securely expose capabilities from its managed functions and services towards its customers. These capabilities need to become available via easy-to-use service APIs. Different options for exposure do exists depending on the management level that the slice provider decides to provide to the slice client, ranging from just usage of the network resources of the provider slice, without managing capabilities to full control of the slice with options in between including monitoring, etc. The progressive implementation roadmap moves from basic API exposure in initial stages (as charging & billing API family) to progressive implementation of additional ones extending capability exposure (e.g., NEST catalogs, device information, location, management data, QoS, etc.) and supporting cases moving towards customer managed slices. Capability exposure might become a relevant topic to consider and explore in some scenarios of integration between terrestrial mobile networks and complete satellite access mobile systems.

2.2 Network slicing in 3GPP, gaps and R17+ studies and normative work

This section consolidates a summary of relevant aspects related to slicing normative work within 3GPP, with focus on terrestrial networks, providing this way additional reference for scenarios where integration with satellite networks is to be considered. A summary of the main reviewed specifications and open work within 3GPP will be given, as well as a reference of identified gaps which require further normative work.

2.2.1 Summary of 3GPP relevant specifications and open studies

Network slicing has been integrated as part of 3GPP technical specifications from R15. Definitions extend to multiple TS produced by the different RAN, SA and CT groups, and this section does not intend to be exhaustive covering them, but to present the key set of reference specifications mainly related to architecture, procedures, and management aspects, used as a reference and relevant for the work conducted within this project.

Basic requirements for 5G systems related to slicing are consolidated in TS 22.261, which provides a reference not only around general ones, but also a minimum set related to management and constraints. Many of the relevant aspects taken as a reference for network slicing are consolidated in TS 23.501, that describes the system architecture of 5G, complemented by the procedure related aspects included in TS 23.502 and policing and charging specific topics in TS 23.503 (including URSP and slicing specific policy control in 5G). Radio access general specifications related to slicing are consolidated in TS 38.300.

From R15 onwards, 23.501 includes key specifications related to slicing, some already mentioned in the previous section, including (not restricted to):

- Identification and selection of a Network Slice, including definitions applicable for the S-NSSAI and the NSSAI, as well as standardised SST values.
- Network slice subscription aspects.
- UE NSSAI storage aspects, and UE configuration. Mapping of S-NSSAIs values in the Allowed NSSAI and in the Requested NSSAI to the S-NSSAIs values used in the HPLMN.
- PDU session establishment.
- Selection and reselection of AMF supporting the network slices.
- Modification of the Set of network slices for a UE.
- Configuration of network slice availability in a PLMN.
- Network Slicing Support for Roaming.

23.501 R15 already addressed an exhaustive set of aspects related to network slicing, which have been progressively enhanced and extended in subsequent revisions through the different releases up to R17 and subsequent 5G advanced releases, R18 and R19. In relation to management, basic network slice lifecycle management features are already introduced in R15, covering introduction of network slice related concepts, provisioning management, performance monitoring and fault supervision of network slice instances.

The most notable enhancements to existing features in 3GPP R16 are in the areas of beamforming and MIMO enhancements, user equipment (UE) power saving, dynamic spectrum sharing, dual connectivity (DC) and carrier aggregation (CA). Additionally, NPNs, new verticals and deployment scenarios are also addressed, including integrated access and backhaul (IAB), unlicensed spectrum, uRRLC and industrial IoT features (e.g. precise synchronization and TSN for uRRLC, etc.) and others as V2X communication positioning. In relation to slicing, R16 brings several corrections and expansions (a dedicated study for slicing enhancements is consolidated in TR 23.740) mainly in relation to slice interworking, CN NF selection for MA PDUs, slice registration, emergency services and NWDAF analytics as well as introduction of slice specific authentication and authorization. In relation to management, slicing service Level Agreement (SLA) attributes and the concept of closed loop automation are introduced.

In R17, linked to standalone 5G network implementations, includes enhancements for all the three 5G main use case families, eMBB, URLLC and mMTC as those related to IAB, MIMO, DSS, multi-radio dual connectivity, power saving, positioning and sidelink, etc. As new features, non-terrestrial networks are one of the key elements, aside others like new high frequency band support, broadcast and multicast services, multi-SIM devices, RedCap and progressive consideration and preparation for support of future services as XR. In relation to slicing (a dedicated study for slicing enhancements is consolidated in TR 23.700-40), some additions in the RAN as UE fast access and service continuity enhancements supporting intra-RAT handover, SNPN slicing support and slices over different non-3GPP access, 5GC assisted cell selection, slice admission control, slicing restrictions and management based on NWDAF analytics and mobility support between SNPNs and PLMN are some of the areas including new definitions and/or enhancements. In relation to management, first definitions (concept, use cases, requirements, solutions and information model for intent driven management of network slices) is introduced in this release. Additionally, management of non-public networks realization using network slicing is also introduced, with closed loop assurance mechanisms specified to support multiple SLA requirements.

R18+ (5G-Advanced) considers a new wave of wireless innovations in three broad directions as shown in Figure 10. 5G wireless innovation directions and 3GPP 5g Advanced timeline., with work in 3GPP starting in 2022 targeting deployment of networks supporting the release progressively from 2024 onwards. Within 5G-Advanced, support for uncrewed aerial vehicles, as well as increased functionality related to non-terrestrial networks, targeting interworking with terrestrial networks is considered as one of the relevant development areas.

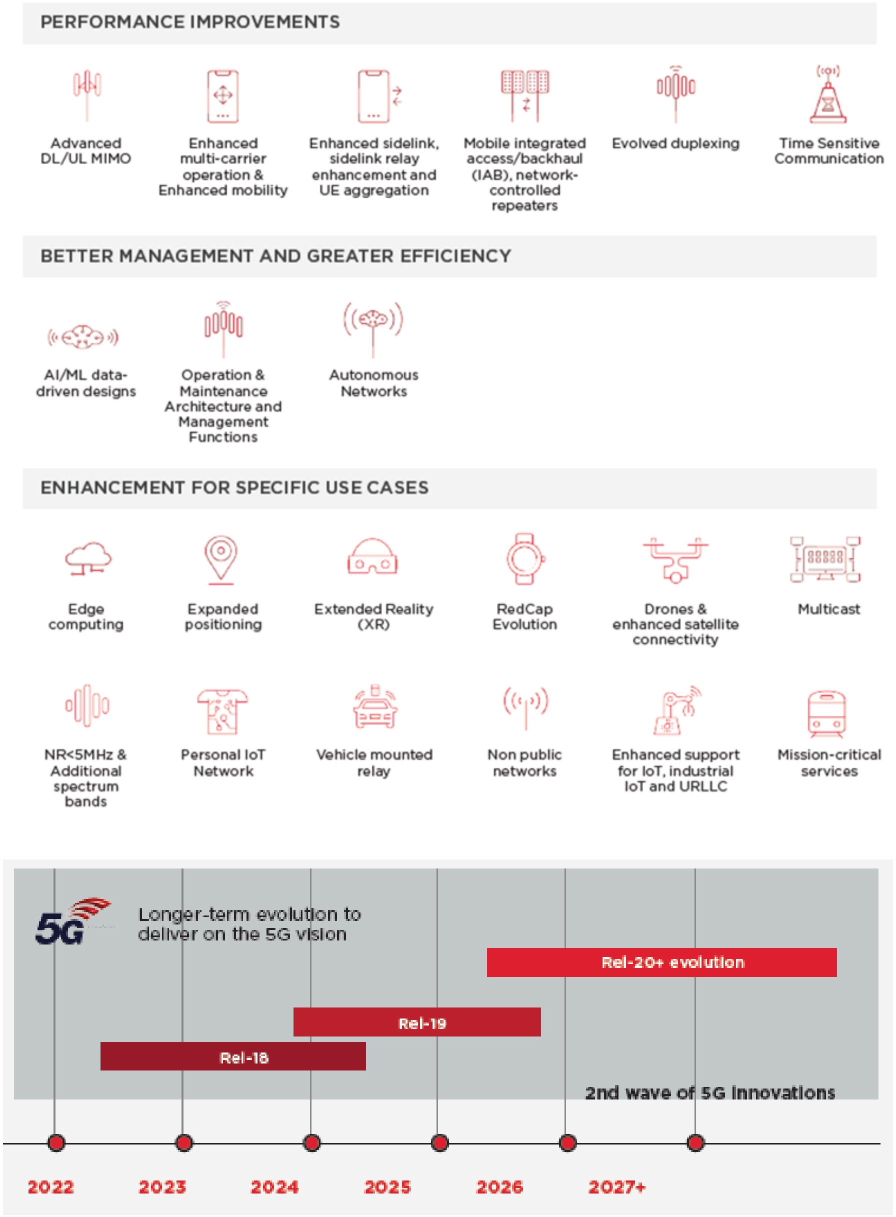


Figure 10. 5G wireless innovation directions and 3GPP 5g Advanced timeline [12].

In relation to slicing, there are already some R18 developments reflected in main technical specifications as 23.501, although there are still open developing studies (see section 2.2.2.1) which will motivate further definitions. As some examples of enhancements already introduced, developments related to external exposure of network capabilities, roaming support (including analytics, mapped NSSAI for UEs, etc.), graceful termination of PDU sessions during decommissioning, NSSAI configuration considering partial slice support within RAs, resolution of open issues related to TA-slice service area or temporarily available network slices. In relation to slicing management, the focus is on improving the provisioning efficiency with rules and asynchronous operations which is currently under discussion as well as developing specific studies including the exposure of network slices to customers and intent-driven network slice management.

2.2.2 Slicing management

The management and orchestration of network slices is key to operators in support of their communication services, and many management-specific studies, reports and specifications have, and keep being developed within 3GPP standardization process, consolidated in a specific specification series, number 28.

Management of network slices is described generally within TS 28.530. This general specification covers general definitions (slices, subnets, etc. as already introduced in section REF), as well as the generic roles which can be considered in network slicing implementation, management, operation and commercialization.

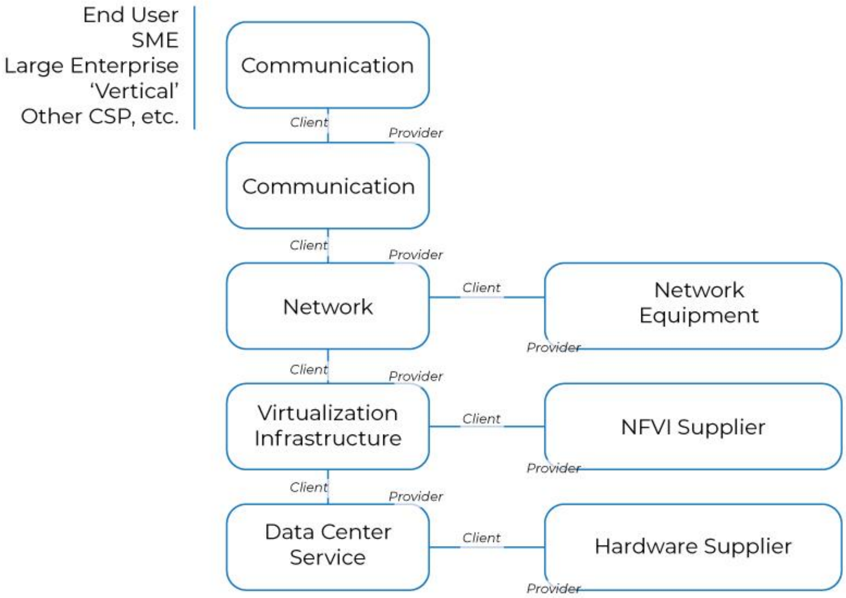


Figure 11. High level mode of roles related to 5G networks and network slicing management [2].

It must be noted here that, although in the initial stages of deployment end-to-end network slicing, operators will start typically deploying slicing as network internals -not visible for the customers but used in the internal operation of communication services-, a key target with 5G networks is typically enable the use and commercialization of network slices as a service (NSaaS). This way, slices can then be provided by an operator or service provider to a customer, agreeing on requirements, SLA and also on scope which is available for the customer (which can extend not only to requests or basic provisioning, but also to monitoring or even configuration). The management phases in network slice lifecycle are also included in this specification, already represented in previous sections, Figure 5.

For definition of the requirements for the slices (SLA) 3GPP adopts GST concept as defined by GSMA [5], translating NEST to ServiceProfile and SliceProfile as defined in NRM TS 28.541, the latter serving to set specific requirements for the components of the slice subnets in the different network domains inside (RAN, CN) or outside (TN) 3GPP scope.

The management of the 3GPP network is provided by management services. The service-based architecture and interfaces support various management services of vastly different requirements on network configuration, network performance, and network fault supervision. TS 28.533 provides the framework and defines the network management and orchestration architecture (SBMA) for 3GPP networks including network slicing, covering generic components and combination, capability exposure governance, management function concepts, capabilities (access control, discovery, etc.) as well as the reference architecture for management services. This specification serves as well as reference for the generic management service definitions developed in TS 28.532, including operations and notifications (for provisioning services, fault supervision, performance monitoring, data reporting, etc.) integrating RESTFUL manage service specifications in the later stages.

The provisioning of network slicing is covered in TS 28.531. Provisioning spans the four general phases, i.e., preparation, commissioning, operation, and decommissioning, including specific methods for the slices as creation, activation, deactivation, modification, and termination (not all applicable to the different phases). Subnets also require as addition the disassociation from specific slices. Full descriptions of each method and stepwise characterizations, as well as specific requirements for provisioning services and operation descriptions are included in the specification. All these definitions rely on the full NRM model, as specified in TS 28.541.

The performance monitoring linked to network slicing, supporting assurance (general specifications and requirements related to assurance are included in TS 28.550) and slice operation is monitored and evaluated at 3 levels, the network function/entity level (specified in TS 28.552, broken down to QoS flow level with the sub-counters for each 5QI) and network slice subnet level and network slice level (specified in TS 28.554). Full specifications of applicable counters and KPIs at each level are included, covering RAN and CN NFs, while for transport relevance of counting with N3 and N6 interface throughput information is identified. Counters and KPIs are defined since Rel-15, and continuously enhanced in every higher release. Complementing performance specifications, and linked to slicing assurance specifics, TS 28.545 includes requirements for fault supervision of 5G networks and network slicing, also at NF, network slice and slice subnet levels.

Starting from R16, leveraging on previous studies and report outcomes, additional specifications related to management have been produced by 3GPP. Closed loop communication services assurance using network slices are introduced building on top of previous specifications with two separate documents covering use cases, requirements, and general background in TS 28.535 and specific solutions for consideration reflected in TS 28.536. In closed control loops there is no human or management operation within the loop, only outside with the inputs provided by an operator or other management entity can include a goal or policies, with the output providing status to an operator or other management entity as well.

Linked to the focus of R16 in NPNs, specific management specifications related to the management of non-public networks using network slicing are consolidated in TS 28.557, including specific general problem descriptions, specific role definitions, and requirements and solutions applicable both to SNPNs and PNI-NPNs.

R17 work includes several specific studies and reports extending work on NPN management and tenancy concepts, enhancing also slicing management aspects, including performance and assurance specific topics, as well as a new specification TS 28.104 related to management data analytics (MDA) for network slices. The MDA is an OAM capability enabling the production of analytics outputs based on a set of analytics input data, including several capabilities and use cases related to related to network slicing. MDA leverages the current & historical data related to already presented specifications, as those related to performance counters and alarms, but also others like location, NWDAF analytics or QoE, reflected in additional specifications. In R17, slice coverage analysis and network slice throughput and load analysis and traffic prediction are included.

A relevant study related to management enhancements is TR 28.811, which includes some topics of specific interest considering some of the potential scenarios for integration of satellite access networks with terrestrial 5G 3GPP ones. These are multi-operator scenarios requiring slicing implementation and management, which includes roaming scenarios. Requirements and solutions are analyzed for reference cases and conclusions for further normative work are derived as a result (with several proposals for updates applicable to NRM TS 28.541 to enable future appropriate support).

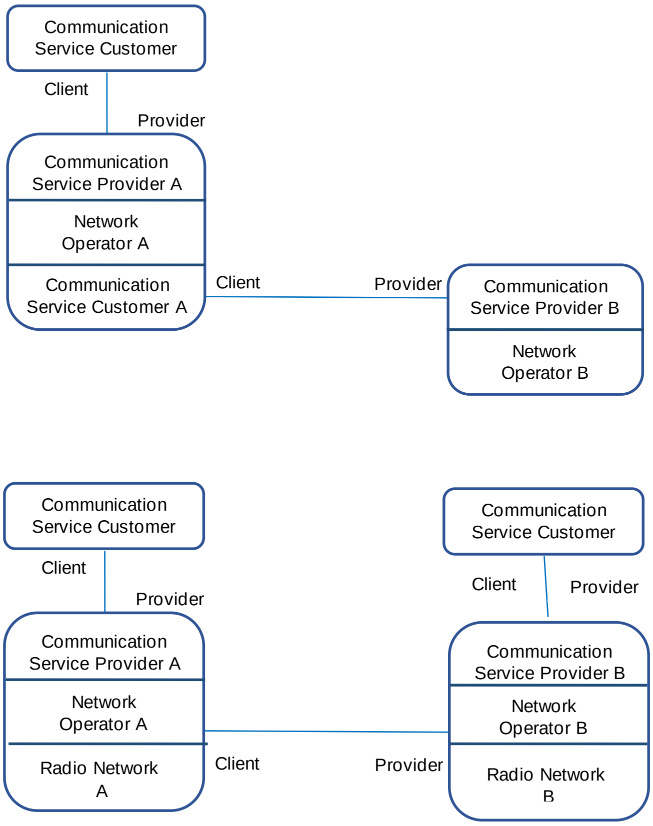


Figure 12. Figure 13. Multi-operator scenario (up) and national roaming concept (down) [13].

Additionally, also within R17 management developments, a specific report related to management aspects in network sharing environments (TR 28.825) was conducted, as first phase to be continued and extended as part of R18, describing some relevant scenarios for MOCN, management requirements, identified problems and proposed solutions which can be adopted for potential implementations (impacting also management definitions and modifications to the 3GPP NRM in order to enable implementations). It must be noted, that RAN sharing might be also relevant in some of the potential integration scenarios between, depending on satellite system solution architectures. This way, developments in R18 related to network sharing (as TR 28.835), and further ones as 3GPP TR 22.851 will be tracked and specific considerations, if any, during the scope of the project will be incorporated to further versions of this document and any additional work.

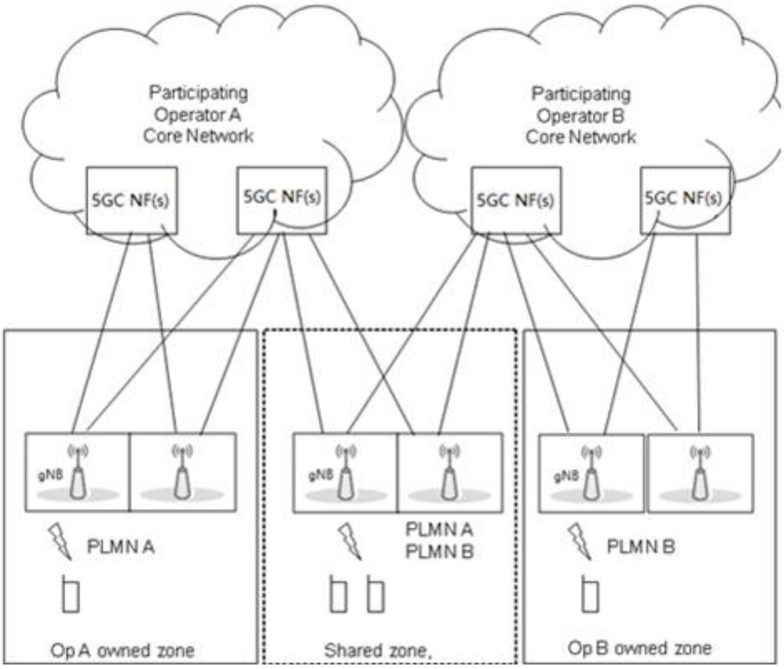


Figure 14. NG-RAN MOCN Network Sharing with same cell identity broadcast scenario [14].

2.2.2.1 R18+ slicing topics

In Rel-18, there are new work/study items for enhancement of SBMA and network slicing, such as enhancements to network slicing provisioning, including provisioning rules, management aspects of network slice management capability exposure and intent-driven management for network slicing.

A dedicated study for slicing enhancements is consolidated in TR 23.740-41, focused on aspects like service continuity, slice information provision to roaming UEs, slice service areas -including multi service areas- and mapping to Tas and control or UE behavior by the network with several conclusions reached with derived proposals for normative work.

In relation to management, two new technical reports are under development relevant to the scope of the project are under development within R18, focused on slice management capability exposure (kicked off in R17) and intent-driven management for network slices.

TR 28.824, focused on capability exposure focuses on use cases, potential requirements, and solutions for exposure of management services to external network slice consumers, as service providers, including main cases, solutions, conclusions, and recommendations on the next steps for the standardization. Conclusions, include reference architectures, proposed for normative phase, and analysis on the relevant ecosystem for aligned interactions (as GSMA or TMForum). Capability exposure can become relevant for some of the scenarios considered for the integration between terrestrial and satellite networks (especially access systems, considering some of the system architectures found developing in the industry and reference scenarios included in 3GPP specifications). Further derived specifications might then become relevant and will be tracked during the project in order to incorporate changes or refinements in further versions of this document or any other further work.

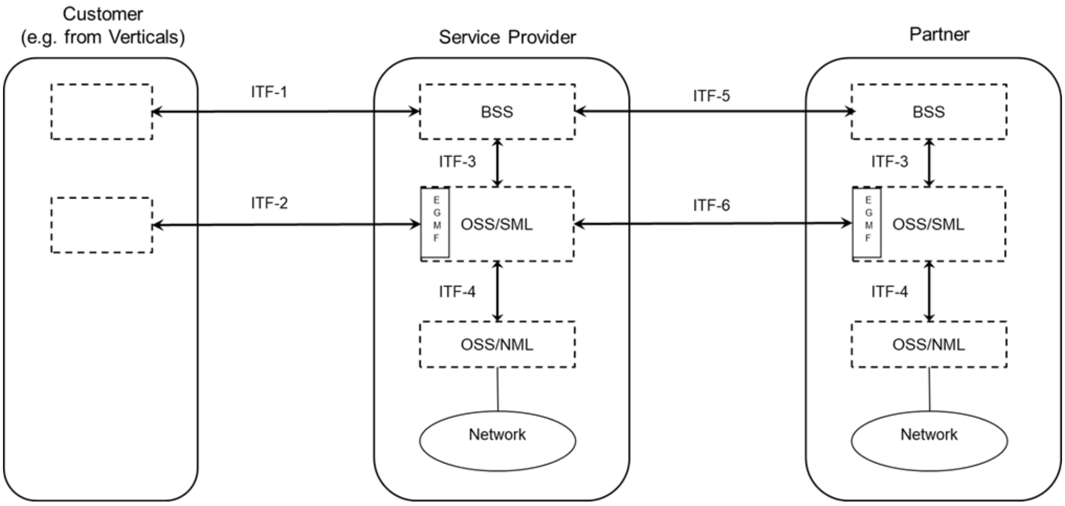


Figure 15. Reference architecture for slice ordering, provisioning, and assurance [15].

Intent-driven management is studied in R18 TR 28.836 building on top of the framework definitions for Intent driven management services in mobile networks consolidated in TS 28.312. The main objective of the new study is to define whether a complete alternative network slice management solution based on intents is practically feasible and evaluate the key pro/cons of such an alternative. Benefits, use cases, requirements, and solutions for intent driven management for network slicing are studied to provide conclusions and future recommendations for subsequent standardization. This intent-based approach would be somehow similar to the concept already introduced in the overall end-to-end and transport network management architectures, where a very high level of abstraction is considered in higher management layers gaining in specific detail as moving down the hierarchy of management element and functions.

2.2.3 Relevant 3GPP elements for slicing implementation and gaps

This section focuses specifically on some of the key elements (defined from R15) that impact the deployment of network slices, and their later provisioning to different devices. Although they have already been briefly introduced or described in previous sections, here they will be analyzed in more detail to present how they are related to each other and, especially, introduce identified gaps that will need to be addressed.

2.2.3.1 UE Route Selection Policy (URSP)

3GPP provides details on URSP definition [16] and implementation [17]. The URSP is a signaling construction that includes information mapping the traffic flows of a client application (user data traffic) to 5G PDU session connectivity parameters. The URSP is used by the UE to determine if the user data traffic can be routed through an already established PDU session or there is a need to trigger the establishment of a new PDU session.

An URSP consist of one or more URSP rules. A URSP rule consists of one Rule Precedence, one single Traffic Descriptor (TD) and one or more Route Selection Descriptors (RSDs).

Information name	Description	Category	PCF permitted to modify in a UE context	Scope
Rule Precedence	Determines the order the URSP rule is enforced in the UE.	Mandatory	Yes	UE context
Traffic descriptor	*This part defines the Traffic descriptor components for the URSP rule.*	Mandatory		
Application descriptors	It consists of OSId and OSAppId(s). (NOTE 2)	Optional	Yes	UE context
IP descriptors	Destination IP 3 tuple(s) (IP address or IPv6 network prefix, port number, protocol ID of the protocol above IP).	Optional	Yes	UE context
Domain descriptors	FQDN(s) or a regular expression which are used as a domain name matching criteria (NOTE 6).	Optional	Yes	UE context
Non-IP descriptors	Descriptor(s) for destination information of non-IP traffic	Optional	Yes	UE context
DNN	This is matched against the DNN information provided by the application.	Optional	Yes	UE context
Connection Capabilities	This is matched against the information provided by a UE application when it requests a network connection with certain capabilities.	Optional	Yes	UE context
List of Route Selection Descriptors	A list of Route Selection Descriptors. The components of a Route Selection Descriptor are described in Table 2.	Mandatory		

Table 1. UE Route Selection Policy Rule

Traffic Descriptor (TD):

Each URSP rule contains one single TD. As seen in Table 1, this TD can contain one or more components.

In a URSP rule, the TD is used by UE to evaluate whether a client application qualifies for this rule. An application is determined to be qualified when the information provided by the application (e.g., in the manifest or via an OS APIs) matches every component in the TD. When this occurs, the URSP rule is determined to be applicable. A URSP is determined not to be applicable when for any given component in the TD:

- No corresponding information from the application is available; or
- The information provided by the application does not match any of the TD components.

Route Selection Descriptor (RSD):

Each URSP rule contains a list of RSDs containing one or multiple components, each having a different RSD precedent value. The list of RDS components is captured in the Table 2 below.

In a URSP rule, the RSD is used by the UE to know which 5G PDU session connectivity parameters shall be used to route the application traffic into operator's network.

Information name	Description	Category	PCF permitted to modify in URSP	Scope
Route Selection Descriptor Precedence	Determines the order in which the Route Selection Descriptors are to be applied.	Mandatory	Yes	UE context
Route selection components	*This part defines the route selection components*	Mandatory		
SSC Mode Selection	One single value of SSC mode.	Optional	Yes	UE context
Network Slice Selection	Either a single value or a list of values of S-NSSAI(s).	Optional	Yes	UE context
DNN Selection	Either a single value or a list of values of DNN(s).	Optional	Yes	UE context
PDU Session Type Selection	One single value of PDU Session Type	Optional	Yes	UE context
Non-Seamless Offload indication	Indicates if the traffic of the matching application is to be offloaded to non-3GPP access outside of a PDU Session.	Optional	Yes	UE context
ProSe Layer-3 UE-to-Network Relay Offload indication	Indicates if the traffic of the matching application is to be sent via a ProSe Layer-3 UE-to-Network Relay outside of a PDU session.	Optional	Yes	UE context
Access Type preference	Indicates the preferred Access Type (3GPP or non-3GPP or Multi-Access) when the UE establishes a PDU Session for the matching application.	Optional	Yes	UE context
PDU Session Pair ID	An indication shared by redundant PDU Sessions as described in clause 5.33.2.1 of TS 23.501 [2].	Optional	Yes	UE context
RSN	The RSN as described in clause 5.33.2.1 of TS 23.501 [2].	Optional	Yes	UE context

Table 2. Route Selection Descriptor

URSP and registration procedure:

As per 3GPP TS 23.501 [18], a UE may use a Requested NSSAI that includes up to eight S-NSSAIs. A UE provides a Requested NSSAI in the Registration procedure amongst others based on available URSP rules or UE Local Configuration. The UE uses applicable URSP rules or the UE Local Configuration to ensure that the S-NSSAIs included in the Requested NSSAI are not in conflict with the URSP rules or with the UE Local Configuration.

The S-NSSAI included in the URSP rules is related to the Allowed NSSAI provided by the network to the UE during the registration procedure. If the Allowed NSSAI contains an S-NSSAI for which a matching URSP rule exists, then this rule can be applied. If the

UE is roaming, then the S-NSSAI in the URSP rule is the HPMN S-NSSAI (see also Section 6.1 of GSMA PRD NG.113).

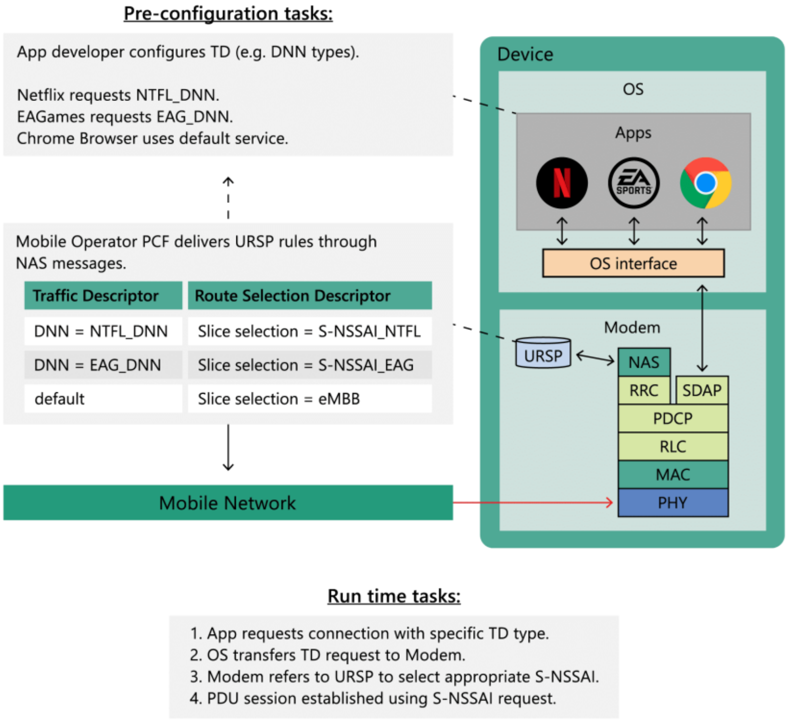
URSP and PDU session establishment:

In the following paragraphs, a quick description on how this procedure works is provided.

1. For every newly detected application, the UE evaluates the information provided by this application (in the metadata or via OS APIs) against the URSP rules, in the order of the Rule precedence. The mission of this evaluation is to determine if this information matches the TD of any URSP rule.
2. When a matching URSP rule is found, the UE shall select an RSD within this URSP rule in the order of the RSD precedence.
3. When a valid RSD is found, the UE determines if there is an existing PDU session that matches all components in the selected RSD. The UE compares the components of the selected RSD with the existing PDU session(s) as follows:
    a. For a component which only contains one value (e.g., SSC mode), the value of the PDU session has to be identical to the value specified in the RSD.
    b. For a component which contains a list of values (e.g., Network Slice Selection), the value of the PDU session has to be identical to one of the values specified in the RSD.
    c. When some component(s) is (are) not present in the RSD, a PDU session is considered matching only if it was established without including the missing component(s) in the PDU session Establishment Request.

The execution of step (3) can lead to different outcomes:

1. A matching PDU session exists. In this case, the UE associates the application to the existing PDU session, i.e. route the traffic of the application on this PDU session.
2. More than one matching PDU session exists. If the UE determines there is more than one existing PDU session which matches (e.g., the selected RSD only specifies the Network Slice Selection, while there are multiple existing PDU sessions matching the Network Slice Selection with different DNNs), it is up to UE implementation to select one of them to use.
3. No matching PDU session exists. If none of the existing PDU sessions matches, the UE tries to establish a new PDU session using the values specified by the selected RSD.
    a. If the PDU session Establishment Request is accepted, the UE associates the application to this new PDU session.
    b. If the PDU session Establishment Request is rejected, the UE selects another combination of values in the currently selected RSD if any other value for the rejected component in the same RSD.
    c. Otherwise, the UE selects the next RSD, which contains a combination of component value which is not rejected by network, in the order of the RSD Precedence, if any. If the UE fails to establish a PDU session with any of the RSD, it tries other URSP rules in the order of Rule Precedence with matching TDs, except the URSP rule with “match-all” TD, if any.



Pre-configuration tasks:

App developer configures TD (e.g. DNN types).

Netflix requests NTFL_DNN.
EAGames requests EAG_DNN.
Chrome Browser uses default service.

Mobile Operator PCF delivers URSP rules through NAS messages.

Traffic Descriptor	Route Selection Descriptor
DNN = NTFL_DNN	Slice selection = S-NSSAI_NTFL
DNN = EAG_DNN	Slice selection = S-NSSAI_EAG
default	Slice selection = eMBB

Run time tasks:

1. App requests connection with specific TD type.
2. OS transfers TD request to Modem.
3. Modem refers to URSP to select appropriate S-NSSAI.
4. PDU session established using S-NSSAI request.

4. *Figure 16. Device slicing [19].*

The next table provides examples of URSP rules accompanied with a description of the result of URSP rule matching:

Example URSP rules		Comments
Rule Precedence =1 Traffic Descriptor: Application descriptor=App1	Route Selection Descriptor Precedence=1 Network Slice Selection: S-NSSAI-a SSC Mode Selection: SSC Mode 3 DNN Selection: internet Access Type preference: 3GPP access	This URSP rule associates the traffic of application "App1" with S-NSSAI-a, SSC Mode 3, 3GPP access and the "internet" DNN. It enforces the following routing policy: The traffic of App1 should be transferred on a PDU Session supporting S-NSSAI-a, SSC Mode 3 and DNN=internet over 3GPP access. If this PDU Session is not established, the UE shall attempt to establish a PDU Session with S-NSSAI-a, SSC Mode 3 and the "internet" DNN over 3GPP access.
Rule Precedence =2 Traffic Descriptor: Application descriptor=App2	Route Selection Descriptor Precedence =1 Network Slice Selection: S-NSSAI-a Access Type preference: Non-3GPP access Route Selection Descriptor Precedence =2 Non-seamless Offload indication: Permitted (WLAN SSID-a)	This URSP rule associates the traffic of application "App2" with S-NSSAI-a and Non-3GPP access. It enforces the following routing policy: The traffic of application App2 should be transferred on a PDU Session supporting S-NSSAI-a using a Non-3GPP access. If this PDU Session is not established, the UE shall attempt to establish a PDU

		Session with S-NSSAI-a over Access Type=non-3GPP access. If the PDU Session cannot be established, the traffic of App2 shall be directly offloaded to WLAN, if the UE is connected to a WLAN with SSID-a (based on the 2nd RSD)
Rule Precedence =3 Traffic Descriptor: Application descriptor=App1 Connection Capabilities="internet", "supl"	Route Selection Descriptor Precedence =1 Network Slice Selection: S-NSSAI-a DNN Selection: DNN_1 Access Type preference: Non-3GPP access	This URSP rule associates the application "App1" and the Connection Capabilities "internet" and "supl" with DNN_1, S-NSSAI-a over Non-3GPP access. It enforces the following routing policy: When the "App1" requests a network connection with Connection Capability "internet" or "supl", the UE establishes (if not already established) a PDU Session with DNN_1 and S-NSSAI-a over Non-3GPP access. After that, the UE routes the traffic of "App1" over this PDU Session.
Rule Precedence =4 Traffic Descriptor: Application descriptor=App3 Connection Capabilities="ims"	Route Selection Descriptor Precedence =1 Network Slice Selection: S-NSSAI-c DNN Selection: DNN_1 Access Type preference: Multi-Access	This URSP rule associates the application "App3" and the Connection Capability "ims" with DNN_1, S-NSSAI-c and multi-access connectivity. It enforces the following routing policy: When the "App3" requests a network connection with Connection Capability "ims", the UE establishes (if not already established) a MA PDU Session with DNN_1 and S-NSSAI-c. After that, the UE routes the traffic of "App3" over this MA PDU Session by using the received ATSSS rules.

Table 3, Examples of URSP rules (columns 1-2) and their matching logic (column 3).

2.2.3.2 Network Slice Template (NEST)

With a large variety of emerging B2B & B2B2C customers in the market, including enterprise customers, verticals, hyperscalers and application service providers, it is fundamental for the operator to define a unified ability to interpret service requirements from different customers, and to represent them in a common language. In this regard, the GSMA has promoted the idea of having a reference slice blueprint called Generic network Slice Template (GST). The GST contains a set of attributes that allow the characterization of any network slice. A complete description of GST attributes is provided in GSMA PRD NG.116 [5].

A Network Slice Type (NEST) is the result of filling GST attributes with values according to service requirements. In essence, a NEST is a filled-in version of a GST and can be used for SLS definition. Different NESTs allow the description of different network slices. In [3], GSMA defines NESTs that address common use cases in the industry, and which are candidates for their availability on a global footprint (and therefore subjected to roaming). Table 3 provides a simplified comparative analysis of the GSMA-defined NESTs. The focus is on the following attributes:

- **SST value**: for a slice specified by "NEST=X", which is the standardized S-NSSAI associated to this slice?
- **SSC mode**: for a slice specified by "NEST=X", which is the SSC mode that this slice must support?
- **Supported data network**: for a slice specified by "NEST=X", which is the data network list that this slice must support?
- **Slice quality of service**. For a slice specified by "NEST=X", which is the 3GPP 5QI list that this slice must support?

NEST (section in [1])	SST value	SSC mode	Supported data network	Slice quality of service
Enhanced Mobile Broadband with IMS support (4.1)	1 (eMBB)	1	Internet DNN, IMS	3GPP 5QI = {1, 2, 5, 6, 7, 8, 9}
Ultra-reliable and ultra-low latency communication (4.2)	2 (uRLLC)	1	Not specified	3GPP 5QI = 82
Massive IoT (4.3)	3 (mIoT)	Not specified	Not specified	3GPP 5QI = 9
High-Performance Machine-Type Communication (4.4)	5 (HMTC)	Not specified	Not specified	3GPP 5QI = 83

Table 4. Comparative analysis of GSMA-defined NESTs

2.2.3.3 Observations on the relationship of URSP rule with NEST

Observation 1

Upon receiving the connection request from a client application, an applicable URSP rule could be found (via its TD) that would then indicate (via its RSD) the connectivity parameters to be used for the PDU session for that connection. Examples of these connectivity include SSC mode, DNN and S-NSSAI (see Table 2 and 3).

When the RSD of the applicable rule does not specify the S-NSSAI, then it means that the target PDU session is not allocated to a slice.

When the RSD of the applicable rule specifies a S-NSSAI, then it means that the target PDU session is allocated to a 3GPP 5G slice. The characteristics of this slice can be represented using a NEST, either as a GSMA-defined NEST (see Table 4) or as an operator-specific NEST.

NOTE 1: The target PDU session represents the PDU session onto which the application traffic is routed.

NOTE 2: As defined in clause 3.1, the target PDU session can be an already established PDU session or a new PDU session.

Observation 2

If the RSD of the matching rule specifies the S-NSSAI that is compliant with the GSMA-defined NEST, then it is obvious that the target PDU session can be associated to any of the 5QIs supported by that NEST (see Table 4). When the application gets executed, a QoS Flow using an appropriate 5QI would have to be established on that PDU session. When the application completes execution, the QoS Flow would have to be removed. There are various signaling mechanisms in 3GPP to indicate to the network when to establish or remove a QoS Flow. As examples:

- If the RSD of the matching rule specifies a S-NSSAI with SST=2, then the slice can be represented with NEST for “Ultra-reliable and ultra-low latency communication”. In such a case, the target PDU session can establish a QoS Flow with 5QI = 82.
- If the RSD of the matching rule specifies a S-NSSAI with SST=1, then the slice can be represented with NEST for “enhanced Mobile Broadband with IMS support”. In such a case, the target PDU session can establish a QoS Flow with any of the following 5QI values: 1, 2, 5, 6, 7, 8 or 9.

If the RSD specifies S-NSSAI of a slice not specified by the GSMA-defined NEST, then only the operator knows what are the possible 5QIs the target PDU session can be associated with. The operator will specify these possible 5QIs in the operator-defined NEST.

2.2.3.4 Observations on the relationship with ServiceProfile with NEST

Clause L.2 from 3GPP TS 28.541 [4] notes the following: “the GST parameters are used as input to ServiceProfile. The ServiceProfile which defines the service requirements related to a particular Network Slice Customer (NSC), is translated into the SliceProfile”. These ideas were already represented in the Figure 4.

Observation 1

If we take a close look at the ServiceProfile attributes (see clause 6.3.3 in [4]), we can realize that most of them map 1:1 with GST parameters [NOTE 1]. This, together with the fact that NEST is a filled-in version of a GST, makes it easy to infer that ServiceProfile be associated to one and only one NEST.

For each GST parameter, there exists a corresponding attribute in the ServiceProfile. However, not all ServiceProfile attributes can be mapped to NEST parameters. The reason is that ServiceProfile takes as input 1) GST parameters, and 2) service requirements from 3GPP 22.261.

Observation 2

GSMA-defined NEST allows representing the service requirements of a network slice when this network slice is associated to a 3GPP standardized SST value. Today, we have GSMA-defined NESTs for the following SST values: 1 (eMBB), 2 (uRLLC), 3(mIoT), 4 (V2X) and 5 (HMTC). This SST value is the same that will be copied to ServiceProfile.ssT. The network slice provisioning service consumer (e.g., CSMF) sends the ServiceProfile to the network slice provisioning service producer (e.g., NSMF) as part of the allocateNsi operation request (see clause 8.1.2 in [4]).

Observation 3

Upon receiving ServiceProfile in the allocateNsi operation request, the network slice provisioning service provider will use the ServiceProfile.ssT value to produce the PLMNInfoList <<datatype>> (see clause 4.3.41 in [4]), which is then written in ServiceProfile. ServiceProfile.plmnInfoList includes “N” PLMNInfo, each representing a {PLMN ID, S-NSSAI} tuple.

Observation 4

According to 3GPP 23.501, a 3GPP network slice is uniquely identified by {PLMN ID, S-NSSAI}. This means that PLMNInfo <<datatype>> is the touchpoint between SA5 and SA2 with regards to unique network slice identification.

Observation 5

As per observations 1-4, one SST value associated to GSMA-defined NEST can be used to generate “N” S-NSSAI, and hence “N” PLMNInfo. The value represented by “N” depends on whether the operator decides to use Slice Differentiator (SD, optional) or not. It must be considered that S-NSSAI (32-bit) includes SST (mandatory, 8-bit) and SD (optional, 24-bit).

If SD is not used, then one SST will map to one single S-NSSAI. In such a case, a NEST will be associated to one single PLMNInfo.

If SD is used, then one SST can be used to generate “N” S-NSSAI, all sharing the same SST value but different SD values. In such a case, a NEST will be associated to “N” PLMNInfo. It must be noted that The SD allows the operator to differentiate among multiple slices with the same SST. This differentiation can be in terms of slice features (e.g., mobile vs fixed-wireless access services, charging), customer information (tenancy) and slice priority [6].

It can be relevant to capture observation 5 in the latest [5]version.

Observation 6

As per observation 5, it can be easily noticed that ServiceProfile.PLMNInfoList with “N” PLMNInfo requires fulfilling one condition and two restrictions.

Condition: SD usage for slice differentiation needs to be supported and activated. This is an ongoing activity in GSMA WAS and ENSWI, as captured in [20]. As restrictions:

- All PLMNInfo in the ServiceProfile.PLMNInfoList will share the same PLMNID, but have different S-NSSAI. This means that: ServiceProfile.PLMNInfoList[1] = {PLMNId = A, S-NSSAI = 1}, ServiceProfile.PLMNInfoList[2] = {PLMNId = A, S-NSSAI = 2} ,…. , ServiceProfile.PLMNInfoList[N] = {PLMNId = A, S-NSSAI = N}.
- S-NSSAIs beloging to different PLMNInfo will share the same SST value. This means:
  S-NSSAI = 1 {SST=B, SD= 1}, S-NSSAI=2 {SST=B, SD=2}, …., S-NSSAI = N {SST=B, SD=N}.

- Current 28.541 specifications [4] allows ServiceProfile.PLMNInfoList to support “N” PLMNInfo. However, it does not capture the one and two restrictions noted above.

2.2.3.5 Conclusions

According to the points clarified and elaborated before, NEST (GSMA NG) links to both URSP rule (3GPP SA2) and ServiceProfile (3GPP SA5). However, there is still a mismatch on slicing interpretations between 3GPP SA2 and SA5.

- **ServiceProfile can be associated to one and only one NEST**. This NEST specifies the SLS for a slice between a network slice provider (NSP) and network slice customer (NSC).
    a. When slices are used to efficiently accommodate B2C services (see clause 4.1.7 from [6]), the NSP and NSC are both played by the operator.
    b. When slices are delivered as a specialized service to 3rd parties (B2B & B2B2C market), the operator acts as NSP, while the 3rd party (enterprise customer, application service provider, etc.) acts as NSC.

- **ServiceProfile is a collection of a PDU sessions associated to the same NSC**.
    a. All these PDU sessions will have the same S-NSSAI, provided that SD usage is not activated (common case, as not conclusions from [20] has been derived yet). This S-NSSAI will correspond to the SST that the NEST is associated with.
    b. Each PDU session will have one or more QoS Flows, each conveying the user data traffic from a particular client application (according to RSD of matching URSP rule). Each QoS flow will be associated to a 5QI. The 5QIs available for selection on a QoS flow will be the ones supported by the corresponding NEST. The 5QI -to-flow association will be done by the 5GC control plane, using 3GPP signaling procedures. These procedures are in scope of 3GPP SA2, and out of scope of 3GPP SA5)

- **NetworkSlice <<IOC>> can accommodate one or more ServiceProfile**.
    a. Each ServiceProfile represents the SLS associated to a given NSC.
    b. All ServiceProfile contained in a NetworkSlice <<IOC>> demand similar performance and functional requirements.
    c. Two ServiceProfile can be associated to different NSCs, or to the same NSC.
    d. The concept ServiceProfile fits well with the concept of communication service that was introduced in TS 28.530 [2]. From a management viewpoint, one network slice (represented with NetworkSlice) can host one or more communication services (each represented with a ServiceProfile).

2.2.3.6 Open issues

There are still open topics that need to be clarified:

- Conclusion (2) draws that ServiceProfile is to be associated to one S-NSSAI, if SD usage is not activated. For the cases where SD usage is enabled and supported, the conditions and restrictions noted in observation 6 in section 2.2.3.4 shall be documented in [4].

- Conclusion (3) draws that for the cases where a NetworkSlice <<IOC>> hosts multiple ServiceProfile, these ServiceProfiles can be associated to the same or different NSC. For example, in the event of having a NetworkSlice <<IOC>> with two ServiceProfile, these ServiceProfile can be associated to:
    - Two NSCs. This is the most common case, wherein each NSC issue a different service order against the same NEST.
    - The same NSC. This is an uncommon yet possible case and means that the NSC issues two different service orders against the same NEST.

  If we impose the constraint that ServiceProfile allocated into the same NetworkSlice must be associated to the same NEST, then we can ensure that all ServiceProfile contained in a NetworkSlice will have the same S-NSSAI. This would allow SA5 to claim that one NetworkSlice represents the management construction associated to one SA2: slice.
- Study the impact on multi-operator scenarios in the Network Slice NRM fragment. This would mean having ServiceProfile.PLMNInfoList consisting of "N" PLMNInfo**,** each with a different PLMN ID. These scenarios are motivated with the increasing tendency of traditional CSPs to offload the ownership and management of access infrastructures to 3rd parties, including terrestrial node operators (e.g., FiberCos, TowerCos) but also satellite operators. As per [21], there are still much work to be done ahead.

2.2.4 Telefonica contributions to 3GPP specifications and studies

This section provides as a general complementary reference the contributions made by Telefonica in coordination with other authors to 3GPP specific technical specifications and studies with relation to the terrestrial network slicing content addressed within the project.

Contrib	Title	Status	Work Item	REL	Meeting	Role	Authors
S5-238148	Rel-18 R TS 28.531 Update use case and allocate for network slice isolation	Approved	NSRULE	Rel-18	SA5#152	Co-signer	Ericsson, DTAG, Nokia, **TEF**, Huawei
S5-238149	Rel-18 CR TS 28.541 Add NRM for network slice isolation	Approved	NSRULE	Rel-18	SA5#152	Co-signer	Nokia, **TEF**, Ericsson, DT, Huawei
S5-238242	Discussion paper to clarify network slice SLA attribute jitter	Not Pursued	AdNRM_Ph2	Rel-18	SA5#152	Co-signer	Nokia, KDDI, Telus, **TEF**

S5-238245	Rel-18 CR TS 28.541 Add slice validity info. to ServiceProfile	Not Pursued	NSRULE	Rel-18	SA5#152	Co-signer	Samsung **TEF**
S5-238209	New Rel-19 Study on Management of Network Sharing Phase 3	Approved	New SID/WID	Rel-19	SA5#152	Co-signer	China Unicom, China Telecom, Ericsson, Huawei, ZTE, CATT, CMCC, **TEF.**
S5-238354	New Rel-19 SID on Enhanced OAM for management exposure to external consumers	Approved	New SID/WID	Rel-19	SA5#152	Co-signer	Nokia, **TEF**, DTAG, Ericsson

Table 5. Contributions made by Telefonica to 3GPP with relation to terrestrial network slicing.

2.3 Transport network slicing in IETF/ORAN and E2E integration

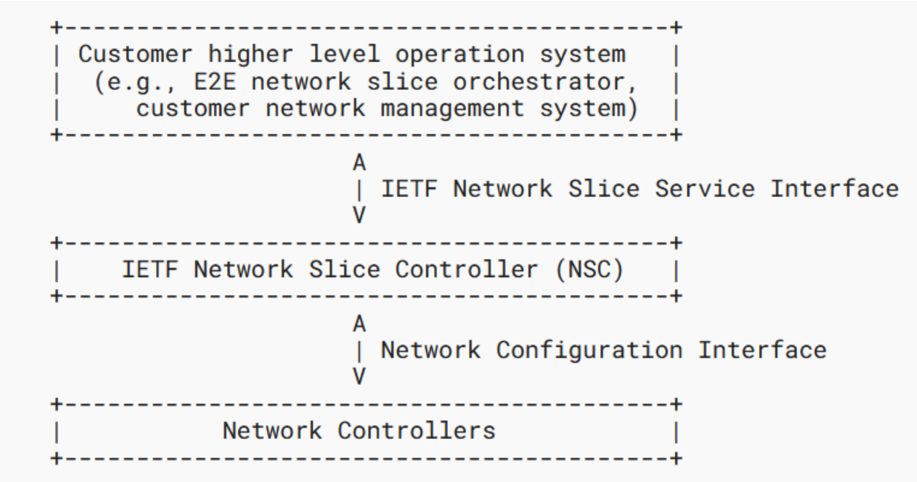
The IETF TEAS working group is the working group within IETF developing documents related to the concept of Network Slicing in which concerns IETF-related technologies. The main outcome of this WG is the framework document [22] which is an informational document describing network slicing in the context of networks built from IETF technologies. Here, the term "IETF Network Slice" to describe this type of network slice and establishes the general principles of network slicing in the IETF context. This is a relevant draft (still not defined as RFC) which will be taken as a reference in this project, together with related work within the TEAS group, which already extend to the definition of the IETF slicing service, interface which aims at the integration of transport slicing management into 3GPP end to end orchestration architectures as presented in the previous section 2.2. It must be noted as well that work within IETF TEAS group is being taken as a reference in other relevant SDOs and industry groups as O-RAN, which considers within the WG9 activities the work ongoing in IETF for the extension of their slicing management architecture and SMO to the transport network domain.

IETF Network Slices are created and managed within the scope of one or more network technologies (e.g., IP, MPLS, optical) and are intended to enable a diverse set of applications or services subject to different requirements to coexist over a shared underlay network. A transport slice will be created to meet specific requirements, typically expressed as bandwidth, latency, latency variation, and other desired or required characteristics. A request for an IETF Network Slice Service is abstracted from the technologies the underlay network to allow customers to describe their network connectivity objectives in a common format, independent of the underlay technologies used. In a similar way to the lifecycles defined in 3GPP, creation, modification, monitoring, deletion, and full management (through the IETF slicing service interface) is considered as part of the IETF slicing framework. IETF transport network slices can be hierarchical (slices can be further sliced) and composed sequentially to achieve a complete end-to-end scope within the TN.

An IETF network slice represents a logical partition of an underlay network that enables connectivity between a set of service demarcation points (SDPs), to fulfil specific Service Level Objectives (SLOs, measurable targets as throughput, etc.) and Service Level Expectations (SLEs, not directly measurable targets as a security, etc.). Service Level Indicators are quantifiable measures which support slice operation and SLA (SLO+SLE) enforcement.

Between the SDPs, different sets of connectivity constructs are considered to flexibly define the network slice (point-to-point, any-to-any, point-to-multipoint), supporting different traffic flow types as unidirectional or bidirectional unicast or multicast. The network slices are defined within SDPs that ultimately attach to the customer's network via attachment circuits. There exists flexibility to define SDPs within attached slice customer CEs or slice provider PEs depending on operational responsibilities of the slice provider.

IETF considers the next basic architecture for the slicing management:



```
+------------------------------------------+
| Customer higher level operation system   |
|  (e.g., E2E network slice orchestrator,  |
|     customer network management system)  |
+------------------------------------------+
                     A
                     | IETF Network Slice Service Interface
                     V
+------------------------------------------+
|    IETF Network Slice Controller (NSC)   |
+------------------------------------------+
                     A
                     | Network Configuration Interface
                     V
+------------------------------------------+
|           Network Controllers            |
+------------------------------------------+
```

Figure 17. Interfaces of IETF Network Slice Controller [11].

En IETF network slice controller (NSC) will be the entity within the transport network management and orchestration layer to manage the slices, interfacing the end to end (e.g., 3GPP management system) orchestrator. Below the NSC, technology-specific network controllers are interfaced using the network configuration interface to realize the slice in each of the managed domains composing the TN. This architecture is in line with that already presented in section REF, where typically, considering the TN end-to-end scope and abstraction level, the NSC is considered for implementation within the SDTN (hierarchical transport controller), having technology specific SDN controllers per domain below. The IETF Network Slice Service Interface is independent of the type of network functions or services that need to be connected.

A high-level description of the creation of a new IETF Network Slice would then be:

- A NSC exposes the network slicing capabilities that it offers for the network it manages so that the customer can determine whether to request services and what features are in scope.
- The customer may issue a request to determine whether a specific IETF Network Slice Service could be supported by the network. The NSC will respond and can complement a negative response with information about what it could support were the customer to change some requirements.
- The customer requests an IETF Network Slice Service. The NSC can provide feedback about the creation process and complement a negative response with information about what it could support were the customer to change some requirements.
- When processing a customer request for an IETF Network Slice Service, the NSC can map the request to the network capabilities and apply provider policies before creating or supplementing the resource partition used to implement the slice.

Independently of how an IETF Network Slice is realized in the network (e.g., using tunnels of different types), the definition of the IETF Network Slice Service does not change at all.

Complementing the general framework, a separate draft [23] application (it must be noted that IETF drafts need to be considered work ongoing) focuses on the actual implementation of 5G end-to-end slices using IETF framework definitions and the IETF network slicing service to implement the slicing in the TN domain, focusing on the mapping between 5G Slices and underlying transport networks.

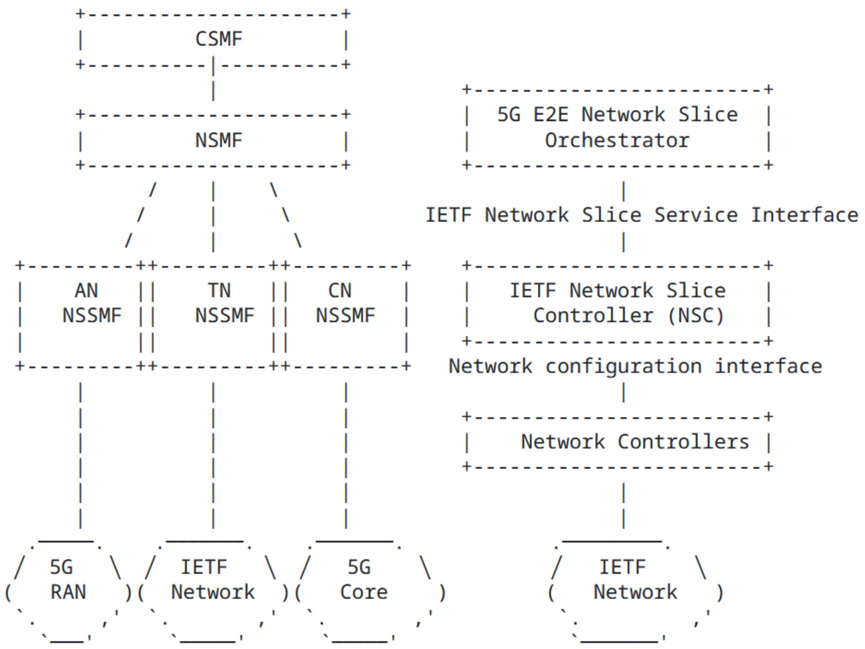


Figure 18. Relationship between 3GPP domain controllers and IETF Network Slice Controller [23].

In the process of end-to-end slice creation, the 3GPP NSMF will send a request to an IETF NSC (acting as an NSSMF for transport network, from the perspective of the 3GPP Management System) for the creation of an IETF Network Slice Service, including attributes such as endpoints (based on the information from EP_Transport IOC), required SLA along with other IETF network slice attributes as well as mapping information for

IETF Network Slice Interworking Identifier. The NSC will realize the slice and send a slice ID back to the 3GPP NSMF, which can maintain the mapping relationship between the slice S-NSSAI and the Network Slice Service ID.

Transport slicing requirements will be derived from initial GST / NEST for the specific service requiring the slice, which should be mapped as already described in other sections of this document to actual NRM objects (e.g., SliceProfile components applicable for the TN).

To provision a slice, it is necessary to include mapping and binding information to stitch the transport domain to the rest of the network domains within 3GPP scope. This includes mapping EP_Transport object in 3GPP NRM and the endpoints at the CE (typically RAN or CN NF, "customer" domain) and PE (transport slice provider domain) sides. The EP_Transport contains parameters as IP address, additional identifiers (i.e., VLAN tag, MPLS label, etc.), and associated QoS profile. This object is related to the endpoints of the 3GPP managed functions (detailed in the EP_Application in TS 28.541). This information should be translated into the CE related parameters. There should be a correspondence between the S-NSSAI that identifies a slice in the RAN and CN and the IETF slice identification in the TN.

The two main options under consideration, in summary, are:

1. Use EP_transport for the mapping, using parameters from its attribute list: ipAddress (IP address assigned on the 3GPP/ORAN subsystem side of the link to TN) and logicInterfaceType and logicInterfaceId (in current release it is an ID of the VLAN, and encapsulation type is 802.1Q)
2. Use EP_RP (TS 28.622 4.3.11), EP_F1U (TS 28.541 4.3.13), EP_NgU (TS 28.541 4.3.11), EP_N3 (TS 28.541 5.3.20) to represent the 3GPP link and association between 3GPP / ORAN NFs, which are not exposed directly to IETF TN domain and can be treated as loopbacks behind the link, defined in EP_Transport object class. Instantiation and manipulation of EP_RPs per slice may be mapped on slices in IETF TN domain, while link defined by parameters of EP_Transport may remain the same, achieving extra degree of flexibility.

There are also different methods considered to map E2E slices to transport slices (as there can be cases in which multiple flows cannot be differentiated by physical port in the CE delivering traffic to the transport PE) in the user plane. The transport network shall be able to distinguish flows corresponding to different E2E slices enable slice interworking. The main options under consideration in IETF are so far:

- VLAN mapping
- MPLS label or segment routing MPLS SID
- Segment Touting v6 SID
- Policy based routing (PBR)
- UPD source port

However, there are still some identified gaps as documented in detail in [23]. The way in which 3GPP is characterizing the slice endpoint and the information provided is not seen as sufficient for the IETF Network Slice Controller for the realization of the transport slice. Basic information such as the mask associated to the IP address of the EP_Transport is not specified, as well as other kind of parameters like the connection MTU or the connectivity type (unicast, multicast, etc.), and others could be required as well, like the level of isolation or protection necessary for the intended slice. There are also cases, as when the 3GPP managed function is instantiated as a virtualized network function, in which the direct association between the IP address of EP_Transport and the actual endpoint mapped at the CE can be not clear and additional information to achieve and end-to-end connection is seen as needed.

QosProfile information in EP_Transport is also seen as incomplete, difficulting the mapping to IETF slice SLO/SLEs and some information accessibility limitations to specific objects in the TN have been identified, aside others like non-existent redundancy mechanisms. In addition, extra information already existing in the 3GPP NRM objects has been suggested to enrich the process of end to end to transport slice mapping and definition, as examples, throughputs per slice subnets available in CN and RAN subnet profile objects.

To provision slices in the transport, the network slicing service interface is under definition with its current full specification and YANG model consolidated in a separate IETF draft, which provides full details ([11]). The main task of the IETF Network Slice Controller is then to map abstract IETF network slice requirements coming from this slicing service interface (NBI to the E2E management and orchestration) to concrete technologies forming the underlying network through specific SBIs to the network controllers which will establish the required connectivity, ensuring also that required resources are allocated to IETF network slice.

The work on the NBI service definition, although still in a draft status, is more advanced than the domain specific realization counterpart (SBI of the NSC). However, there has been recent work addressing the problem and analyzing and proposals for the first domain-specific slice realization examples, as for example in the IP/MPLS transport domain [24], [25] and specific additional framework specifications for the optical transport domain [26].

```
          | (1) NBI: Request to create/modify/delete
          |          5G IETF Network Slice
          V
+-----------------------+
|  IETF Network Slice   | (2) Mapping between technology
|    Controller (NSC)   |     agnostics NBI to technology
+-----------------------+     specific SBI
          ^ ^ ^
          | | |
      |---| | |---|  (3) SBI: Realize 5G IETF Network Slice
      |     |     |      by using various IETF models for
      V     V     V      services, tunnels and paths
+-----------------------+
|        Network        |-+
|     Controller(s)     | |-+
+-----------------------+ | |
  +-----------------------+ |
    +-----------------------+
```

Figure 19. Relationship between transport slice interface and IETF Service/Tunnels/Path data models [23].

Slice realization in other domains as radio transport (MW and mmWave) is still not addressed in IETF or other SDOs (e.g., ONF) working on radio transport standardized management, at least within the general presented framework (although the industry already has a set of available NETCONF/YANG radio device models used for agnostic management in the specific domain such as ONF TR-532 [27] or IETF RFC 856 [28] and network models for specific functionality as topology exposure [29], so it is a domain already integrated in agnostic management and control and this way filling this gap is seen as feasible in short term).

It must be noted additionally that no similar baseline or groundwork has been found for satellite-specific domain open management and equivalent common NETCONF/YANG modeling to that available for other technologies, which is a clear gap that would need to be addressed, especially for the cases where satellite transmission is used as backhaul/midhaul within the mobile network, in order to be managed within the same proposed architectures presented here.

As for the proposed realizations, in [11], additional considerations are made to those already consolidated generally in the slicing framework [22] and slicing application [23] references. For example, recommendations for the automated provisioning and management of the attachment circuit (technology specific TN resource in-between the CE (subject to transport slice customer -3GPP- side) orchestration and PE (transport slice provider -IETF- side) orchestration, as data and control plane should be consistent in the boundary, [30] includes a potential option for automation.

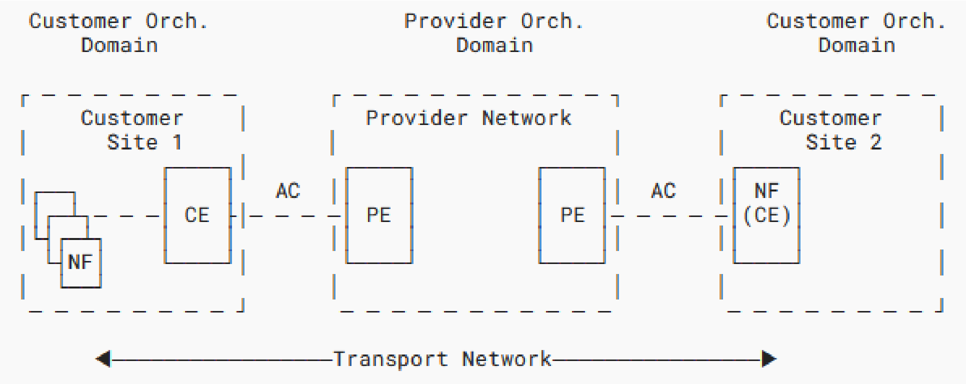


Figure 20. Reference design used for modelling the Transport Network based on management perimeters (customer vs provider) [25].

Additionally, the concept of distributed PEs and CEs are introduced as well as specific cases for CEs (co-managed, etc.), keeping in any case as main focus for the enforcement of end-to-end SLOs the Network Slice segment between PE interfaces connected to the AC.

The proposed realization can be taken as at least as a first reference to guide future work to be carried out in other network domains. It is based on:

- L2VPN or L3VPN service instances for logical separation: These might be used as a basic form of logical slice separation. Furthermore, using service instances results in an additional outer header to provide discrimination between 5G QoS and TN QoS.
- Admission control or traffic conditioning at the PE, with the main target of enforcing the bandwidth contract for the slice right at the edge of the provider network where the traffic is handed-off, using tools as ingress policing (rate

limiting) to enforce contracted bandwidths per slice and, potentially, per traffic class within the slice. In the egress hierarchical schedulers/shapers can be deployed, providing guaranteed rates per slice, as well as guarantees per traffic class within each slice.

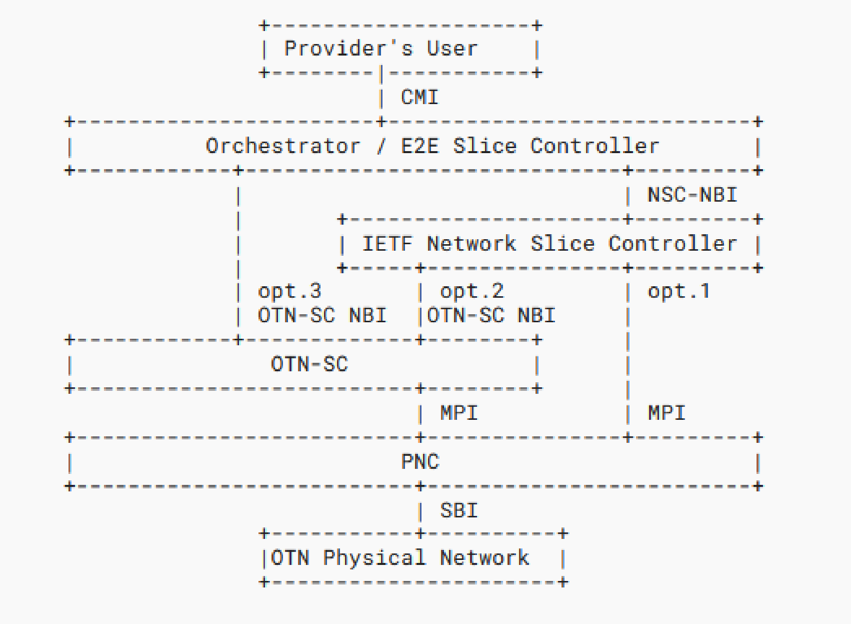
- Resource control at the transit links in the provider network using a flat (non-hierarchical) QoS model is used on transit links in the provider network, e.g., up to 8 traffic classes. At the PE, traffic-flows from multiple slice services are mapped to the limited number of traffic classes used on provider network transit links.
- Capacity planning/management for efficient usage of provider network resources, including detailed planning or TE techniques.

As for the mapping between end-to-end slices and transport slices, as the S-NSSAI is not visible to the transport domain as already introduced before, mapping to explicit Layer 2 or Layer 3 identifiers, such as VLAN-IDs, IP addresses, or Differentiated Services Code Point (DSCP) is proposed in this realization example following the general reference given in earlier [23]. Additionally, tools are proposed for OAM, aside the individual parameters reflected in the network slicing service interface at SDP level.

In the specific case of the optical domain [26] different options for the management architecture are presented according to the optical domain specific constraints, considering as alternatives:

1. In the multi-domain transport orchestrator (SDTN) hosting the IETF NSC there is internal logic to translate agnostic requirements coming from the network slicing service interface (NSC NBI) to OTN domain specific requests for realization (opt 1 in Figure 21)
2. The NSC works still mostly abstracted from the underlying domain and device specifics, relying on an intermediate element (OTN-SC) implementing the network slicing management, which will work with an augmented version of the abstract NSC-NBI (a proposal for augmentation is described in the document). The NSC still needs augment the service request coming from the NSC-NBI with some domain specific data, but aside this works abstracted from the technology, being the OTN-SC the element assuming the final realization of the OTN slice.
3. The NSC is bypassed in case the E2E slicing controller is including functionality to manage, at least at high level (using the proposed augmentation of the NSC-NBI service interface) requests for the OTN-SC.

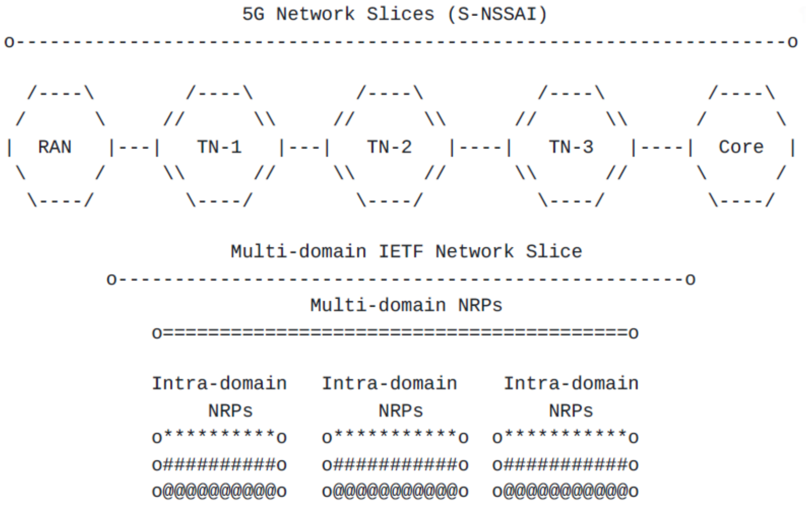
This type of alternatives can also be seen as a reference to adapt new transport domains to the generic IETF slicing management framework. It must be noted anyway that in all the cases all this reference work is ongoing, at draft status.



```
               +--------------------+
               | Provider's User    |
               +--------|-----------+
                        | CMI
+-----------------------+----------------------------+
|         Orchestrator / E2E Slice Controller        |
+------------+-----------------------------+---------+
             |                             | NSC-NBI
             |       +---------------------+---------+
             |       | IETF Network Slice Controller |
             |       +---+-----------------+---------+
             | opt.3       | opt.2         | opt.1
             | OTN-SC NBI  |OTN-SC NBI     |
+------------+-------------+--------+      |
|              OTN-SC               |      |
+--------------------------+--------+      |
                           | MPI           | MPI
+--------------------------+---------------+---------+
|                        PNC                         |
+--------------------------+-------------------------+
                           | SBI
               +-----------+----------+
               |OTN Physical Network  |
               +----------------------+
```

Figure 21. Positioning of OTN Slicing Interfaces [26].

Another relevant draft in early development considering the typical multi-domain nature of the transport network is [31], where options for the implementation of composite (across multiple domains) or hierarchical slices (which also can become relevant in wholesale provisioning to customers which use slices for their end clients) within the transport network are presented, relying on additional identification fields internal to the transport domain (aside per domain resource partition IDs and the 5G slice S-NSSAI, multi-domain IDs need to be introduced to map in domain border nodes). The management layer (at the multi-domain SDTN) needs to implement methods to support multi-domain lifecycle management.



```
                   5G Network Slices (S-NSSAI)
o--------------------------------------------------------------o

  /----\      /----\        /----\         /----\        /----\
 /      \    //     \\    //     \\      //     \\      /      \
|  RAN   |---|  TN-1  |---|  TN-2  |----|  TN-3  |----|  Core  |
 \      /    \\     //    \\     //      \\     //      \      /
  \----/      \----/        \----/         \----/        \----/

                  Multi-domain IETF Network Slice
        o----------------------------------------------o
                        Multi-domain NRPs
            o=====================================o

            Intra-domain  Intra-domain  Intra-domain
                NRPs          NRPs          NRPs
            o**********o  o***********o o***********o
            o##########o  o###########o o###########o
            o@@@@@@@@@@o  o@@@@@@@@@@@o o@@@@@@@@@@@o
```

Figure 22. Multi-domain slice composition, relying on per-domain network resource partitions [31].

As a final additional informational document under definition in IETF related to transport slicing, [32] focuses on the applicability of abstraction and control of traffic engineered networks, outlining the applicability of ACTN to network slicing in a TE network.

2.3.1 O-RAN transport specific considerations

O-RAN slicing use cases and requirements are consolidated in [7], including as main case slice and slice subnet provisioning (similar lifecycle actions to 3GPP specifications are considered, from creation to termination), and others as RAN slice assurance, multi-vendor slices (for the specific case of having different HW/SW vendors in fronthaul/midhaul RAN centralization setups), dynamic resource allocation optimization including full requirement specifications and other relevant procedural aspects and including also initial assessments for multi-operator RAN management service exposure (referring to previously introduced 3GPP TRs and TSs), in line with some already introduced open point objective of current work in 3GPP slicing management standardization, although with a main focus on RAN management scenarios.

General considerations related to slicing in the transport network are also introduced as part of WG1, although analyzed and developed in more detail in coordination with WG9 [1]work, that addresses in more detail general packet-switched network architecture aspects [33] as well as transport management [34], including slicing specific topics in both cases.

Slicing work in ORAN related to the transport network is organized in phases, which are incremental in terms of scenario scope, functionality, and complexity, which published specifications so far focused on initial phases 1-2 and work ongoing focused on the definitions for further phases.

Phase 1 is constrained to single RAN and CN MNO and single transport network operator (which can be the same company), shared management and control plane (slices consider in the user plane dedicated CU-UP and UPF) and general eMBB, mMTC slices, and centralized radio deployment considering as options RU+DU at end site and only RU at end site (with 7.2x functional split).

Aside some constraints related to the envisaged scenarios (legacy RAT support or enterprise service support), the way considered for the integration between O-RAN and the transport domain is a particular case of those already presented in the previous section within IETF considerations to integrate the TN to the 3GPP domain.

- RAN and CN NFs present slices to the TN using logical ethernet interfaces and VLAN+IP separation.
- For QoS management and mapping from end-to-end flows, it is assumed that RAN and CN NFs can mark traffic using DSCP (possible for backhaul in DL/UL)

Phase 1 does not consider slicing in fronthaul and midhaul scenarios, a common service overlay is assumed in fronthaul and midhaul section if the RAN architecture requires for separation between components. Phase 2 considers additional service and slice types in reference scenarios, including multicast and larger slice scalability to support

---

[1] There is also relevant work in relation to transport slicing in WG4 (related to fronthaul interfaces) and WG6 (cloud implementation, applicable for example for intra datacenter links)

enterprise vertical implementations. As relevant addition, scenarios aside, slicing support for midhaul connections (F1 interface between CU/DU) is considered in phase 2, still based on similar VLAN handoff and DSCP QoS concepts used in phase 1.

Further phases target extension of the slicing support to the fronthaul interfaces between RUs and DUs (latest phase, 5). This requires different approaches for the mapping, being the current view the potential use of PLMN ID information to corresponding VLAN+ optional IP pair on C/U Plane of Open Fronthaul interface.

In specific relation to management, although the current ORAN SMO scope has been mainly focused on the RAN domain, specific groups as WG4, WG6 and, especially WG9 (with direct focus on transport network, including management aspects) integrate considerations and cases related to the transport domain. Extending the scope of the ORAN SMO to the transport and core domain is also under consideration and part of the standardization efforts in O-RAN.

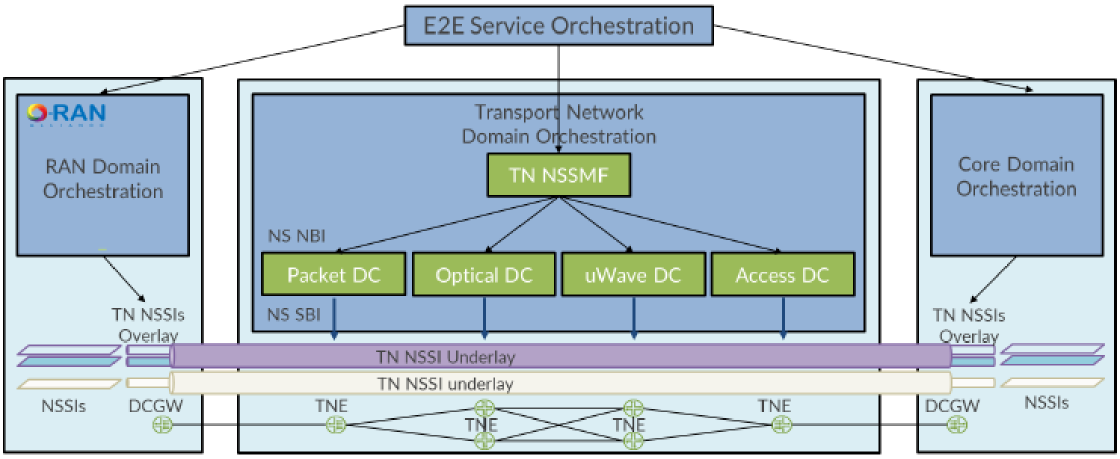


Figure 23. Architecture of the network slicing use case [34].

In the specific case of the transport domain and slicing, work ongoing is so far aligned with other relevant SDOs as 3GPP and IETF (TEAS group definitions), marking as a desirable target to define open and complete interfaces (covering the typical configuration management -inventory and provisioning-, fault and performance management and lifecycle management), independent of specific supplier implementations. For configuration management NETCONF protocol with SSH or TLS are taken as a reference. For Fault and Performance Management using NETCONF is also considered an alternative, including additional methods as relying on streaming telemetry. This is totally in line with the architectural definitions made in this document, which will serve as a reference for satellite technology integration analysis. For the specific case of the transport network, domain specific realizations and interfaces (NS NBI) and mapping from the higher-level TN NSSMF is still a topic not addressed. Note in Figure 23 that main identified technologies for the transport network are not still including satellite transmission -backhaul-, which is an alternative for radio access nodes deployed in remote location as it will be presented in the next chapter.

Aligned with the device and network models already outlined in the previous sections, O-RAN focuses on YANG as the recommended 3 schema for modelling. No new YANG models are defined for transport technologies by ORAN, that refers to already available ones developed in other SDOs (ONF, IETF, etc.) for the different technology domains in the transport network (with no consideration so far for satellite technologies, which is identified in SDO as well as a relevant gap).

O-RAN WG9, for slicing management, has followed 3GPP definitions in R15-R17, considering, in line with the NRM objects already introduced in previous sections, also used in other SDOs as IETF. The EP_RP (available since R15) which represents endpoints of the links between 3GPP network entities (characterized with other specific objects as EP_F1C, EP_F1U, EP_N3, etc.), extended by the EP_TRANSPORT in R16 to allow inclusion of the transport network slicing management in the overall end to end are key elements, complemented with NRM object augmentations in R17 to support midhaul connections.

O-RAN also identifies several gaps for the correct integration of transport network IP networking capabilities, similarly to other groups:

- No IP subnet mask is present on EP_RP resource, which is required for the configuration of the gateway. This is something which impacts both user and control plane slicing, and the model is seen inconsistent.
- More complex TN integrations such as redundancy require development and integration.
- Specifically for O-RAN, no indirection capabilities exist to support O-CLOUD infrastructure, where attachment of the TN can happen at different IP subnets than those employed in the deployment of cloud NFs.

As a result, O-RAN considers enhancements of the 3GPP NRM, which will be requested previously looking for alignment with transport network slicing IETF definitions. For example, a request for change was submitted to SA5 group including extending EP_Transport with a link to external object class model in IETF framework (IETF network slicing service model [35]).

This alignment is also considered within WG9 specifications as of the main options for the slicing management within the transport network. As main differentiation, with still uncertainty and not a mature definition yet, O-RAN has recently introduced the concept of uniform network modelling for potential applicability in the end-to-end SMO architecture. The main underlying idea is to add an abstraction layer that exposes a uniform network model to other SMO components and enables managing different technologies having different YANG models in the SMO southbound.

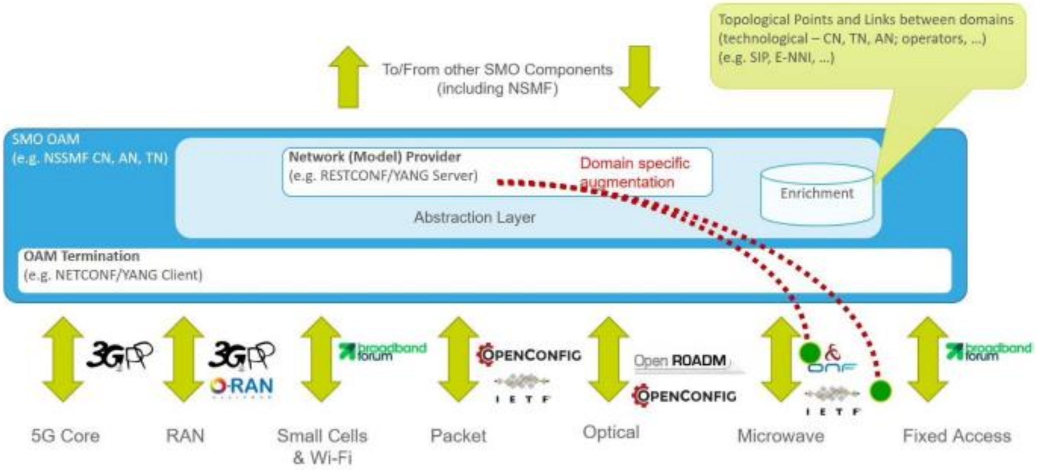


Figure 24. High level view of an Abstraction layer exposing a uniform Network Model. Source [34].

The next Figure 25 shows a detailed view of the concept applied to the transport network slicing management. The main differentiation to that already introduced in this document cones linked to this uniform network model which would apply between the hierarchical multi-domain transport controller and the domain controllers. For implementation, there are several options, still under study, including adoption T-API (ONF), IETF network models or develop new ones (complete or via augmentations of existing ones. In all the cases there are several advantages and disadvantages, and there is still not a defined way forward in ORAN in terms of specification or implementation.

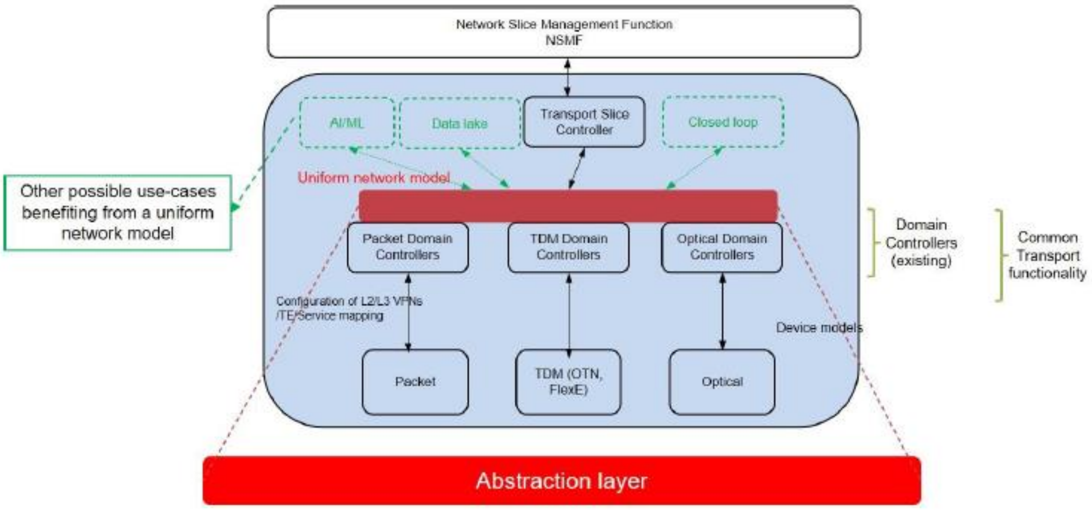


Figure 25. High level transport slicing controller architecture including uniform Network Model [34].

In this document, the general architecture presented in section REF, considering its alignment as well with the current transport slicing work in IETF will be kept as a reference. However, this topic within ORAN will be tracked during the project to see if any relevant modification to the general management reference architecture is worth considering.

3. Non-terrestrial networks, system architectures and management considerations

Typically, satellites have been used as a complementary transmission medium (permanent or temporal) to terrestrial solutions as fiber or microwave links, especially in low population density areas (requiring lower capacity) and difficult areas where deploying a terrestrial solution is unfeasible or requires a very long time to be deployed. The main relevant satellite-based services that have been historically deployed using satellite connectivity include:

- **Video broadcast**: satellite video broadcast has meant for many years the largest market for satellite connectivity, leveraging the wide regional and continental footprints of satellites, with many millions of users connected worldwide. More recently, with the development of high capacity FTTH networks and OTT video, satellite video broadcast penetration has been progressively declining as FTTH networks have gained coverage.
- **Residential broadband access**: satellite connectivity also makes it possible to provide internet for residential customers or deploy Wi-fi access in public administration buildings -rural schools, health centers, etc.- in remote areas with limited fiber, FWA or mobile network coverage.
- **Enterprise connectivity**: Enterprises also require connectivity in very complex locations (e.g., remote mines, oil platforms, etc.) and areas with poor terrestrial network coverage. Government / military projects also require communication services in specific locations which not easily reachable with fiber (airbases in islands, research stations in arctic areas, …).
- **Backhaul links:** sites deployed by mobile operators require connectivity to aggregate the access traffic towards the mobile core (backhaul). Rural base stations (3G/3G/4G and extending to 5G), in many cases deployed linked to coverage obligations, might require a complex, too expensive, or excessively long period to expand the terrestrial backhaul network to reach the sites, benefitting from satellite connectivity (which can be a temporal gap filler solution while the terrestrial transmission develops or in case of disaster-recovery scenarios that require setting up temporal access nodes and backhaul links)
- **Mobility:** aero and maritime markets also constitute a relevant market for satellite connectivity. In these cases, satellite in fact constitutes a primary transmission medium, as no terrestrial connectivity is typically viable but in specific areas (e.g., close to shore in maritime). Military projects do rely also in many cases on SOTM *"satellite on the move"* solutions leveraging wide satellite footprints and portable end devices that can connect to the satellites.
- **IoT:** connectivity to small sensors can also benefit from satellite connectivity for areas in which the mobile network cannot provide it due to lack of coverage. Data transmission to and from sensors is required by many companies or users in many types of use cases (container monitoring in mobility projects, environmental-related detection systems in remote areas, etc.)**.**

Most of these cases have been implemented so far using the satellites as a transport medium, with proprietary transmission devices (including antennas, RF, baseband). In the specific case of 3GPP mobile services -2G/3G/4G- satellites have been typically used within the transport network backhaul with the satellite transmission devices being connected on the central side to a transport network ultimately providing connectivity connected to a mobile core and, on the remote side to a mobile standard base station implementing the mobile services to users.

Non-Terrestrial Networks (NTNs) relying on multiple satellites or constellations at different orbits are seen as a key technology to support the full development of 5G use cases, especially as a complementary technology to deliver continuous connectivity even in remote or isolated areas where terrestrial ones can be not feasible or difficult to deploy. Leveraging on technology developments, aside keeping satellites as an option to deliver backhauling for 5G services, the use of non-terrestrial networks is extended to directly deliver the mobile access to users, according to different architectural options. This way, 3GPP has incorporated NTNs as part of the 5G standard normative process, extending additionally the considerations not only to satellite based solutions but also to other types of aerial platforms[2] as high-altitude platforms (HAPS) and unmanned aerial vehicles (UAVs). This range of options will develop in the long-term opening a multi-technology and multi-orbit scenario for the NTN.

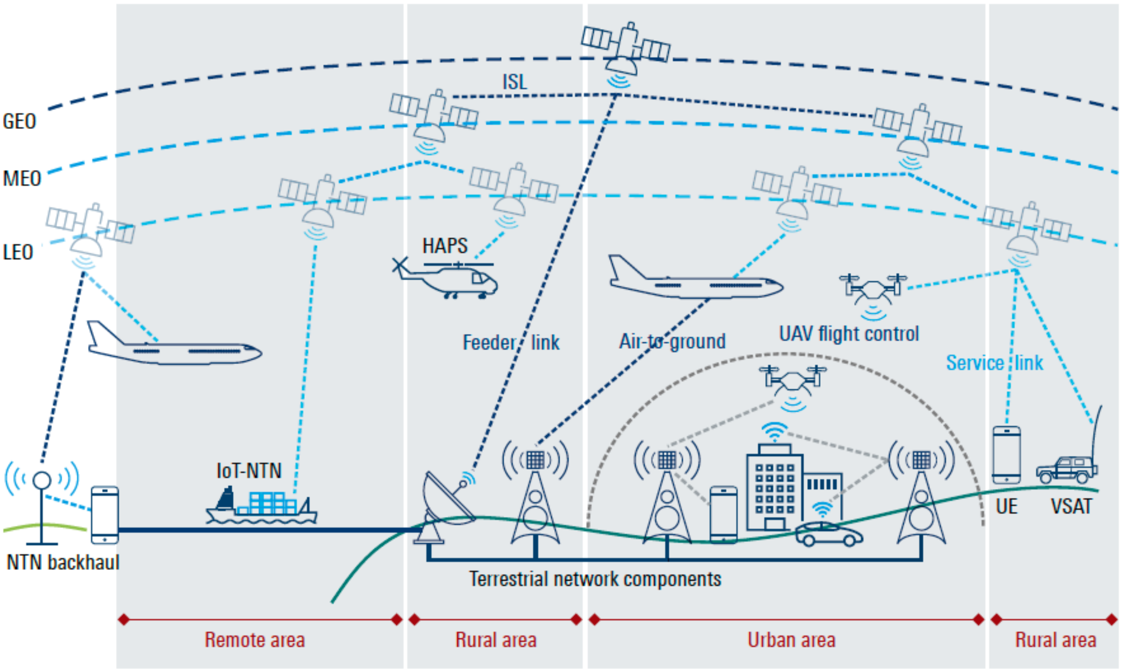


Figure 26. General connectivity overview of NTN [36].

Considering the typical service categories considered within 5G, NTNs can play different roles. Within eMBB, GEO satellites and MEO/LEO constellations can benefit areas without service (rural or remote areas) enabling fixed or mobile access services, support also mobile services in mobility scenarios (trains, ships, planes) or enable fast restoration of communications in emergency scenarios or catastrophic situations. Within mMTC, GEO / MEO / LEO satellites serve to develop scalable continuous global IoT services, for example, sensing applications in various scenarios as smart agriculture, animal tracking, freight transportation services, smart medical devices, protection of infrastructure and the environment, etc. However, URLLC cases (especially critical

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[2] Given the lower maturity of HAPs, this project will keep focused on satellite communications.

services requiring very high availability and, more importantly, very low latency) present higher challenges for non-terrestrial networks, due to the considerable achievable delay with satellite transmission, even in LEO, where typically overall latency (RTT will be in the low tens of milliseconds).

Additionally, 5G satellite use cases are typically grouped into several categories[3], which can apply flexibly to the different 5G service types.

- **Service continuity:** Use cases described under this category will address the opportunity for users to provide continuous access to services granted by the 5G system. The aim is to provide satellite access in areas where is infeasible through terrestrial networks and maintain connectivity while they are moving between terrestrial and satellite networks. Inside this category it can be found multi-connectivity (handover or roaming between TN and NTN), wide area IoT services, backhaul between NR in remotes areas and 5G core network…
- **Service Ubiquity:** It may happen that due economic reasons, natural disasters, war conflicts or infrastructure failures the partial or total destruction of the terrestrial network in a determinate area. Meanwhile they are restored, can be rapidly replaced by NTN proving a backup network and so as not to lose communications services. Somes examples could be the network restore, network resilience public safety uses etc.
- **Service scalability:** Thanks to the large coverage of NTN (thousands of terrestrial cells), satellites are very efficient in multicast and broadcast distribution (is expected that even directly to user devices). This can be very useful to contribute to off-loading traffic from the terrestrial networks by multicasting or broadcasting non time sensitive data during the busy hours or balancing the traffic when it is necessary. For example, for optimal routing or steering over satellite.
- **5G system backhaul services:** In scenarios where the segment between the RAN and the Core is provide by satellite backhaul connectivity. Especially useful to provide connectivity to base station in isolated areas. The 5G systems architecture evaluates the options of having part of the gNB on-board to distribute the complexity of the radio access technology tasks.

It must be noted that these categories are not exclusive from each other so a specific use case may belong to one or more.

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[3] The presented categorization is based on [40].

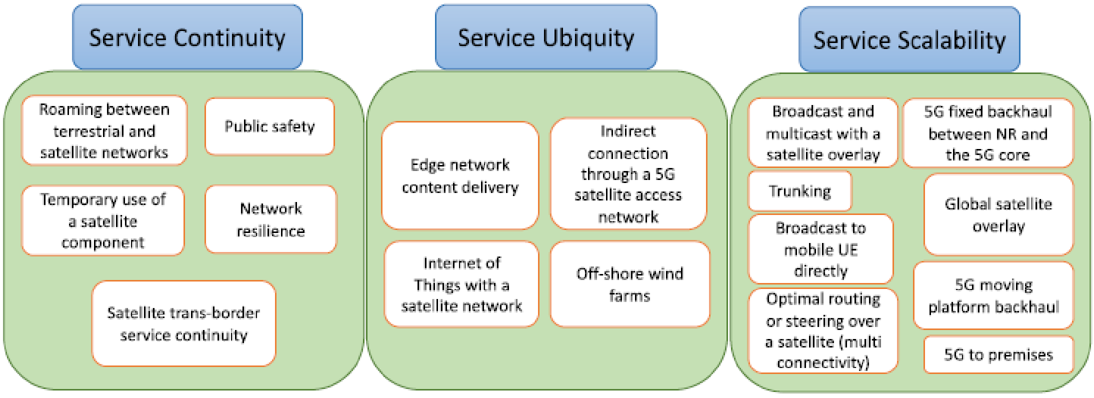


Figure 27. Service categories of NTN [37].

NTNs, this way, span multiple services, multiple use cases and multiple types of satellites and architectures to implement them, which directly brings extra complexity to define a single architecture for the integration with terrestrial networks and in most of the cases, integration architectures will be dependent on the NTN use case, service, and NTN system architecture.

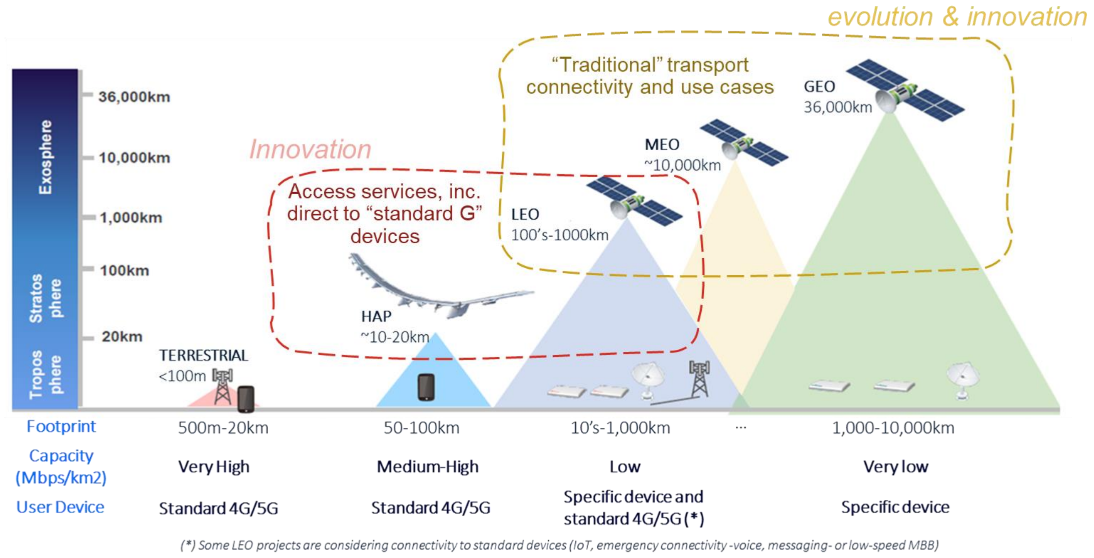
In the following, the evolution of satellite systems will be presented, analyzing the main solutions and general architectures developing and how mobile operators are using -and expect to use those developing in the market-, which will serve as a reference for the analysis of TN-NTN architecture integrations to be covered in section 4. 3GPP key studies, specifications and normative open topics will also be presented to provide context of maturity, challenges, and implementation timelines of the different NTN options. Additionally, a high-level reference of relevant aspects in relation to management will also be covered in this chapter as TN-NTN integration needs to be considered in the context of the evolving orchestration architectures already presented in section 1.

3.1 Satellite system evolution and typical architectures

Traditionally, satellite connectivity (transport) was provided by big transparent (bent pipe) satellites in geostationary orbit (GEO). Being at 36000 km from the earth, coverage footprints can be very large which constitutes one of the key strengths of satellites (ubiquitous connectivity). However, their capacity density is low, with limited scalability and reconfigurability, high latency (GEO RTT typically lies beyond 500-600 msec) and, for a reasonably large committed target throughput, they have a larger cost per bit than terrestrial solutions, which means that, to achieve an affordable cost, quality – e.g., committed rates/availability – needs to be sacrificed in comparison to terrestrial transport solutions like fibre or microwave links, for example considering large multiplexing ratios between all connections within a given network.

Major technology advances during the last decade have favoured however a significative evolution of satellite solutions. Aside others, a key aspect has been the development of efficient on-board processors, flexible channelizers and SDR payloads, which have served first to bring large capacity enhancements and operational flexibility to GEO satellites, which have evolved to High or Very High Throughput satellites (HTS/VHTS) with software reconfigurability.

Aside these, the second major area of development has been the development of the launch market, with new companies entering and with revolutionary developments as rocket extensive reusability, which have impacted quite positively the launch costs and periodicity making it possible to develop the satellite constellation market (including large scale) at lower orbits, enabling new performance enhancements, commercialization paths and models. Orbits closer to the earth as MEO (medium earth orbit – around 10000km) and LEO (low earth orbit -around few hundreds and 1500km-) have the direct benefit of reducing the latency of the communications to low hundreds of msec in MEO and to tens of milliseconds in LEO) also boosting the capacity density at ground level due to the lower distance from orbit to the earth and reduced beam sizes.



Footprint	500m-20km	50-100km	10's-1,000km	···	1,000-10,000km
Capacity (Mbps/km2)	Very High	Medium-High	Low		Very low
User Device	Standard 4G/5G	Standard 4G/5G	Specific device and standard 4G/5G (*)		Specific device

(*) Some LEO projects are considering connectivity to standard devices (IoT, emergency connectivity -voice, messaging- or low-speed MBB)

Figure 28. Non terrestrial networks – relevant satellite types.

However, the earth field of view of a satellite gets reduced as the satellites get closer to it, with orbits becoming non-geosynchronous and existing then relative movement within the satellites and a fixed point in the earth. This means that a much higher number of satellites is required (much more as the orbit lowers) to provide a global coverage in MEO and (especially) LEO and that, aside this, a more complex system architecture, including the supporting ground infrastructure is needed to connect, operate, and manage the satellites and including their relative mobility and constant handover procedures. As the satellites have gained in complexity and capacity, first in HTS/VHTS and then evolution towards at much higher overall system scale in MEO / LEO, operational complexity and costs and complexity to deploy have increased significatively. For these reasons, network operators have shifted from the direct operation and management of GEO satellite constellations to leasing satellite operators this task using own human and ground network resources as RF, antennas, baseband platforms, etc. (in many cases in own teleports), towards the leasing of fully managed services from service providers (in many cases satellite operators) according to service contracts and service SLAs. This has direct impact in all the potential TN-NTN integration cases, where satellite connectivity is going to be typically deployed, operated, and managed by a service provider of the mobile operator, which will limit or conditions the way in which the networks can integrate, and will leave many of the operational aspects of the non-terrestrial part outside the scope and direct responsibility of the MNO.

In the following sections, the key aspects -with special focus on architecture and most relevant use cases- of the main satellite systems relevant for the integration with terrestrial networks will be presented considering the current solutions that are already deployed or in the process to become operational in different term for the different type of systems, which not only include the typical use as a transport solution but also new systems to develop direct mobile access services from LEO orbit. It should be noted for the latter that, even many of the actual solutions developing are 4G, the focus of this project will be kept on is the integration of 5G networks and current references will then be used to anticipate future similar architectures in 5G.

Moreover, in relation to use cases, the focus will be kept on complementary services extending terrestrial networks. This because all in all, even with all recent advances, some of the inherent characteristics of satellite connectivity (spectrum availability and link distances, scalability constraints, satellite lifetimes, deployment, and operational costs for large scale constellations, etc.) make still non-terrestrial connectivity non-competitive with a terrestrial network in a well-served area. Satellite networks are still a more suitable solution to extend coverage and services in lower density or specific deployment areas, where they can complement efficiently the terrestrial networks, supporting new use cases as performance and cost per bit enhance and further integration is achieved.

3.1.1 GEO and GEO HTS / VHTS

Nowadays GEO traditional satellites are still an option despite their evolution towards HTS or V-HTS (*High or Very High Throughput Satellites*) enhancing throughput scalability and cost per bit. One key aspect has been the development of efficient on-board processors that have been able to provide much larger bandwidth and footprint flexibility. Also, thanks to the frequency reuse using the different available FSS bands (C, Ku, Ka) with a transition towards Ka or mixed band approaches higher capacity density and higher capacity per satellite is achieved, positive impacts on performance and cost per bit. However, technical challenges as high latency still remains in this type of satellites.

Evolution has led to a growing complexity not only in the electronics on board but also in the gateways and ground station supporting network, promoting the transition (in the case of mobile services using satellite backhaul) from the direct exploitation from MNOs using leased spectrum from capacity providers towards service provision by satellite service companies to MNOs using fully managed services.

Eutelsat Konnect, Viasat-3 or Hughes/Echostar Jupiter-3 satellites are some of the examples of VHTS projects taken as a reference in this category (with many other HTS not commented here for the sake of simplicity), and while in many cases the typical service target is residential broadband services, other services can be supported, so they can be extended for mobile services as backhaul solution.

3.1.1.1 GEO and GEO HTS/VHTS transport satellites

In the context of 3GPP mobile services, GEO satellites are typically used to provide satellite transport (backhaul) connectivity. Despite the limitations that have already been discussed (large delay, limited throughput, and capacity[4]), network operators have been using this as a solution (or temporal one) to bring connectivity to areas which other transport network topologies are not feasible as for example isolated or remote areas, as thanks to their wide footprint that can achieve coverage areas of thousands of kilometers.

In Figure 29 a 5G case with backhaul GEO satellite is represented. There are two different parts in the system architecture. One provided by the terrestrial operator (represented in blue) and the other provided by the satellite operator (represented in yellow).

The MNO owns its 5G system architecture and uses the satellite backhaul segment to reach the remote side with the base station (gNB). It is connected via the transport network (TN) to the point of presence (PoP) provided by the satellite operator. The latter, trough the NTN gateway provides a feeder link to the GEO satellite establishing the communication. The satellite acts as a space repeater (only frequency filtering, conversion and amplification are done on board) and delivers the signal to the base station that is inside their coverage area. In the remote side a specific equipment is necessary to receive and transmit the signal of the satellite and process it to deliver to the gNB. The maximum throughput that can be achieved for a single gNB with this technology is dependent on the architecture (point to point or point to multipoint), satellite footprint and the devices on the ground, but hundreds of Mbps are feasible with reasonable ground elements in VSAT multipoint, and potentially higher in point-to-point dedicated links with specific devices. However, in practice, in VSAT, which tends to enable cost efficient solutions, the average committed rate tends to be lower, depending on costs, and the satellite capacity is normally shared with multiple users.

In the case of the HTS/VHTS GEO thanks to the use of higher frequencies and frequency reuse the capacity per satellite can scales up to many hundreds of Gbps. Capacity density grows per satellite beam in this case thanks to the smaller beams with reduced coverage area and higher capacity (represented in Figure 30). Nevertheless, a frequency plan is required in order to avoid interferences and the ground gateway network needs to scale up to with more gateways spread around the overall visibility area also considering the frequency plan. Also, in the figure it can be seen that these changes in the satellite functionality do not heavily impact the overall architecture with the main complexity coming from the gateway ground network and the scale and complexity of the ground platforms to handle the additional capacity and beam scale. As a result, In GEO (V)HTS there has been a progressive transition to managed services. The terrestrial operator in these cases will not be able to manage the resources on the transport network as flexibility as if were its own. It will be the satellite operator who will have control over these resources and provide the operator with relevant parameters (telemetry, alarms) and to respond to its request.

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[4] In GEO / (V)HTS, peak throughputs in the range of 10's to 100's (high end of the range feasible with high-end equipment), with the main limitations being latency and practical CIR achievable to keep a reasonable cost, which needs to be considered especially for slice definition and comparability between TN and NTN (or configuration of multi-connectivity cases).

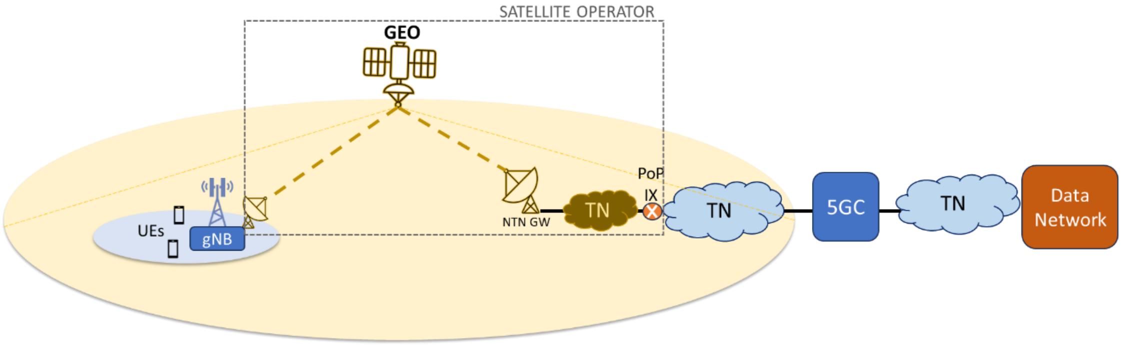

Figure 29. GEO satellite backhaul architecture – figure depicts a managed service to the MNO.

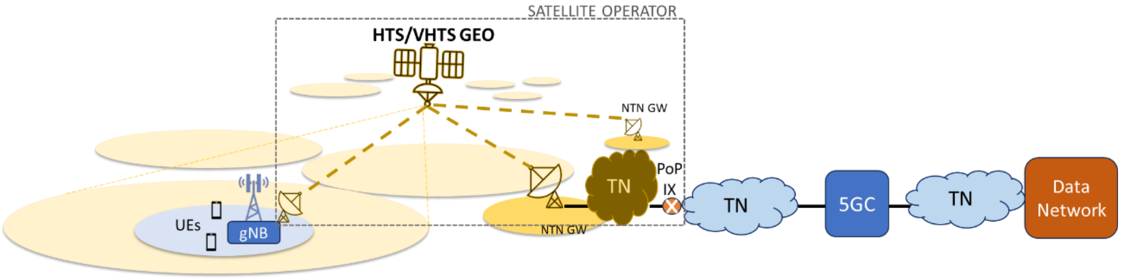

Figure 30. GEO HTS/VHTS satellite backhaul architecture- figure depicts a managed service to the MNO.

Both system architectures can cover not only isolated area deployment, but also service continuity 5G uses cases. Thanks to their wide coverage area can fill connectivity gaps between covered sites. Also, can be used to offload traffic from the terrestrial network delivering the non-sensitive delay data trough satellite network.

3.1.1.2 GEO Access satellites

Most GEO satellite constellations are used for backhauling connectivity, but their use can be contemplated for access use cases as well. Specifically, for IoT or low-rate services in which the wide coverage area of this type of satellite can be very advantageous. Another option could their use by the emergency services in hard-to-reach locations or in case of destruction of the terrestrial infrastructure after a natural disaster.

3.1.2 MEO/LEO constellations

Despite the advances made improving the performance of the GEO satellites and shift towards (V)HTS platforms, in parallel, more recently the satellite industry has gone through several breakthroughs and further innovation to advance in new and improved solutions that can bring additional performance and enable other type of scenarios and connectivity requirements.

A key factor driving the evolution of satellite systems has been the evolution of the launch market through the development of reusable launchers, driven mainly by SpaceX and followed by other companies as well, which has already made it possible to reduce costs, increase launch frequencies and provide scale for the more ambitious projects and will enhance over time with larger launchers as well. Another key one has been the development of advanced antenna systems (planar phased arrays) as a necessary technology enabler, to support the satellite relative mobility and, together with on-board processing, achieve large on-board capacity per satellite with efficient frequency reuse and higher capacity density per beam, resulting in a very large aggregated constellation-level capacity (reaching many Tbps distributed globally through all the satellites within the system).

Many LEO (and some MEO) constellation projects have then kicked off and developed during the last years and continue developing nowadays, pushed by traditional satellite operators, new space companies and startups and governments worldwide. MEO/LEO constellations provide a good enhancement in the overall service latency, which can go down to tens of milliseconds (in practice, including other contributions than pure physical radio transmission delay) in LEO lower orbits, and also in terms of capacity density (lower sized beams due to closer orbits and similar frequency bands and multi-beam patterns with frequency reuse) and throughput to a given user. On the other hand, the complexity in terms of ground technology to cope with relative mobility of the satellites increases, and the global nature of the systems, to achieve continuous coverage, impacts heavily the required supporting ground network, and overall system cost and complexity to deploy and operate.

The systems already deployed or soon-to-be deployed provide mostly broadband connectivity in a similar architecture than previous GEO systems, requiring dedicated ground terminals (including antenna and modem-router in the remote side at customer premises) to connect to the satellite and to which other elements in the communication network as base stations, wi-fi devices, etc. need to be connected. However, a new wave of systems, targeting direct connectivity direct from the LEO satellites to end devices (so, providing directly mobile access) is developing also pushed by their inclusion in 3GPP 5G standard definition in their latest releases.

3.1.2.1 LEO Transport constellations

A review of the main systems under development in the LEO market has been conducted to provide context to the project activities. Nowadays, the main system within this space is (so far) Starlink, from SpaceX, that has become the first very large-scale broadband constellation to reach operational state, with more than 4000 satellites already deployed (leveraging on their in-house successful launch business) and more than 2 million users worldwide. Starlink initial focus was put on rural residential broadband services, but is now expanding their service offering to enterprise, backhaul and mobility, and already launching enhanced generation 2 satellites (around 7000 planned and approved) to add extra capacity and serve as replacement for generation 1 satellites. Other relevant reviewed projects, close to become available or under development are:

- Oneweb, having a larger initial focus on enterprise and mobility markets which will reach fully global operational status in short, with the satellites already deployed (around 700), bringing as main differentiator SLA backed services, interesting for mobile backhaul applications amongst others.
- M-power (MEO system by SES -global GEO capacity provider-), with 12 high throughput satellites under current deployment, evolution of their previous O3B MEO system, mainly focused on high- capacity satellite links for backhauling or mobility (e.g., maritime) services, also relevant for the type of scenarios relevant to the project.
- Kuiper (LEO system by Amazon), under planning and development, with around 3300 satellites planned to reach fully global operational status in 2026, targeting

horizontally enterprise, backhaul, mobility and residential access services, which would mean, if successful, the second very large-scale broadband LEO constellation in the market.

- Lightspeed (LEO system by Telesat -global GEO capacity provider-), lower scale -below 200 satellites- delayed project, targeting now 2027 to reach global services, with a clear focus on high-capacity links for backhaul, enterprise and mobility.

Several other projects are also under development, including for example EU IRIS[2] constellation for government or commercial services, China LEO *"Starlink-like"* Guowang project, and many others, including not only broadband but also many IoT-specific projects (where time, complexity, and costs to deploy can be lower than large scale broadband projects, as services allow for simpler satellite design and a lower scale in the constellation).

In general terms, the system architecture which follows these types of solutions are described in Figure 31. The principal difference between the GEO architecture (we assume here as well a managed service, in this cases is would be not totally realistic to assume that a given MNO can have its own constellation) described in the previous section is that in this scenario the beam sizes decrease (typical footprint diameter LEO lower orbits can get down to low tens of km) and consequently the size of the constellation grows considerably (even growing up to thousands of satellites in orbit) to have a continuous coverage and high capacity over a given area. The footprint typically stays fixed using beamforming techniques, but the satellite serving a given area changes over the time, so handovers need to be managed in user and gateway beams, and the number of gateways to support the satellite operation, maintaining the connectivity along the entire trajectory of the orbits also increases. On the side of the terrestrial operator, the management and the architecture are practically the same as in GEO option, the network operator deploys the base station in the remote location that is under the constellation coverage area, and interconnects in specific points of presence where the satellite operator delivers the traffic.

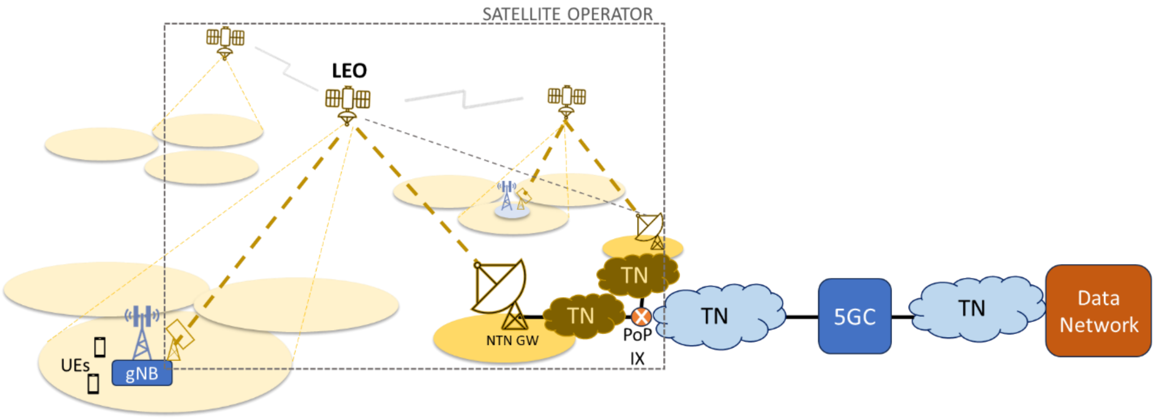

Figure 31. LEO satellite backhaul architecture.

From the 5G point of view, this scenario can cover several uses of cases. In terms of continuity of service in addition to being use for fixed backhaul, is also possible to use for moving backhaul connectivity. The dedicated ground terminal of the remote node of this type of solutions are less bulky and easier to carry in a ship, bus or even in a plane.

3.1.2.2 LEO Mobile access constellations

As newer evolution in LEO constellations aside broadband projects, where a lot of focus is put nowadays as well are direct to device constellations, with different approaches developing in the industry.

- First, projects and collaborations have been developing and in some cases already reaching the market, focused on the development of systems to provide direct connectivity from the satellites using already deployed constellations to specific modified handsets or chipsets, developed by specific manufacturers to provide basic services as messaging or alerts. In this case, working in MSS spectrum already allocated in L and S band (L and S at 1.6GHz y 2GHz). SOS service by Apple and Globalstar, or the collaboration between Qualcomm and Iridium (terminated in Q42023) are some examples of this type.
- Second, a more recent wave of projects are developing targeting the launch of new specific LEO constellations to deliver basic services as messaging, but also supporting other ones as voice or low-rate broadband to unmodified smartphones, relying on the terrestrial spectrum bands where MNOs have their spectrum allocations. This will open new use cases for low throughput data, voice, messaging/alerts, mobile emergency services and IoT without needing to deploy terrestrial RAN systems at very remote locations, using similar frequencies (unlike broadband GEO/MEO/LEO services that operate in specific fixed satellite service or mobile satellite service bands) than those used in the access. Here, projects by Lynk, AST or SpaceX (part of their second generation Starlink phase) are the main ones which have been analyzed and taken as a reference. SpaceX constitutes the largest-scale project with reasonable plan certainty with around two thousand of their planned generation 2 satellites including a payload for these services. AST SpaceMobile plans deploying tens to low hundreds of large LEO satellites (supporting broadband services) and has already a test satellite deployed and under testing with MNOs as AT&T and Lynk global, with 3 basic simple low-capacity satellites for SMS messaging and alert broadcast already deployed and tested, close to start commercial operations in several countries with partner MNOs. These projects have different architectures, which constitutes and extra degree of complexity.

Projects for direct to device are anyway in a more immature status, especially those requiring launching new constellations and satellites specific for the services, existing a larger uncertainty around future evolution. Aside basic messaging (non-continuous), which can be available in some of them in late 2023/2024, commercial continuous global services including voice or low throughput data are not expected before 2025. However, we have taken them as a reference for integration architecture analysis, as these are projects theoretically less constrained to a very basic set of services (as those using existing constellations) or designed for a single service type (as those IoT-specific). It must be noted that current projects are focused so far on 4G services, but in any case, in terms of architecture they will be kept as a reference.

Some key challenges in direct to device satellite connectivity are similar to those applicable to broadband transport constellations as costs and potential business in low ARPU areas, throughput scalability considering LEO distances to the devices and bandwidth limitations in the satellites as well as co-existence with terrestrial networks in the cases that systems operate in the same frequencies (dedicating spectrum, sharing downlink and dedicating uplink, need for exclusion areas, frequency reuse patterns and joint terrestrial and non-terrestrial planning are some areas which require further analysis and development, and testing experiences will help to develop the systems). Also, regulation is uncertain as there is still work with local organizations to enable the use of terrestrial mobile spectrum for use by non-terrestrial solutions to deliver complementary services (country border power density, emergency-related regulation, etc. are to be developed on a country per country basis).

The analyzed mobile access non-terrestrial solutions can be divided into two main categories in terms of architecture, which some differences even within each category depend on the functionality on board the satellite and the core network integration. The first represented in Figure 32 is the transparent one, where no base station functionalities are included on the satellites but kept on the ground. There are several possibilities in terms of roles for the MNO and the satellite provider here. In the figure, we depict one of the models which are developing, where the gNB and the CN (The TN can also be extended by the MNO towards the GW) responsibility of the MNO but deployed in the gateway site of the satellite operator. The satellite operator provides this way the gateway resources and the physical satellite connectivity. Others, as having the gNBs under the responsibility of the satellite operator are also viable, which will constitute a scenario of RAN network sharing.

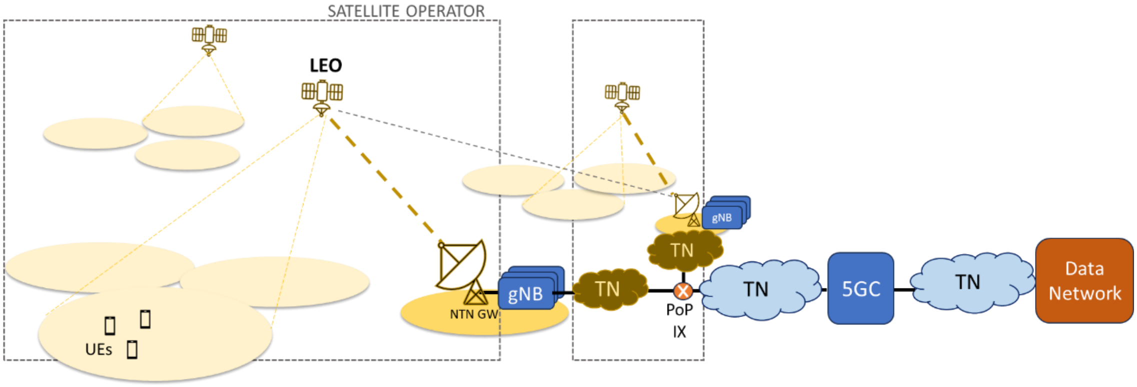

Figure 32. LEO Mobile access system transparent architecture.

On the other hand, the Figure 33 represents an architecture in which the base station functions are on board the satellite (regenerative payload). There is a big difference between the previous architecture is that the satellite operator has its own completely 5G system architecture (with its own RAN, transport network and 5G core). The satellites can include in this case inter-satellite links (ISL) and thus be able to share relevant information as for example user session data information, as well as to incorporate dynamic routing strategies. So far, the main option for interconnection with the MNO in these cases (this has also been seen in IoT focused projects) is the interconnection between core networks in a roaming scenario. For the terrestrial operator side, in terms of deployment of infrastructure the scenario is considerably simplified as it does not have to deploy any base stations at the remote nodes.

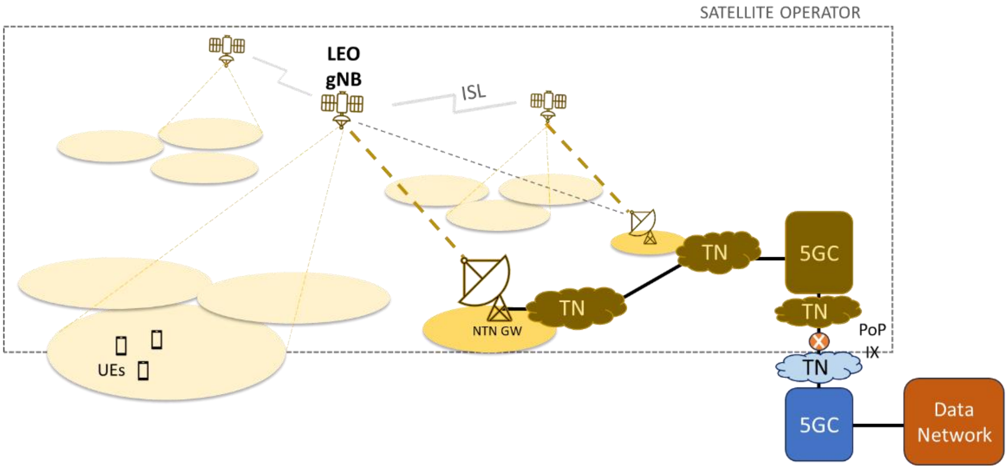

Figure 33. LEO Mobile access system regenerative architecture.

As can be seen, these two scenarios of satellite access will lead to different management architectures. In the first one, the terrestrial operator has to handle the base stations that are not physically in its network and in the second one it there are two 5G networks. These complex issues will be discussed in section 4.2.

In any case, considering the inherent limitations of satellite connectivity with respect to a terrestrial network (in a relatively well covered area), the role of satellite connectivity with these solutions also remains unchanged, considered as a relevant complementary technology to address specific new use cases complementing terrestrial networks, where they are not available or cannot be deployed efficiently or as fast as needed.

3.2 3GPP non-terrestrial networks for 5G access and backhaul

Historically, terrestrial and satellite networks have been considered as independent systems. Indeed, during 4G and previous generations, satellite networks and terrestrial networks were designed independently, and specifications dealt with interoperability issues mainly. 3GPP work related to non-terrestrial networks linked to 5G has aimed at a higher integration of terrestrial networks and non-terrestrial ones in future mobile communication standards.

During 5G and 5G-Advanced specification, there has been a strong effort to support the integration of satellite for example for coverage and availability extension. The trend of NTNs integration and support within mobile communication standards is expected to continue on a reinforced path for future releases. It is foreseeable for Release 20 onwards that the design of future generations (6G) takes into account characteristics of both terrestrial networks and satellite networks for a common set of requirements and stage-2 specifications, including support for slicing features independently of the nature (Terrestrial or Satellite) of a network segment (device, access, backhaul, core…). In this section an overview of the 3GPP vision is made.

To address NTN support and integration in the standards, 3GPP has been studying the subject for the last years introducing related work and study items within the different relevant working groups as those within all the Technical Specification Groups (Radio Access -RAN-, Service and System Aspects -SA- and the Core Network and Terminals -CT-).

3.2.1 Summary of relevant aspects NTN in 5G up to R17

Initial work related to NTN kicks off in Release 15 with the Technical Report (TR) 38.811 'Study on New Radio (NR) to support Non-Terrestrial Networks (NTN)' [38] to investigate the impact of non-terrestrial networks (NTN) on 5G New Radio (NR). This document defines the main use cases of 5G networks where satellite networks play a significant role. Due to the long propagation delay of satellites systems, none of the uses cases refer to URLLC. Instead, there are several options where satellites can play an important role for eMBB for example: multi connectivity, fixed and mobile cell connectivity, network resilience, hot spots on demand, direct to node/mobile broadcast or public safety. In the case of mMTC the IoT services will play an important role. Moreover, system parameters (different architectures, coverage areas, terminal characteristics…), the adaptation of the channel models for NTN as well as a full assessment to support further work. For this purpose, the specific contains associated to NTN are described (multipath delay and Doppler effects on the propagation channel, the frequency plan and frequency bandwidth, mobility of the infrastructure's transmission equipment, etc.) and the NR features and protocols at different layers that can be potentially affected as for example HARQ or the radio resource management adapted to network topology or service continuity between land based 5G access and satellite based access networks. According to the report, the fundamental roles that NTN should cover in 5G systems are:

- Provide 5G service in unserved and underserved areas (isolated, remotes, aircrafts, vessels, rural, etc.) that cannot be covered by 5G terrestrial networks.
- Upgrade the performance of terrestrial networks.
- Provide 5G service continuity and availability for M2M (machine to machine) and IoT devices as well as for passengers on board airplanes, vessels, trains etc.
- Provide multicast and broadcast traffic delivery (towards the networks edges or even user terminal) to achieve an efficient network scalability.

In Release 16, 3GPP continued with TR 38.821 'Solutions for NR to support NTN' [39] presenting solutions for adapt 5G NR to support NTN. The aim of this document was to have as less impact on 5G networks as possible studying the system architectures, the protocol layer, and the physical layer characteristics with a priority on satellite access.

About the system architectures, in this report two scenarios of satellite-based NTN providing access to user equipment are described based on transparent or regenerative payload. The difference between the two architectures relies on the RF processing capacity on-board the satellite. On the one hand, in the transparent architecture the satellite acts as a repeater doing the radio frequency filtering, conversion and amplification. On the other hand, the regenerative architecture is equivalent to have the base station (the full gNB or the gNB-DU) on-board. Apart from doing the radio frequency filtering, conversion and amplification tasks as demodulation, decoding or routing are processed by the satellite. In this way, user equipment can be served by the satellite directly. Another upgrade are the inter-satellite links (ISL) that are an option to have direct connectivity over satellites of the same constellation (is a transport link between satellites). This new functionality will require regenerative payloads on-board, and it can operate an RF or optical frequency bands (FOA). For the study, satellite access networks are composed by: Use Equipment (UE) at ground level, service link between the UE and the satellite, a satellite with transparent or regenerative payload, ISL in the case of regenerative payload, ground level gateway connecting the satellite access network with the core network and the feeder link between the satellite and the gateway.

Another novelty is the multi-connectivity architecture that involves NTN based RAN that is focused on dual connectivity with simultaneous use of two radio access. Several combinations are studied involving transparent and regenerative payloads. These include multi connectivity between: transparent NTN based RAN and terrestrial RAN (Figure 34,a), between two transparent NTN based RAN (Figure 34,b), involving regenerative NTN RAN and terrestrial RAN (Figure 34,c) and with both regenerative NTN based RAN (Figure 34,d).

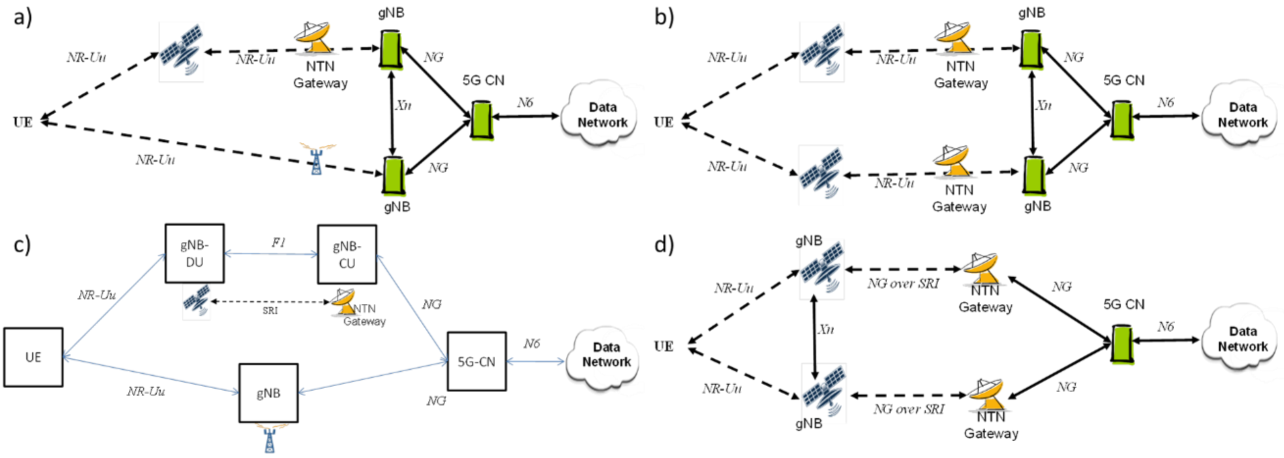

Figure 34. Different multi connectivity scenarios based on terrestrial, and satellite RAN with transparent and regenerative payloads [39].

Lastly, service continuity between NTN and TN is also presented for cover those scenarios in which UE's connectivity changes from NTN to TN or vice versa. Among these architectures, the main objectives of this study are the consolidation of potential impacts on the physical layer and definition on related solutions, performance evaluation of NR in the chosen scenarios through link level and system level simulations and solutions NR related to interface protocols and layers 2 and 3. Some of the solutions presented were left to be finalized at future releases. The most remarkable are related to the tracking area management in which the different options about their definition and NTN cells (fixed or moving) are evaluated in [39].

Figure 35. NTN-TN interworking [39].

Following with the Release 16, the TR 22.822 'Study on using Satellite Access' [40] categorizes the use cases considering the integration of 5G NTN based access components in the 5G system according to the type of service (service continuity, service ubiquity, service scalability and backhaul for 5G services) that has been presented in section 3. As a result, potential requirements related to connectivity, roaming, QoS, user equipment and security were consolidated as well as new ones related to configuration, maintenance, or regulation. A recompilation of the presented uses cases can be found in Table 6.

USE CASE	DESCRIPTION	POTENTIAL REQUIREMENTS
Roaming between TN and NTN	UE will have worldwide connectivity via TN and/or NTN while roaming between different terrestrial and satellite operators. Optimal network selection will be possible when both terrestrial and satellite networks are available	**1)** 5G system shall provide connectivity with a 5G satellite access network. 5G system with satellite access: **2)** shall enable roaming between the 5G NTN and TN **3)** support network reselection based on home operator policy even when a UE is still in coverage of its current network.
Broadcast and multicast with satellite overlay	High demand for digital content distribution services by many UEs might lead the saturation of the transmission capabilities of the MNO. A SO can boost the capacity of terrestrial MNO and serve UEs that are located beyond terrestrial network coverage	**1)** A 5G system supporting satellite access shall be able to optimise the delivery of content when using the 5G satellite access network. **2)** A UE supporting satellite access shall be able to send and receive in parallel via satellite access network and terrestrial access network.
IoT with a satellite network	IoT service provider uses a LEO satellite constellation that can provide global continuous coverage for UEs (IoT devices with limited RF and energy capabilities)	**1)** A 5G system supporting satellite access and mMTC/Nb-IoT services shall also support mMTC/Nb-IoT on the 5G satellite access. **2)** Satellite access shall allow optimal selection between NTN and TN. The selection can be based on

		e.g. operator policy, subscription settings, QoS settings...
Temporary use of satellite component	5G satellite RATs can be used to provide access to 5G networks after a disaster where 5G RATs may be partially or completely destroyed.	**1)** A 5G system with satellite access shall support at least one 5G satellite RAT **2)** UEs with satellite access shall support at least one 5G satellite RAT
Optimal routing or steering over a satellite	At the edge of the radio coverage of a 5G terrestrial RAT the performance of eMBB and mMTC services might be limited at certain time. Delay-insensitive communications can be routed through satellite whereas delay-sensitive communications can be achieved through terrestrial 5G RATs. Decisions on routing between satellite and terrestrial access networks can be based on e.g. operator policy, subscription settings, QoS settings...	In a 5G system with satellite access **1)** UEs with terrestrial access and supporting satellite access networks shall be capable of dual connectivity. **2)** shall be capable of stablishing independently uplink and downlink connectivity through the satellite and terrestrial access networks.
Satellite trans-border service continuity	5G terrestrial coverage is not always available near countries borders, UEs crossing borders need to switch from one operator to another. A 5G satellite access network covering border areas can provide continuous coverage and support a smooth transition from one operator to another	**1)** the 5G access network shall support 5G access network sharing **2)** support 5G CN sharing and it shall support MNOs of different countries attached to the same 5G satellite network **3)** Satellite access network belonging to different 5G systems in different countries shall be able to meet the corresponding regulatory requirements **4)** shall support the management of a 5G satellite network as a radio extension of the 5G terrestrial network with QoS capability **5)** shall support roaming between 5G satellite and terrestrial network.
Global Satellite overlay	Distance between 2 sites increase the difference in latency between air and optical fibre transmission media may become critical in some applications. Constellation of LEO satellites (each sat with gNB on board) interconnected via ISLs provides and overlay mesh network for uses that need long distance connectivity with improved latency performance or specific end-to-end security	**1)** A 5G sys with global satellite overlay access shall be able to select communication link providing the UEs with the suitable quality with respect to latency, jitter and required bit rates **2)** Two 5G systems with satellite access connected to each other shall be able to select the communication links providing the UEs with the suitable quality with respect to latency, jitter and required bit rates **3)** shall be able to support meshed connectivity between satellites based on 5G RAT.

Indirect connection through a 5G satellite access network	UE with no direct access to the 5G network can access through 5G satellite enabled interconnection	**1)** be able to support relay UEs with satellite access. 2) support roaming of relay UEs and the remote UEs connected to the relay UE between 5G networks **3)** 5G system with satellite RAT shall support service continuity for relay UEs and the remote UEs connected to the relay UE when a relay UE is moving between different 5G RANs in the same 5G network
5G fixed backhaul between NR and the 5G Core	Rural areas where terrestrial infrastructure is not available. Site of cell tower in a rural can be connected to the 5G core through satellite backhaul	Shall support the use of satellite links between the radio access network and the core network and within the core network by enhancing the 3GPP system to handle the latencies introduced by satellite backhaul
5G moving platform backhaul	Provide backhaul connection for 5G base stations mounted on trains or airplanes where there is not terrestrial coverage	Shall support the use of satellite links between the radio access network and the core network and within the core network by enhancing the 3GPP system to handle the latencies introduced by satellite backhaul
5G to premises	Terrestrial mobile operator works with satellite operator to provide better service to customers in unfavourable geographical areas with old terrestrial network infrastructure, using a new home or office gateway unit to combine the available signals from satellite and terrestrial networks and to present go WIFI coverage within the premises. Satellites are used to broadcast and multicast media. Caching can be done in the gateway. Uni cast will use the cellular route, especially for delay-sensitive applications	**1)** shall support the use of satellite links between the radio access network and the core network and within the core network by enhancing the 3GPP system to handle the latencies introduced by satellite backhaul **2)** UEs shall have the capability for simultaneous dual mode operation, supporting 5G sat. and terrestrial access at the same time 3) shall be able to optimally distribute user traffic over both types of access
Offshore wind farms	At offshore wind farms the win power plant communication network connects to the on shore and land remote service centre through a 5G satellite connection	**1)** shall support high uplink and downlink data rates for 5G satellite UEs **2)** shall provide suitable interfaces for QoS monitoring of the 5G satellite connection at the 5G satellite UE **3)** enable the selection of the satellite access per communication service based on QoS requirements **4)** shall support communication service availabilities of at least 99.99%

Table 6. NTN uses cases studied on TR 22.822 [40]

Each use case presents different challenge and 3GPP is in charge of looking at the way forward in order to reach a solution. Some of them after having been evaluated have been left for future releases as issues relating to roaming or RAN sharing. From the point of view of the project and its increased maturity the cases that will be discussed in more detail are the ones related to satellite backhaul and simplest satellite access solutions.

After the improvements on Release 16, 3GPP started a work item addressing NTN in Release 17 where 5G architecture enhancements to support satellite access and backhaul were developed at SA/CT groups. Analyzing the issues related to the interaction between the core network and the RAN, evaluating the performance of LEO and GEO based satellite access scenarios and identification of solutions for the two reference satellite integration scenarios: terrestrial and satellite network roaming and 5G fixed backhaul. Furthermore, RAN Working Groups worked on enhancements to the 5G New Radio and to the 4G NB-IoT/eMTC Radio protocols to support NTNs. The enhancements required for LEO and GEO have a simultaneous focus on supporting HAPS and air-to-ground networks in future deployments. This effort addresses among others the physical layer aspects, protocols, architecture specifications, aspects of radio resource managements, RF requirements and designated frequency bands. In parallel, in the SA group critical issues and potential solutions to the orchestration and management of 5G with satellite components were studied.

In relation to frequencies for access services and band duplex operation, FDD (Frequency Division Duplex) for the NR-NTN connections is determined as the primary frequency duplex mode. For the frequency ranges, 3GPP has defined two groups: FR1 and FR2. The first one goes from 450 MHz to 6GHz and there is an agreement in Release 17 for use the S-band and the L-band for NTN. Their frequency ranges are:

- 1980-2010 MHz in uplink and 2170-2200 MHz in downlink for the S-band (n256)
- 1626.5-1660.5 MHz in uplink and 1525-1559 MHz in downlink for the L-band (n255)

These frequencies are already in use for varied uses (aside MSS) so is a part of the spectrum with a high occupancy rate with a 40 MHz as a maximum bandwidth. Coexistence aspects have been studied for this first bands under consideration in [41].

Discussions for future releases are in the way to operate above 10 GHz for the FR2 frequency group. With higher frequency bands the available bandwidth can be more and for broadband services is a key point. The already existing Ka-band with 17.7-20.2 GHz in downlink and 27.5-30 GHz in uplink is a potential candidate together with the Ku-band (10.7-12.75 GHz downlink and 12.75/13.75-13.25/14.5 GHz uplink) but there is not any agreement for the moment. In parallel, there are other organizations as the ITU that are addressing this point and the Ku and Ka bands have been approved for the usage on ESIMs (normally for IoT devices). For future approvals they are contemplating mew frequency bands for MSS (Mobile Satellite Services):

- MSS in IMT bands between 694 and 2.7 GHz
- MSS in 2 GHz bands including 2010-2025 MHz, 2160-2170 MHz and 2120-2160 MHz
- MSS for low data rate in IoT services

The usage of bands near the spectrum of terrestrial mobile operators can cause some problems related to interferences between terrestrial a satellite system opening a new regulatory issue.

According to the proposals of Release 17, on the TR 23.737 [42] identifies the impact areas of satellite integration in 5G architecture. Considering the use cases of TR 22.822 (Table 6) different key issues are evaluated related to the mobility management (with large or moving satellite coverage areas), delay in satellite, QoS with satellite access and backhaul, RAN mobility (NGSO regenerative architecture), multi connectivity with satellite access and backhaul and about regulatory services. Some of the most relevant solutions and final consideration from the point of view of this project will be addressed in the following.

The first one is that the workgroup decided to work first on the standardization of the transparent solutions due to technical reasons. So, the architecture of satellite access remains as in Figure 36 where the UE is served by the satellite directly through the radio interface NR-Uu. The NTN gateway that is connected to the gNB delivers the signal to the satellite that acts as a repeater (transparent payload). In this structure the interfaces between the satellite and the gateway and between gateway and gNB are not defined on 3GPP and may become proprietary. Also, some modifications are needed to support the proposed architecture as the NR-Uu timers have to be extended in order to cope with the long round trip time (that also has to consider the possible inter satellite links). This delay also means that both CP and UP protocols have to be adapted.

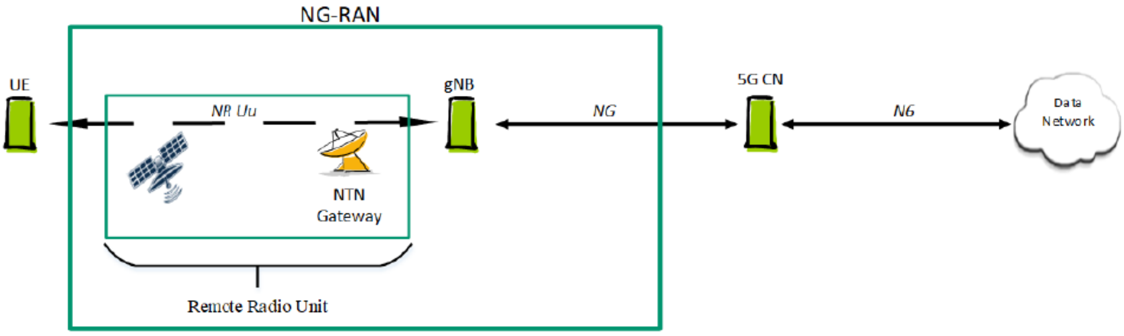

Figure 36. RAN architecture with transparent satellite [39].

Following with the system architectures, key issues related to multi connectivity scenarios with satellite access (Figure 34), and hybrid satellite/terrestrial backhaul have been studied and finally decided not included in the release specifications (necessary solutions with simultaneous PDU sessions and dual connectivity RAN need to mature).

After the evaluation of key issues related to mobility management aspects, the conclusions were considering as best options keeping satellite ground beams and tracking areas (TA) fixed, although solutions to manage moving ones were also in consideration. GEO satellite beams are already fixed and generate a fixed radio coverage, but in the case of NGSO (LEO and MEO) satellites do not have a fixed position relative to the earth's surface so consequently the beams coverage area will change over the time. In this situation, fixed TAs can be ensured for moving beams as is explained in TR 38.821 section 7.3.1 Idle mode mobility enhancements [39]. Also, the registration procedure needs to be modified to enable the AMF determines the Registration Area despite the delay introduced by GEO satellite systems. Operation of NTN access networks takes as a condition that the necessary mechanisms to obtain location in the UE are implemented, that satellite ephemeris data is known by the gNBs generating the radio access and that several CN components -AMF, etc.- are aware of the satellite nature of the connection to adapt procedures to support NTN connectivity.

One of the main objectives of 3GPP is to impact as less as possible the 5G core network during the implementation of NTN. With the transparent payload architecture and the position based on the fixed tracking areas this can be achieved. Only one element has to be modified and is related with the necessity to extend the timer value in session and mobility management planes to face with the large delay of satellite constellations. A challenge that must be study in future releases is to support in the core network national roaming and RAN sharing as satellites cover large areas with 5G terrestrial networks and the same 5G core for both. These functionalities will extend the uses cases related to multi-connectivity, mobility, and traffic balancing.

New RAT types have also been created to support the different necessary processes to support NTN components, differentiating between GEO/LEO/MEO due to their inherent differences. Another reviewed aspect where slight changes were introduced is the QoS environment. As before, the main problem is the longer round-trip times of the satellites (specially GEO constellations) so it is defined a new 5QI with an augmentation of the packet delay budget of 100ms. Key uses cases for 5G as network slicing can be affected by this problem but according to 3GPP there is expected to be no new elements added to the Network Slicing Standard so above the TN framework operators may create new slices based on NTN characteristics (coverage, speed, delay) and charge accordingly.

3.2.1.1 Management impact from NTNs in 3GPP

The integration of satellite segments in the 5G systems increase the level of complexity to manage and orchestrate the complete network in an efficient manner. In relation to this, 3GPP TSG SA developed a dedicated study on management and orchestration aspects and impacts in this type of networks with integrated satellite components (Release 17 TR 28.808 [43]).

Normative work following the previously cited studies as well as the NTN management specific one was conducted by all the 3GPP TSGs[5], with direct impacts on the 3GPP management specifications and the 3GPP NRM, which was updated to include support for the new functions required. For example, new objects and datatypes related to the necessary ephemeris data, which is essential to manage mobility of the satellites and related impacts as on timing advance or doppler correction were introduced. New RAT types specific for satellite service, as well as location and coverage information parameters and new elements were also introduced complementing the former.

The specific management study carried out in R17 [43] focused on potential new requirements and solutions such as network slice management and monitoring and management of gNB components for several reference cases:

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[5] Most of the focus in this document is on system architecture aspects, impacting directly the integration. However, plenty of new definitions and specifications for NTN have been consolidated in the 3GPP 38 series (RAN) in documents as 38.300, 38,413, 38.331, 38.101-5, 38.108, 38.181 and several others which are also work in progress.

- Integrated satellite NR-RAT: the 3GPP management system manages the 3GPP RAN composed by the terrestrial and the satellite RAT.

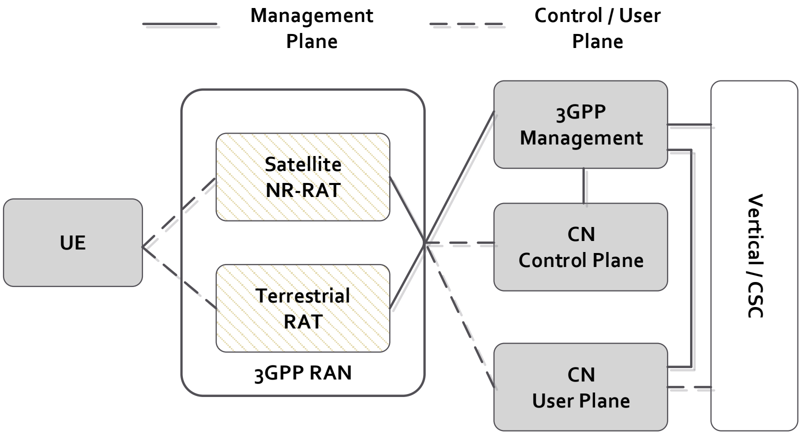

Figure 37. Reference architecture for management of satellite RAT [43].

The scenarios considered from that reference architecture are two:

a. Satellite network as a roaming network for terrestrial network operator. Roaming is used by the terrestrial operator to use the satellite access, and both have their own separate 3GPP management domain. Figure 38,a) represents this scenario with satellite 3GPP network in green and terrestrial 3GPP network in blue.

b. Network with both satellite and terrestrial access network. In this case there is one 5G core network and both are managed by the same 3GPP management system.

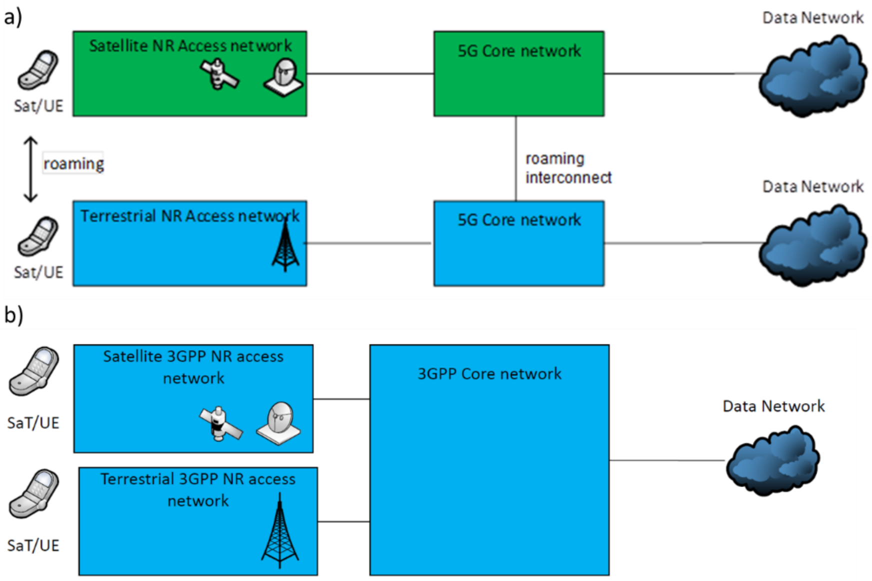

Figure 38. Two different architectures for 3GPP terrestrial and satellite RAT [43].

- Integrated non 3GPP satellite RAN: the 3GPP management system manages both the 3GPP RAN terrestrial RAN and the non-3GPP satellite RAN. In this case there is not scenario contemplated.

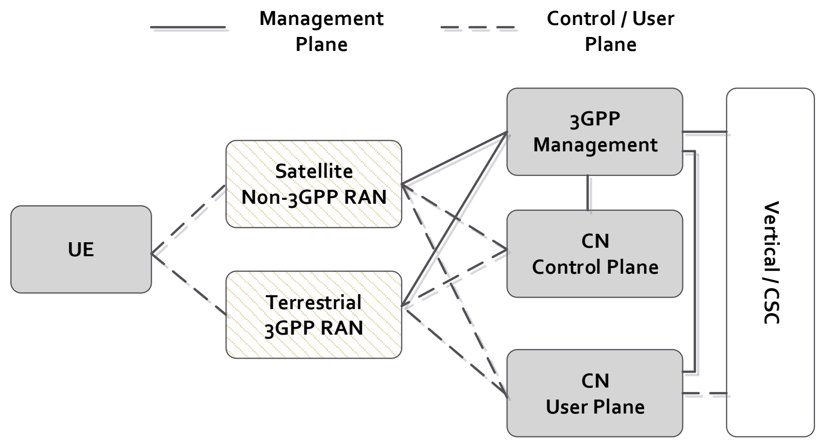

Figure 39. Reference architecture for management of non-3GPP satellite RAT [43].

- Integrated satellite transport network providing 5G backhaul: the 3GPP management system directly manages the satellite transport network or works in coordination with the satellite transport network management system.

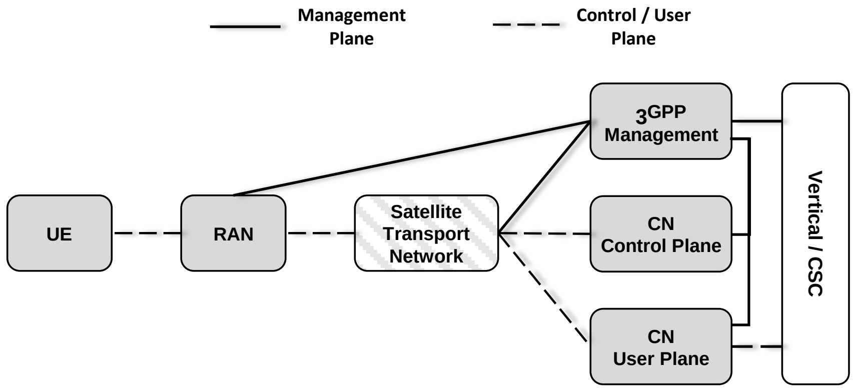

Figure 40. Reference architecture for management of satellite transport network [43].

Two scenarios are contemplated:

a. 3GPP management system working in coordination with satellite transport network management system. Both management systems work in coordination assuming that the capabilities and requirements of the non-3GPP can be provided.

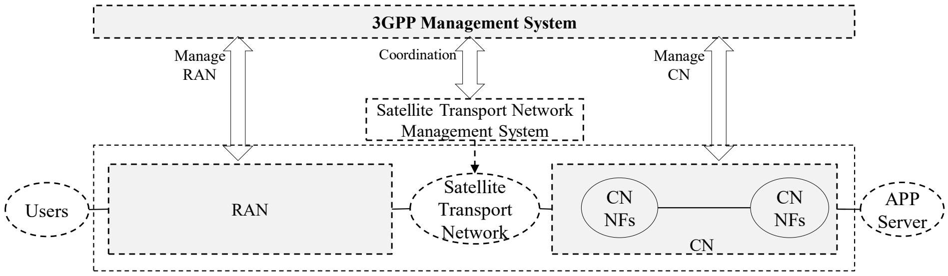

Figure 41. Architecture scenario with 3GPP management system working in coordination with satellite transport network management system [43].

b. 3GPP management system manages the satellite transport network. The management system has to consider the satellite transport networks capabilities in order to ensure the performance a communication service according to the business requirements.

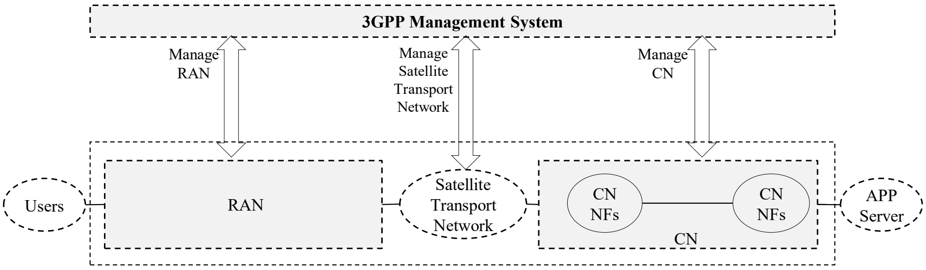

Figure 42. 43Architecture scenario with 3GPP management system managing the satellite transport network [43].

In all the cases the network operator (NOP) can operate the 5G network through API's interface with the communication Service Customers or Verticals on the one hand and delivering services to UEs on the other hand.

To study the presented architectures, the report examines three uses cases related to network slice management, management of satellite components and for monitoring satellite components to identify the main key issues and potential solutions. The use cases addressed for each topic and their potential solutions are:

- Network slice management.
    a. Create a NSI associated with a satellite RAN.
    b. RAN sharing of a 5G network with satellite components.
    c. Creating and managing a network slice associated with satellite components.
    d. Network slice instances associated with both satellite and terrestrial RAN.

  After the study of the potential requirements of each one, to create and manage a network slice associated with satellite components the proposed solutions indicate that a potential adaptation of the ServiceProfile to include satellite specific parameters. As it has been explained in section 2.1.1, the ServiceProfile describes the properties of network slice requirements and should include satellite RAN specific attributes, although it is recognized that many of the attributes in the ServiceProfile do not set strict constraints to the values. Some examples are latency or coverage area. Around coverage area, linked to the geographic region where a NSI is available, the study concludes that a shift towards geographical area references is more appropriate than base on node lists.

- Management of satellite components.
    a. NGSO regenerative satellite components
    b. NGSO transparent satellite components

  Two potential solutions are described. The first one is to allow a network slice instance to be associated with both satellite and terrestrial RAN. Different specific requirements for each one need to be set in the SliceProfile (section 2.1.1) to instantiate an NSSI which includes terrestrial and satellite RAN. For this purpose, to set separate performance requirements the perfReq attribute can be extended to allow entries such as experienced data rate, latency and coverage area. The other potential solution is for the management of NGSO regenerative and transparent satellite components in order to prevent PCI (Physical Cell Identities) conflicts and NCR (neighbor cell relation) reconfigurations. This only will affect to satellites with moving beams and future work to extent the SON (Self-Organizing Networks) ANR (Automatic Neighbor Relation) and PCI reconfiguration functions (see TS 28.313 [44]) to adapt these to support continuously moving cells.

- Monitoring of satellite components
    a. Monitoring of performances of NGSO satellite components with split gNBs.
    b. Monitoring of average delay on DL-Air interface for MEO and GEO satellite components.
    c. Multi-RAT load-balancing associated with both a satellite and terrestrial RAN.

  For the first use case, no potential solutions are considered for this release. For the second one, a solution for adapt the average delay DL air-interface measurement and Distribution of delay DL air-interface measurement to support cases where HARQ feedback is disabled is contemplated. In previous releases (TR 38.821 [39]) this issue is addressed but is still not sufficient, so a new mechanism has to be studied for future releases. For the last use case two potential solutions for switch traffic from currently active RAT to another RAT and to split traffic into two RATs are considered for future normative work.

Compared to terrestrial NR, the biggest challenge of integrating satellites mainly comes from MEO/LEO scenarios where satellites carry gNB components (gNB-DU) and their rapid movement of their orbits. The issue of the long delays of these constellations requires improvements to maintain key performance indicators and monitoring functionality in 5G networks. The conclusion of the study was that the concept of Self-Organizing Networks (SONs) for 5G requires some enhancements to support the mobility of non-terrestrial gNBs. Although efficient network management is essential in future integrated networks to fully utilize the available network resources, the standardization work on NTN management is nevertheless quite limited within the 3GPP working groups. An overview of the main recommendations and solutions obtained because of the study are:

- Specify/extend SON (Self-optimizing network) concepts to allow for moving non-terrestrial gNBs.
- Adapt the performance measurements which make use of the HARQ process, which may be unavailable when using satellite RAN.
- Extend the 5G NRM TS 28.541: "5G Management and orchestration; 5G Network Resource Model (NRM), Stage 2 and Stage 3" [4] to support satellite components, for example by adding ServiceProfile attributes.
- Specify the approach to use load balancing between terrestrial RAN and non-terrestrial RAN to guarantee service continuity and reliability.

The TS 23.501 ‘System architecture for the 5G System (5GS)’ [18] is the Technical Specification that compiles all the necessary requirements for the 5GS. From Release 17 non terrestrial requirements started to be introduced. First, with 3GPP specific access aspects as the support for integration NR satellite access into 5GS and the support of discontinuous network coverage for satellite access. Also, there are aspects related to IoT as the support of high latency communications and others as support of 5G satellite backhaul.

3.2.2 Relevant NTN 3GPP work beyond R17

3GPP continues with the technology evolution of NTN in 5G systems in Release 18 and upwards. In Release 18, SA2 worked on normative specifications in two work items dealing with NTNs, for the definition of enhancements, optimizing performance and enabling new capabilities.

For instance, the objectives for NR NTN focus on coverage enhancements, further improvements to the mobility procedures, methods for the network to independently verify the reported UE location and the incorporation of methodologies to enable satellite-based communications for IoT devices. Some of the objectives aligned with the technology evolution are an increased feeder link capacity, a lower power consumption on the UE side or deploy smaller satellites:

- Regenerative architecture to allow on board gNB.
- NR-NTN and terrestrial mobility enabling handover between terrestrial and NTN 5G and dual connectivity between terrestrial and NTN links.
- Frequency extension (FR2).
- From IoT NTNs point of view: introduction in the Network Resource Model of solutions to support handling of coverage holes or discontinuous satellite coverage in a power efficient manner.

Some of these new normative enhancements have relied on two specific studies conducted as part of R18 definitions: [45], focused on backhaul, and linked to the extension towards regenerative architectures, to enable support of dynamic QoS and others like UPF implementations -relying on satellite backhaul towards the gateway node- and local switching capabilities and [46], focused on power saving and mobility management enhancements in cases of discontinuous satellite coverage.

Additionally, in Rel18, two work items related to NTN have been developed in 3GPP SA2: “Satellite Access Phase2” and “5G System with Satellite Backhaul” and one related to Slicing: “Network slicing Phase3” (or eNS_Ph3).

The latest does not mention specifically Satellite access or Satellite Backhaul as integrating components of the Slicing capability. Similarly, there is not anything in the two work items about Satellite communication which makes it possible to connect both technologies.

Beyond, up to the present moment in Release 19, only one study item about NTNs has been approved (Sep 2023) to be part of this Release in SA2 “Integration of satellite components in the 5G architecture Phase III”. This release is expected to define a second set of enhancements optimizing performance and enabling more capabilities.

Concerning Rel19, the only study item related to these two technologies which has been approved so far is: “Integration of satellite components in the 5G architecture Phase III”. This study has just started and does not include any feature to support or enhance a Slicing capability.

Amid the literature available in 3GPP and other industry papers, we can conclude that the support of slicing in NTN is, of today, not in the prioritized plans of Rel-19 timeframe. Nevertheless, it is true that with the sight set on Rel-20, there are some aspects that deserve discussion in 3GPP:

- The need to enrich the information models of access & mobility core network functions (e.g. AMF), provisioning them with new configuration parameters that reflect the properties of satellite backhaul.
- The need to define additional reference points in the core network system, to make distinctions between terrestrial UPFs (e.g. UPFs hosted in PLMN nodes) and non-terrestrial UPFs (e.g. UPFs onboarded on satellite nodes). These potential reference points would be variations of existing N4 (SMF-UPF interface), N6 (UPF-DN interface) and N9 (UPF-UPF interface)
- The need to enrich GSMA Generic Slice Template (see NG.116) with attributes that allow the network slice customer (NSC) to express requirements regarding satellite backhaul access and coverage. As of today, this template only captures requirements regarding mobile access in public-private terrestrial networks.
- The need to support multi-operator scenarios, where the CSPs need to coexist with other terrestrial node operators (e.g. FiberCos, TowerCos) and satellite operators. As captured in the open issues clause section 2.2.3.6, implementing E2E slicing in these scenarios can be challenging from OAM viewpoint. For example, in a neutral host scenario, we have one RAN-only network slice (provided and managed by the Principal Operator) connected to different CN slices (provided and managed by individual Participating Operators). How different operators can connect their E2E slicing management functionality to the access network slice manager in this case, so that they can individually manage the network slices from e2e viewpoint. The situation becomes even worse when having an NTN, as we have an additional backhaul and a partially shared CN with terrestrial operator. This requires further elaboration on a “as-a-service” models targeting network slice subnets and network slices, as anticipated in TR 28.811 [13].

3.3 Management & SDN in satellite networks

As introduced in the previous sections, there are many solutions with different architectures already available and developing, which brings also specific considerations to the management and orchestration of the different solutions, with different maturity with respect to the terrestrial networks, which creates additional challenges for the future integration of terrestrial and non-terrestrial solutions. This section will focus on identifying the main aspects applicable to the different solutions and architectures which have been investigated, and which are the main gaps that can impact the integration with terrestrial networks, considering especially the end-to-end service and slicing orchestration architecture references given in chapter 2 for end to end and transport domain (especially for backhaul). The analysis will start from GEO, which already will serve to introduce some of the problems and challenges identified, and then addressing the rest of the cases focusing on incremental complexity.

3.3.1 GEO and GEO HTS/VHTS

VSAT (point to multipoint connectivity) satellite networks on traditional GEO satellites are operated using vendor specific baseband platforms (HUBs) typically deployed at the gateway and remote end devices (modem-routers), not being interoperable with other platforms from third vendors. The same applies for point-to-point connectivity, although in this case vendor-specific modems are used in both sides of the satellite link. Shared or dedicated RF (HPAs, LNAs, up/down convert, IF or L-band combination networks, etc.) and antennas are used on the gateway side, with smaller dedicated elements (antenna and BUC/LNA), compatible with the baseband modem/router at the remote side.

3.3.1.1 Baseband platforms and management systems / interfaces

For the management of the baseband platforms forming the VSAT networks (applicable also to point-to-point connections, although the focus will be on VSAT here), specific NMS systems from the baseband vendors are typically used. End devices implement a proprietary management interface typically based on SNMP and can be managed either locally at the site or remotely via the NMS (e.g., in-band management), using either a GUI (typically web-based) or the NMS. The NMS aside allowing client connections to manage the also exposes NBIs to integrate with the higher-level OSS platforms of the satellite service operator.

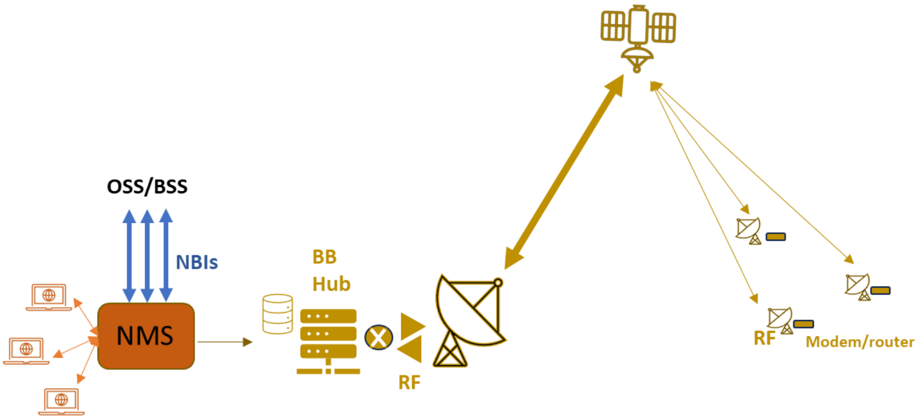

Figure 44. NMS Management and integration with OSS layer

As already introduced, different cases need to be differentiated, especially:

- Those where the mobile service operator operates internally the satellite network (MNO=satellite network operator) with its own resources and platforms (typically in legacy GEO satellites, simpler to operate), having a complete access to the NMS resources
- The more typical cases nowadays in HTS/VHTS where the mobile service operator leases a managed service from a satellite service operator which will be the one operating the satellite network and managing the platforms and NMS, exposing a subset of the network capabilities to the mobile operator. Here, as HTS and VHTs satellites and platforms increase the amount of capacity available in each network and platform, the satellite operator can implement a dedicated network for a client but also a common one on top of a single platform sharing

resources for different MNOs using different VNO options supported by the baseband platform.

So, the general problem related to management and integration with OSS is the same in both cases, with the main difference being that in the latter case, the access by the mobile service operator to the management (through the exposed API by the third-party satellite service operator) of gets restricted to the resources available for a given mobile network operator and the capabilities that the service operator decides to expose and enable. The transition to HTS and VHTS, with the increased complexity and scalability in terms of traffic, functionality, beams, connected terminals, simultaneous operation with multiple MNOs and networks, etc. has caused a progressive shift in terms of NMS implementation towards cloud based and virtualized solutions, with options for geographic redundancy, load balancing, intelligent replication in both centralized cloud and distributed instances in gateway locations, etc.

In terms of interfaces, aside SNMP and different legacy interfaces (and also those specific for management user client applications) current satellite NMS systems have also transitioned typically to SOAP or REST interfaces to integrate management with higher layer OSS/BSS platforms, which can programmatically manage the baseband resources or monitor relevant information from the satellite network (topology, configuration, performance and fault information, etc.). Via NBIs the satellite network operator (MNO in direct internal operation or a satellite service provider in third party managed services) can create a fully automated system that controls the entire process of network: from buying a service to using and managing it by end users, including procedures such as remote device management (IP router, VLANs, QoS, service profiles, …), SLA modification, monitoring (modulation, power, frequency, etc.), reboot, etc.

In relation to management, there are several challenges ahead when comparing with the evolution of the terrestrial networks towards open architectures and standard interfaces.

- First, the baseband platforms are vendor specific, non-interoperable, and, in terms of management, devices implement proprietary interfaces. No device standard interfaces with device common models (e.g., NETCONF/YANG) have been found to be supported commonly and no work in this specific aspect has been found in the SDOs analyzed and tracked for terrestrial transport. This limits the short-term options for implementing agnostic management in the satellite domain the same way it is considered and already deployed in other technologies in the transport network.
- Second, although NMS platforms implement typically REST/SOAP interfaces, APIs are not standardized, but vendor specific. This also creates limitations for the integration of the satellite network management in the simplified orchestration architectures as presented in section 2.1.2, which cannot rely on common interfaces, creating extra complexity as many separate vendor-specific networks need to be integrated.

In relation to the latter, there might be many cases in which a satellite service provider (this also applies for direct operation of the satellite networks by an MNO) implements many networks (for backhaul or any other service), with multiple platforms (from different vendors), using different satellites to different clients. The next figure shows this situation for a simple case with two networks implemented using a common platform and two different satellites, and a common satellite supporting two networks implemented with different baseband platforms. Different NMS systems will need to be deployed to operate and manage the networks, exposing their specific NBIs to the final mobile service operator.

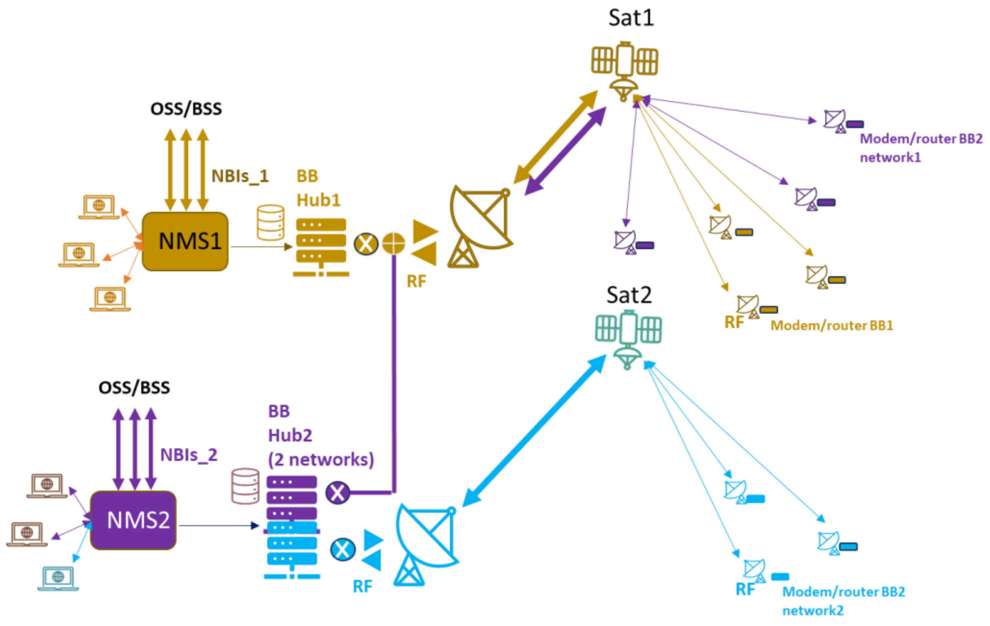

Figure 45. Multi-satellite, multi-platform network operation from a single service provider, simple example

In these cases, umbrella systems on top of the proprietary management layer are developed to expose a common set of management APIs to clients of the satellite services, as depicted in the next figure. This can simplify management and integration through common provisioning, fault and monitoring APIs, but requires developing specific systems for this effect, and this common NBIs are not yet harmonized across industry, with a common set of functionalities.

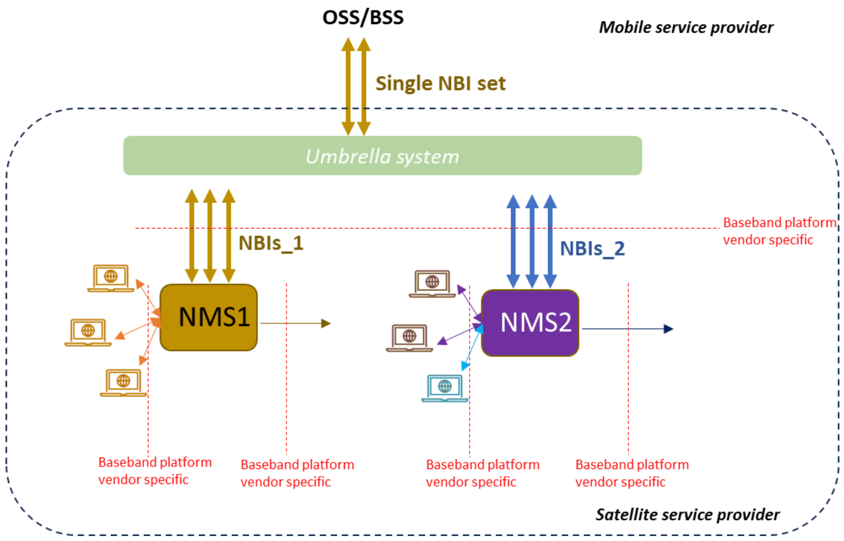

Figure 46. Umbrella system to expose common management to service clients. Simple example.

Aside the baseband platforms, the ground segment includes other components as combination network, up/down conversion devices, IF and RF amplification and antennas, as well as the elements (routers, firewalls, etc.) to interconnect with the transport backbone, towards the traffic interconnection PoPs. RF and IF systems, as well as the antennas include management interfaces and tools which are typically integrated by the service provider in the network operating centers managing and operating the different networks (allowing that many of the necessary processes can be implemented remotely in centralized NOCs, with minimal support on the gateway locations). Although recent advances in technology also allow for the digitization of radio signals and virtualization of satellite specific communication modules (as for example modems), enabling the dynamic implementation of part of the typical functions for the satellite transmission (e.g. modems) in remote datacenters / cloud, in this type of cases (GEO or GEO VHTS) we will consider that the RF / IF / antenna systems are configured statically by the satellite network operator and no need for exposing or dynamically managing resources will be needed for the integration with a terrestrial network.

3.3.1.2 Software defined satellites and SDN control

As part of the technology evolution in GEO, significant advances have also led to the development of higher reconfigurable satellites leveraging SDR (multiple frequencies, multiple waveforms, etc.), on board digital processors and flexible channelizers (full routing flexibility among available channels and dynamic power allocation per channel) and phased array active antennas allowing for beamforming and beamsteering bringing flexibility as well to the footprint. Platforms with different types of flexibility have developed over time reaching the satellite market, developing the GEO HTS/VHTS ecosystem.

Growing flexibility in the satellites, linked to the need to provision of multiple services subject to different targets via same or different platforms to final satellite service clients brings the need to develop efficient satellite dynamic resource management techniques. Traditional approaches were based on static policies which in many cases lead to inefficiency, and developments, both in the satellites and in the supporting ground networks target dynamic resource allocation adapting to traffic demands and service requirements. This concept of software defined satellites, allowing for reconfiguration opens similar research lines to those followed in SDN defined terrestrial networks. Decoupling user and control plane, simplifying the satellites and moving the dynamic management of the network to an SDN management layer which can be implemented in different ways (for example, centralized at one gateway location, etc.). This topic gets extra relevance in satellite constellations where, technologies in terms of reconfigurability are also employed but with the additional problem of the constellation size and relative movement of the satellites and the ground, impacting a lot the overall complexity.

We will consider in this document that satellite resource management, even in the simplest case (single reconfigurable GEO HTS/VHTS satellite) is typically outside the mobile service operator scope, which fits the more typical systems that have been investigated so far, so there would be no big impact in terms of the management scenario which was referenced in the previous section. Additional work during the second phase of the project will be dedicated to explore developing trends in terms of opening satellite resource management interfaces to service clients.

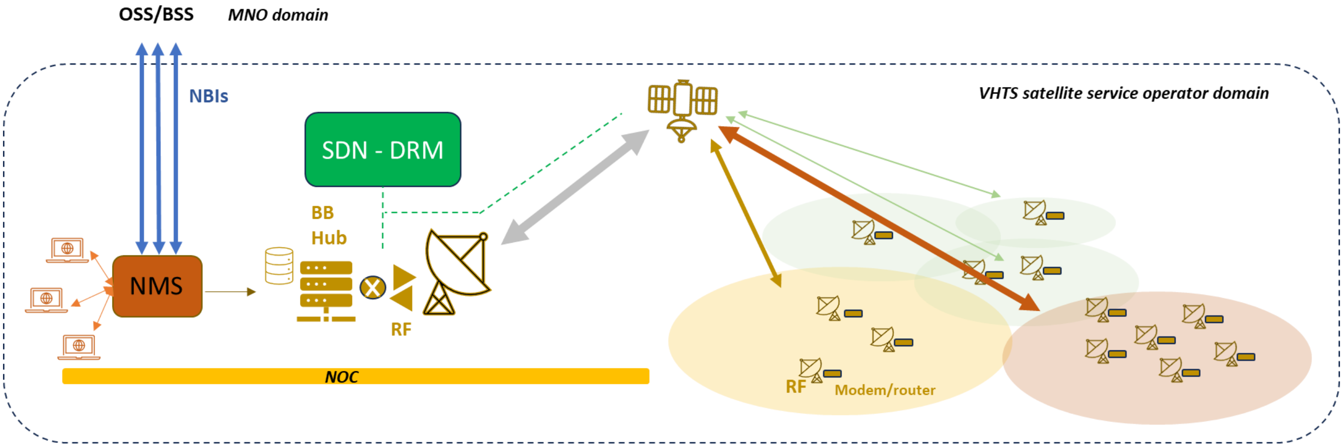

Figure 47 SDN management – dynamically reconfigurable satellite and satellite operator domain

3.3.2 MEO/LEO constellations

Many of the already introduced considerations applicable to the management of GEO HTS / VHTS are also applicable in satellite lower orbit constellations, especially to those providing transport connectivity. However, there are some quite specific considerations linked to the impact of the system scale and complexity, and different system architectures, especially in satellite access systems, which span additional components and require specific consideration.

3.3.2.1 Transport constellations

In lower orbit satellite constellations, due to their architecture and system characteristics, already presented before, there is little room for MNO direct operation and services will be typically operated by the satellite company developing and deploying the system, which will commercialize a managed services to clients on top of it. So, in terms of management (activation, de-activation, provisioning, configuration, monitoring, etc.) the system can be seen as a “black-box” limited to the APIs and capabilities exposed by the satellite system provider. Like managed services over a GEO HTS/VHTS, the service provider will expose an API for their clients in order to have programmatic integration with their OSS/BSS layer and integrate into their service operation.

Similarly, APIs are typically constrained to specific procedures and capabilities, as determined by the satellite system operator, and are not standardized, which needs to be considered in integration scenarios. An initial analysis has been carried out for existing LEO satellite systems, showing that basic management of the LEO satellite connectivity services is viable, with additional visibility from service and remote terminal monitoring. Within provisioning and configuration, activation of services (once physically installed at the end site), de-activation, transfer of services between regional service pools and accounts, data bucket increase, service plan configuration are possible, although direct management of fine-grain service aspects (QoS, etc.) is closed for the customer and under responsibility and management from the service provider. In relation to monitoring, statistics and telemetry data including data consumption, throughput in DL/UL, latency, basic indicators of service quality are available and can be exposed through the available API.

Even in most of the cases outside the direct management from the satellite service customer, the evolution towards low orbit constellations has brought significative challenges and changes to the operation and management of the satellite systems (on top of all the aforementioned ones related to the satellite advances in flexibility). As main identified impacts:

- The ground supporting network gets extra complexity as compared to even VHTS projects, with many ground gateways required globally to operate global services and interconnected through an IP/MPLS transport network. This impacts platforms and their management.
- System scale grows significantly with even thousands of satellites with continuous movement around the globe. The system (satellites and ground network -gateway and remote-) need to manage satellite mobility and periodic handover events at a large scale with a topology which is constantly changing. In the case of implementing inter-satellite links, an additional degree of extra complexity is gained, and dynamic routing between satellites and ground stations need also to be controlled according to traffic and service requirements.

Platform evolution and NMS

All these impacts have required evolution of the ground baseband platforms to support all this scale, ground network and system complexity and flexibility. Accompanying the evolution of the technology, management platforms have also evolved, essentially towards more dynamic systems that offer the possibility of dynamic orchestration together with the satellite resources. An increased shift towards virtualization and cloud implementations allowing for de-centralization, load balancing and distribution of functionality and more importantly flexible scalability in the management plane has been identified in commercial solutions.

Aside SOAP/REST APIs for external management and configuration, in addition, telemetry interfaces (e.g., Kafka bus or gRPC) begin to be included as part of the NBIs exposed by the baseband platform management, to provide highly granular / real time dynamic information about the system behavior effectively exposing status, fault and performance data to additional orchestration systems.

Finally, considering the additional complexity a progressive transition to a more technology agnostic service configuration has been also identified in newer baseband systems for MEO/LEO constellations, which is in line with the transition towards a more “intent-based” approach already presented for the terrestrial network management and orchestration.

SDN control and orchestration

The impact from the constellation scale growth, extra complexity of the ground segment and the need for dynamic reconfiguration to exploit the flexibility from ground and satellite resources and address the different needs from multiple services subject to different requirements also has motivated research and evolution towards satellite system SDN control, with some similarities to the approaches followed in terrestrial networks, but also some specific challenges. SDN is further proposed for achieving a more efficient routing scheme in the satellite network, especially when multiple routes are available between them (constellations with inter-satellite links).

Aside the presented management and orchestration evolution of the ground platforms, satellite resources and services require to be managed and orchestrated as well. This leads to including new functional units and interfaces between them to dynamically manage the satellite constellation shared resources and provide the final service orchestration.

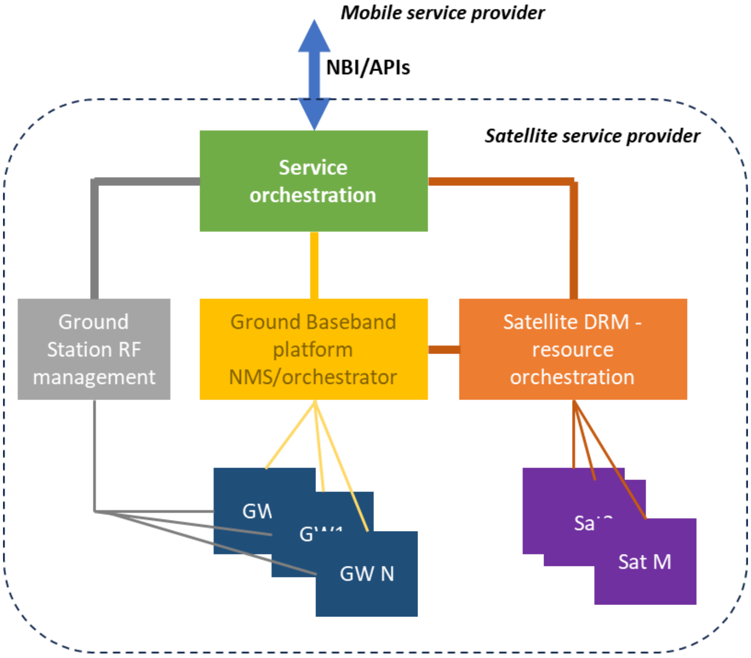

Figure 48. Satellite constellation SDN orchestration.

Although, as commented, considering that for MNOs operating a terrestrial network, services from satellite constellations are complementary and to be acquired as managed ones (being the problem of satellite system SDN control internal to the satellite operator developing and operating the constellation) some of the main identified research and development topics to address the key challenges (as example [47] provides many references about different research publications addressing parts of the overall problem), will be cited here:

- Current constellations base on transport forwarding as simplest switching technique, although evolution to more flexible channel or packet switching is seen as the future way forward.

- One of the key research topics is the SDN architecture. Depending on the constellation type and scale (or if an extension to a multi-orbit concept is considered), the controller placement and distribution of functionality between necessary logical management instances or management layers (single instance at datacenter or ground station, multiple distributed at several ground stations, instances at the satellites and functionality split between ground and satellites, etc.) becomes one of the key research topics.
- Satellite mobility management (including metrics to enforce quality of service - e.g., throughput, latency, etc.-) and efficient traffic addressing, routing and forwarding within the constellation constitutes another key field of research. It must be noted here that there is a strong dependency on the type and scale of the constellation as well. Multi-connectivity to ground stations, topology changes and delay variations linked to satellite movement as well as performance variation between satellites and ground and between satellites gain relevance and impact the applicability or suitability of network protocols.
- Also, in relation to the previous point, the integration with a terrestrial network also not only needs to consider a wide range of services with large variance in terms of requirements, but also the typical (large) differences in terms of capabilities within the satellite networks with respect to the terrestrial ones (throughput limitations, latency impacts, etc.).

Work in relevant networking SDOs as IETF also has started to address these topics, with many new personal drafts under development identified in different working groups as the routing area (RTGWG), link state routing (LSR) or time variable routing (TVR). In addition, showing also the raising interest on this topic, the creation of a dedicated ETSI WG for NTN networks has also been discussed as proposed by some companies in the communications industry to work on these topics, still under discussion.

The analysis done so far has not identified common standardized interfaces defined to work between the different functional blocks within the previous Figure 48 for the NBI / APIs towards customer platforms, also showing the lower maturity in this respect in comparison with the current status and developments in the terrestrial network. The main gaps in relation to integration in the management architecture of terrestrial MNOs will come linked to the NBIs, being the rest a relevant topic as well, but applicable for the satellite system operator developing and operating the constellation.

Developments are expected in this field linked anyway to the evolution of the current LEO systems to more advanced ones and the development of multi-orbit systems (starting with GEO + MEO/LEO). As practical example, systems targeting for multi-satellite system orchestration have already been identified, as the spacetime system developed by Aalyria (coming from the initial definition for applicability in the Google Loon project), that has relevant partners in the satellite GEO industry as Telesat, Intelsat, others in the process of developing future LEO systems as Rivada and further development projects with the European Space Agency. The SpaceTime system exposes an NBI[6] which for now can be seen more as an internal interface for the satellite system provider than an external API towards mobile operators -although it already

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[6] Available definitions at https://docs.spacetime.aalyria.com/

incorporates methods linked to service requests-, as well as a SBI interface definitions for the control of managed devices (beams, RF, links, etc.). A system like this can be used single or multiple roles (service orchestration / ground orchestration / satellite orchestration) as shown in the previous Figure 48.

RF and ground network virtualization

An additional field under development linked mainly to LEO constellations in parallel to the enhancements in the baseband ground platforms and the satellites is that related to the virtualization of ground stations, making it possible to virtualize and dynamically generate instances in remote datacenters of part of the baseband / IF components typically implemented locally in ground stations, minimizing the footprint required in the gateway sites (Antenna and RF) and making it possible to develop satellite gateway connectivity as a service to users (which can develop satellite communications, process data, and commercialize services, without requiring to build and operate the ground station infrastructure), leveraging also on cloud network capabilities building added services on top.

Some big cloud companies have entered this space, as Microsoft, Amazon, etc. in partnership with MEO/LEO and ground infrastructure companies to deliver this type of services. In these cases, APIs are also available for provisioning, managing, and monitoring the services, but also not standard between companies.

It can be seen, linked to the development of software defined satellites as a first step towards Satellite as a Service future models (larger scale models are for example expected linked to the Amazon Kuiper project, where integration with AWS developed, and similar can become available in other similar projects (e.g., SpaceX also announced collaborations with Microsoft and Google in the past). However, for now, current LEO large scale systems as SpaceX, as already introduced, expose a reduced set of functionalities via the system API.

Evolution to multi-orbit systems

Long term evolution to multi-orbit high scale systems (GEO/MEO/LEO and even extensive to other NTN solutions as HAPs in full flexibility) inherits and combines all the complexity from each of the single satellite layers and add extra complexity to handle the management of solutions which can be provided by different satellite providers with different systems. Ground network gets also impacted with devices and stations that need to handle effectively multi-connectivity and dynamic service routing among the different systems and will need to develop to enable future large-scale flexibility combining many solutions and orbits, especially at large scale. Many research projects address this topic to drive long term evolution of the non-terrestrial networks. For management, it can be considered for now at high level anyway subject to similar considerations applicable to large scale LEO constellations (external system to the MNO -with much higher complexity and technology challenges ahead- presenting interfaces for the integration with the terrestrial network, covering the minimum set of needs to ensure that the main connectivity cases are achievable, including slicing support in a 5G environment.

However, in short term, multi-orbit operation is gaining relevance already linked to the development of enabling technologies as specific baseband devices (e.g., dual transceiver), antenna arrays and other networking solutions as SD-WAN, together with already deployed MEO and LEO systems, with partnerships, trials and commercial products developing between large GEO satellite operators like SES (which also has the operational O3B and the future M-Power MEO system under deployment) and Intelsat with MEO and LEO companies as SpaceX or Oneweb, amongst others. In most of the cases, so far services are targeting mobility or government market to serve cases to balance services between low-latency LEO/MEO connections and wide footprint stable lower capacity GEO connections (which also serves to lower the overall cost per bit of the solution).

In many cases, to achieve seamless service flow balancing and handover between solutions SD-WAN systems are used, also serving to manage multi-connectivity cases in several scenarios (quality enhancements, cost efficiency, backup, load balancing, etc.). This also includes cases in combination with a terrestrial path, so they can be seen as an initial step in terms of integration between networks, in this case delivered using a specific terrestrial networking technology as SD-WAN in combination with different satellite systems. In these cases, SD-WAN constitutes a solution that provides a virtual overlay network for connectivity between sites, private cloud, or public cloud/Internet. SD-WAN operates over one or more underlay networks, and enables to offer more differentiated service delivery capabilities, forwarding traffic based on application flows, according to the policies which include rules and constraints on the forwarding of the application flows. In relation to one of the key topics within this project, as network slicing, SD-WAN may be provided as a network slice, or it can be realized on several network slices provided as underlay connectivity, as already envisaged in [35].

In SD-WAN, each application can be delivered over the optimal underlay connection (WAN), and dedicated software instances can be deployed as virtual network functions that run on general-purpose “universal” equipment with solutions provisioned, managed, and controlled by software which can run in the cloud. Operators like SES use specific open-source orchestration platforms as ONAP to manage the multi-orbit services to customers.

This type of shorter-term multi-orbit satellite services will also be no exception in comparison to the others presented before, and for MNOs will we available as managed services by a satellite service provider that manages the complete solution (including for example, in shorter-term cases specific parts of the solution as the SD-WAN).

3.3.2.2 Access constellations

Access constellations are developing and generally in a less mature stage, especially those projects that require launching a dedicated system for the services, which are the ones with a larger focus on this document. Of course, concepts exposed for transport constellations are also applicable here (especially for regenerative access constellations), with the additional complexity of including radio access nodes and a mobile core generally as part of the overall system. It is still soon to foresee details around the management, which are also highly dependent on the final architectures to develop over time. So far, considering the regenerative constellations under planning and development in the industry (although having still in several cases a 4G initial mobile service target) the typical shorter-term scenario would be that of the satellite system being a complete mobile network that includes the RAN and the CN. These additional elements bring additional complexity to the overall system management but, again, in most of the cases this will need to be managed internally by the satellite operator which will not expose directly the option to manage these components which form their system and will provide instead managed services to multiple MNOs according to agreements and SLAs. Interconnection with the terrestrial networks of the operators in these early systems consider a roaming connection between mobile cores.

So, in these systems, if this roaming-based approach is continued for 5G access constellations, they can be seen as complete parallel end-to-end networks in which the satellite operator faces similar problems and challenges to a terrestrial network in terms of 5G service provision and slicing management and would require having their own end-to-end orchestration solution. This solution, if 3GPP compliant, as any terrestrial one, will need to consider API exposure for service clients to request slices, monitor service status, etc. (as already presented in section 2.3) or even east-west interfaces to terrestrial 5G mobile network orchestration equivalent systems, which depends on the level of integration and further developments linked to capability exposure under development in the 3GPP standards. In the specific case of roaming in a 5G service environment supporting slicing, as also introduced in the same section, further developments need to reach mobile network implementation (as, aside common network slicing features, inter-company agreements and further considerations under study and normative work need to consolidate.

Other options as potential network sharing scenarios – e.g., MOCN sharing the radio access from the satellite operator) might also develop in relation to satellite access networks, which will be tracked during the project to refine potential architectures to consider -slicing and sharing also have running studies targeting further developments within 3GPP--.

Additionally, according to the analysis done in relation to currently developing access systems, some specific cases can also be found related to transparent solutions, where instead of a full parallel access network supporting roaming – which would be generally the same case to the one exposed before, but for the RAN nodes, which would be on the ground – or sharing, the satellite system does not include the RAN node itself, being responsibility of the mobile operator in terms of management. Although it would be close to a sharing scenario, it can have specific considerations on top in terms of management and has not been identified as totally reflected on 3GPP specifications, so further work would be needed to gain more insight on management specifics.

In summary, in the case of satellite access systems, although in terms of technologies many of the mentioned aspects are equally applicable, the management problems and scope as described applicable to backhauling cases tends to shift towards a 3GPP management inter-platform orchestration, with lots of dependency on the satellite system target architecture.

4. Integrated terrestrial and non-terrestrial architectures, gaps, and key challenges

In this section a first analysis of integration architectures, feasibility and challenges will be done considering a set of relevant cases among all those potentially possible using in combination a terrestrial and non-terrestrial network (in the latter case with multiple options as access systems of different type and transport systems). It must be noted that the maturity of the evolution of the slicing support and management, as well as the satellite system development will differ between cases. At this stage, the focus will be on presenting the key cases and main considerations identified for each one, to then elaborate in depth during the project second stage those options which can be seen of higher priority and interest.

4.1 NTN as 5G mobile backhaul

One of the key use cases of satellite networks in relation to mobile communications is to serve as a backhaul[7] solution to remote RAN nodes which serve generally to provide coverage and mobile service -eMBB, IoT- extension in underserved or not served areas, for many of the individual connectivity use cases already introduced (permanent eMBB services, temporal connectivity in disaster recovery, complementary backup backhaul to a terrestrial solution, etc.) Here, GEO, MEO, LEO and mixed multi-orbit solutions can be employed depending on the target service requirements, which will be analyzed through some separated cases in the following. In most of the cases, even considering the large advances in satellite technologies and solutions, the inherent limitations coming from spectrum availability in the satellite bands, and the orbits and distance to earth mean that the performance and quality -especially in relation to guaranteed throughput, latency, or in some cases availability- achievable can be lower in comparison with a terrestrial network (this way normally used by tier-1 MNOs having a large terrestrial footprint as complementary solution for mobile coverage extension, ubiquitous service continuity or backup).

Additionally, a differentiation will be done between internal operation of satellite services by the MNO, nowadays mostly restricted to traditional GEO or GEO HTS systems and managed services provided by a specific satellite service provider (can be an operator or a specialized integrator for example). This, because the way of integrating, especially within new orchestration and management architectures can pose different challenges or restrictions in both options.

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[7] We will take as a reference as the more feasible case a backhaul application (see 2.1.1). Throughput (committed) restrictions and latency constraints make it very difficult to consider satellite connectivity to be used for fronthauling. A potential case which might be feasible, but probably not that typical at least in initial deployment stages in satellite scenarios -especially if slicing is to be considered- would be midhaul with RAN RU+DUs deployed in the remote side, with CUs in centralized MNO PoPs (distributed across the TN network or in CN locations depending on the desirable degree of distribution and technical constraints)

4.1.1 Case 1: 5G backhaul GEO - internal operation

This would constitute the case in which a traditional GEO or a GEO HTS satellite is used as a transport solution to provide backhaul to a remote 5G station. The simpler case within this category can be that of an isolated RAN gNB that requires a backhaul connection to the core. Of course, many other cases in terms of practical implementation can be found as:

- Several gNBs deployed in a common area to achieve a contiguous larger coverage over a region, all requiring satellite backhaul.
- Several gNBs deployed in a common area to achieve a contiguous larger coverage over a region, some of them having contiguous RAN terrestrial node. Similarly, we can assume that the mobile network supports the 5G NTN functionality and procedures to handle mobility, etc. are properly supported by the MNO access and core network.
- One or several gNBs having dual backhaul connections, one of them terrestrial, supporting cases as dual connectivity with load balancing, backup, or switchover (for example, in cases where the gNB is mobile e.g., on a boat which might have only for some time access to terrestrial backhaul, as a wireless link connection).

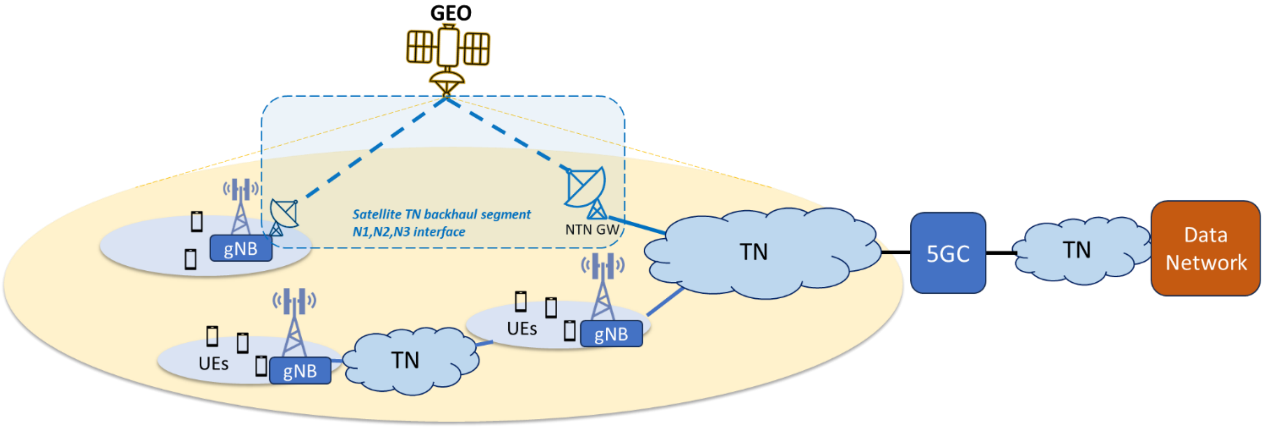

Figure 49. general representation: GEO NTN backhaul – internal operation by MNO, leasing only satellite capacity.

Similar ones where the backhaul is used as temporal connectivity are also possible. For many of these variations, it will be assumed that the MNO mobile network manages incremental aspects in terms of complexity, as handover mechanisms between the nodes independently of their backhaul solution, etc., and will not be differential in terms of the integration in the management architecture. The focus will then be on the simpler case, and then include specific aspects identified as differential for the rest. It must be noted anyway that satellite backhaul can be provided in any case within the same or different regions using a different satellite and baseband technology (so, multiple parallel networks), but the main differential factor in this case is that in all the cases, the GEO satellite service is operated by the MNO (using own platforms and systems and just relying on satellite capacity leasing by one or several satellite capacity providers).

A first relevant assumption in this case is that the mobile network from the MNO, in order to correctly integrate 5G satellite backhaul is a R17+ 3GPP compliant network, which already has the minimum functionality defined in the standard to support the NTN (QoS specifics, handover mechanisms, all the necessary procedures, etc.). As introduced in the section 3.2 several studies carried out by RAN and SA groups focused on NTN support, including both access and backhaul cases. In TR 23.737 (R17) specific challenges and cases relevant for the backhaul were addressed, especially focusing for the latter on how to handle constrained QoS (e.g., latency) linked to satellite backhaul and adapting the 5G system architecture and procedures to cope with that, including mobility aspects (e.g., when and how to allow handover in cases where PDU sessions are subject to QoS that cannot be met by a RAN node with satellite backhaul. As a result, modifications on architecture impacting many CN elements and their related procedures were defined (as context, impacts extend to the AMF, UPF, SMF and PCF) and translated to R17 -with updates and modifications in R18- technical specifications (e.g., 3GPP TS 23.501 and 3GPP TS 23.502), including as example the introduction of satellite backhaul categories (-GEO / MEO / LEO / OTHER -) in R17[8] to be used as part of the notification process between elements to adapt to NTN backhaul, and also including procedures to handle mobility based on this knowledge of the satellite backhaul type and constraints.

This way, having a RAN and CN compliant with the latest requirements and specifications becomes a need and will be considered as pre-condition. As a side note in this respect, reflecting that normative work is still ongoing some change requests are already opened in relation to the management series (28) specifications, where some of the new required modifications (e.g., implementation of the datatypes in the AMF to support the backhaul type class need to become integrated in the network model NRM TS 28.541.

As shown in the Figure 49, in this case the GEO (or GEO HTS) backhaul can be seen as an additional technology within the MNO transport domain, deployed with own components and assets but for the satellite capacity, which is provided by a third party “statically”, i.e., according to an agreement and contract dimensioned by the MNO in terms of capacity to meet target service requirements, where adjustments can be made, but not dynamically linked to operation. This way, in order to seamlessly become a technology fully integrated like any other equivalent one within the transport domain in terms of joint service management and slicing orchestration, the Figure 9. Transport SDN architecture .and descriptions in sections 2.1.3 and 2.1.4 can be taken as direct reference. Slices can be this way deployed and managed in a full end-to-end scope via the operator management architecture.

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[8] Later complemented in R18 to handle cases where QoS and latency can vary dynamically linked to LEO and especially LEO with ISLs.

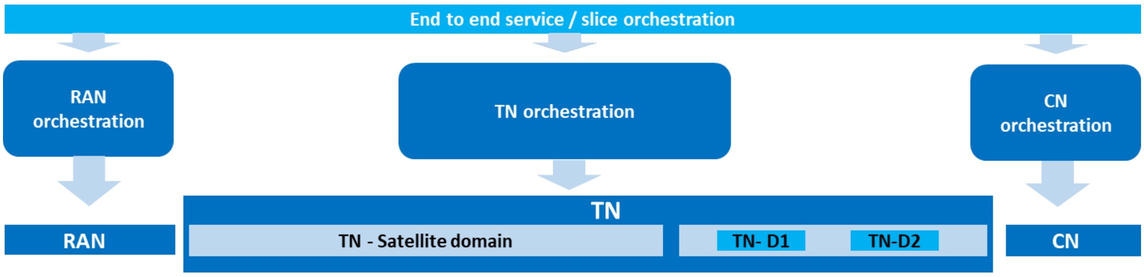

Figure 50. End-to-end slicing management overview – case 1.

The next Figure 51 shows the way in which satellite GEO networks can be integrated as transport solution in the TN domain orchestration for cases where direct operation is considered.

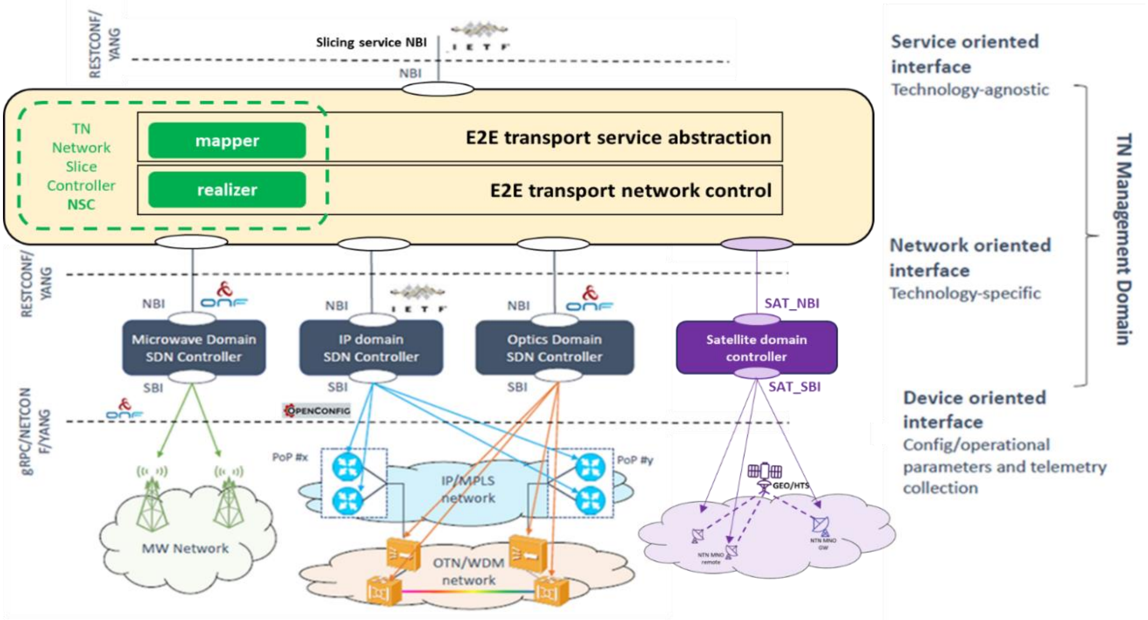

Figure 51. 5G Slicing transport management architecture integrating GEO in direct operation.

As presented in section 2.3 this architecture considers for service-oriented interface definitions in progress in IETF. The SDTN controller -hierarchical, managing the full transport end to end - implements the transport network slicing control functionality, interfacing through standard SBIs agnostic domain controllers per domain, which implement management across all devices within it using common standard interfaces and device models.

Within the same section, some of the main options under consideration around how the mapping of RAN and CN slices to the necessary TN slices can be implemented was also presented, with IP and VLAN mapping being one of the potentially simpler options to consider in early stages (Also in consideration in O-RAN ecosystem) with DSCP marking and QoS to as one of the common tools to segregate and manage flows within the transport domain to implement it. In terms of potential implementation similar to other transport domains, no critical blocker on satellite GEO/HTS systems have been identified at this stage, and modern platforms include, aside those aspects specific for the satellite transmission standards, a typical set of L2 and L3 functionalities and protocols (vlans, vrfs, ipv4/6, QoS at differ levels -per terminal, group-, diffserv, traffic marking, policing etc.) which in principle should offer the possibility of implementing a similar solution for mapping and managing slices within the domain.

The main high-level identified gaps to implement an architecture like this are the following:

As already mentioned, typically more than one backhaul network is operated by the MNO, in the same or different regions, using the same or different satellites and using normally different ground platforms. The optimal architecture in terms of simplification would be one that can rely as depicted before in a single agnostic SDN domain controller able to manage any technology using an standard SBI (in the proposed case, a NETCONF/YANG interface similar to any other domain, but with using common device (satellite baseband platform) model and implementing a single -reducing significantly the complexity of the architecture- a similar RESTCONF/YANG interface with common network YANG models to interface the SDTN.

However, at the time, as identified gaps to materialize this architecture:

1. No common interface and model support has been identified in SDOs developing common models for any other transport domain which are applicable to satellite platforms. and could be used as a common SBI to manage the set of required functionalities to fully configure the platform, including those aspects related to slicing. Support of other than proprietary management interfaces has not been identified in most devices of typical platforms.
2. No common network models have been found in SDOs defining relevant NBIs for other transport domains which are defined for satellite management or supported by the common platforms or their NMS (which, as commented in section 3.3, include RESTful APIs, but with proprietary definitions).

So, two relevant requirements in terms of management are not directly feasible, at least in a short term (standardization work is typically slow). In relation to (1), with the work done so far, there is also the uncertainty around the potential to achieve a common model to manage multiple vendor platforms. Although many of the features are common, different types of proprietary functionalities in terms of subnet, terminal and terminal group QoS management, forward -and especially- return protocols, etc. exists which can complicate work towards a common definition. However, this is something not explored in detail at this stage.

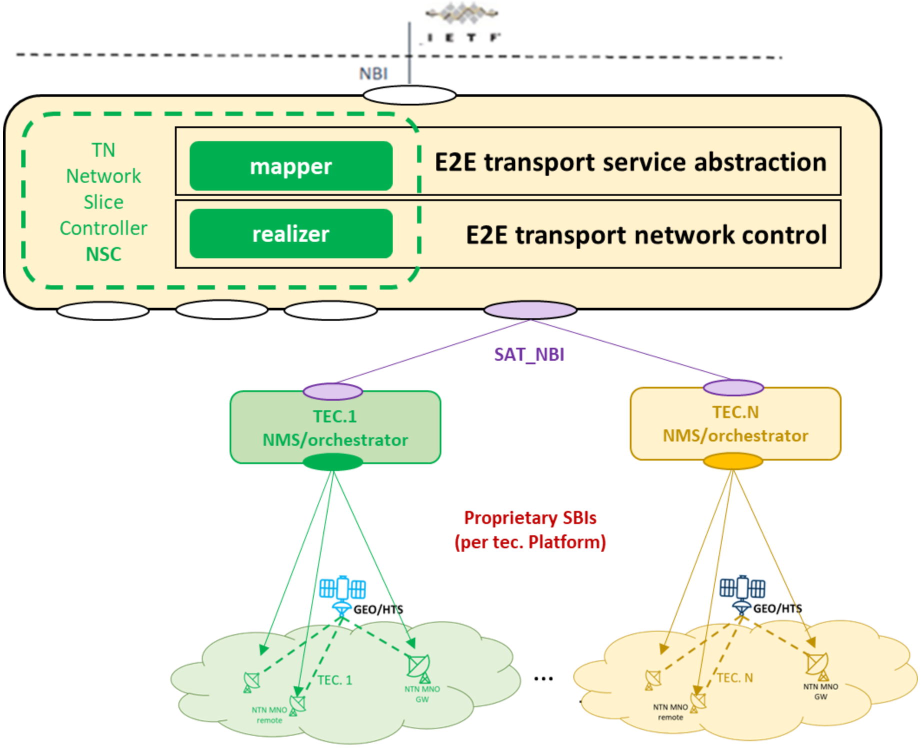

Figure 52. Architecture variation to support per-technology proprietary SBIs leveraging on vendor NMS.

An intermediate alternative to adapt to this potential constraint, while not impacting too much the SDTN controller (moving to this element specific complexity from the satellite domain) would be to consider that the NMSs play the role of technology specific controller per platform, implementing a proprietary SBI within the domain, but exposing a common NBI towards the SDTN.

This is something used as an alternative in other domains as optical (or even in microwave domains for MNOs which still want to rely on NMS functionality while migrating to a common and simpler integration in their management architecture). However, as indicated in (2), no common definitions or standardized NMS APIs have been found supported across the checked platforms either. A third alternative would be then to introduce additional elements in the architecture that absorb the complexity of the translation between proprietary interfaces (again to avoid putting this functionality in the SDTN, which is an element that ideally should be as agnostic as possible to the underlying domain complexity). However, it must be considered that, the higher the complexity (and additional elements/development) required to integrate a domain, the higher the probability of limiting the integration, which has been one of the key problems with satellite networks in the past.

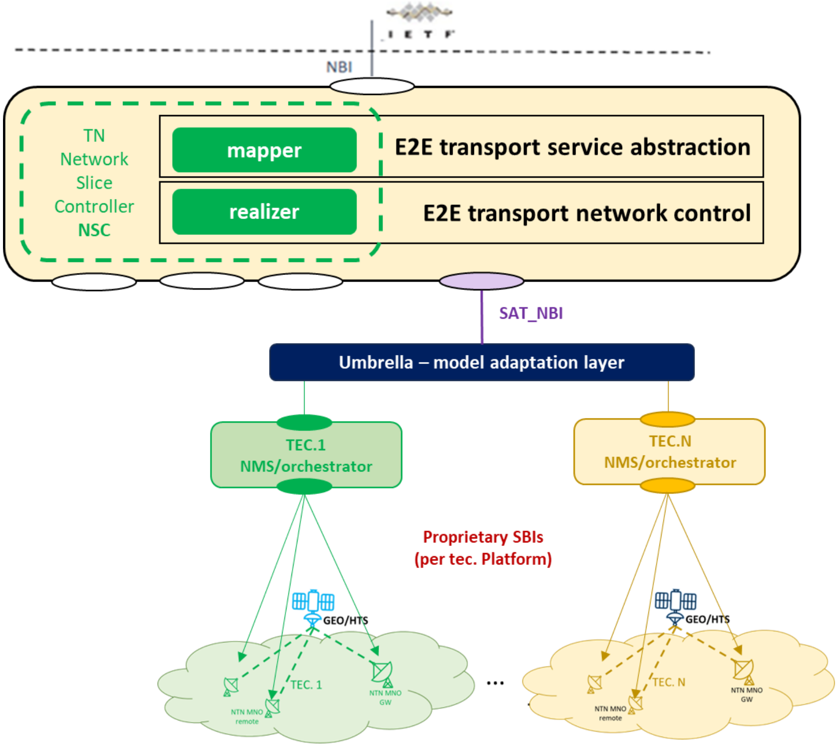

Figure 53. Architecture variation to support per-technology proprietary NBI/SBIs, including adaptation layer.

In any of the variations, the target is having a common interface facing the SDTN. As minimum functionality at this interface level (keeping RESTCONF as a base requirement), a minimum set of models / interfaces are required to cover, as explained, the common set of functionalities across all domains to fully implement the transport end-to-end, which included specific interfaces to cover the new needs derived from slicing full lifecycle management.

- **Topology exposure** – models like *T-API* (optical) and network, *ietf-network*, *ietf-network*-topology (and specific augments for L2/L3, TE or MW topologies) models in IETF (IP and microwave domain) are some references of models already adopted in other transport domains.
- **Service / slice provisioning –** *L2NM, L3NM, draft-ietf-ccamp-client-signal-yang* from IETF are some typical examples of developed and adopted models in this respect in the IP or microwave domain. In relation to slicing, realizations at the SDTN NBI are under definition, as presented in section 2.3.
- **Fault management** – as example, via NETCONF notifications
- **Monitoring and performance** – here NETCONF/YANG PM according to the underlying device models and gRPC telemetry tend to be the more typical ones.

So, further work is required in this domain to fully integrate in the common terrestrial orchestration architecture, especially in the field of harmonized management, with the minimum of the satellite platform NMS NBI, which would be probably achievable at a shorter timeframe than a fully common SBI as well, avoiding the complexity of developing intermediate vendor specific adaptation systems.

4.1.1.1 Multi-connectivity TN+NTN in backhaul scenarios

This case can be seen as extension of the previous one, where both satellite backhaul and terrestrial backhaul are available permanently (for example, for backup or load balancing) or intermittently (which might apply for gNBs in mobility scenarios as maritime applications).

This case is left for further study linked to the extra complexity. In terms of focus and support in 3GPP standard, R17 studies as TR 27.737 included this scenario, but SA working group left it finally not addressed with no normative derived work so further research will be needed in this respect to see how other groups might have addressed the topic.

In terms of implementation, leaving aside normative work, solutions based on SD-WAN are anyway seen as feasible here. As already introduced (and reflected in IETF transport network slicing work), transport slices are seen compatible with SD-WAN, which is an overlay connectivity solution which might work on top of defined slices in both the TN and NTN transport domain (in both, all presented work then would apply). SD-WAN management, to define policies to direct flows between the available transport (and underlying slices, if any) might be seen on top of the presented management and orchestration architecture.

4.1.2 Case 2: 5G backhaul GEO / LEO - managed service.

This second case is directly related to the previous one, especially in terms of target services and use cases. Satellite connectivity will be used as transport solution for 5G nodes, complementing the terrestrial network in the same way which was presented generally in the case 1, but with the main difference here being that satellite connectivity will be used by the MNO as a fully managed service provided by a satellite service provider or integrator, meaning that all the systems, ground network and satellites are direct responsibility and under direct management by the service provider, which can use either dedicated platforms per client or common platforms and systems for multiple clients as VNOs. The next figure shows a representation of the case, having in blue all those elements which are within the responsibility of the MNO and highlighting the domain responsibility of the service provider.

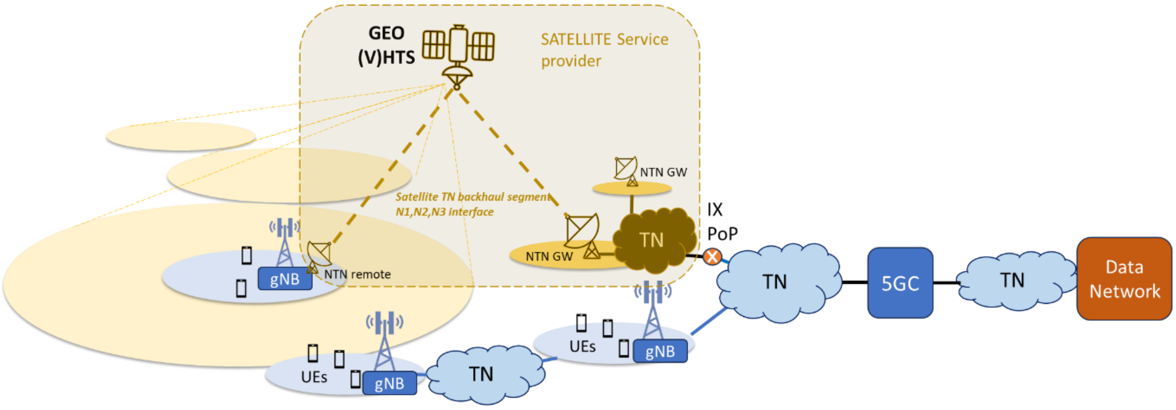

Figure 54. general representation: GEO NTN backhaul – managed service to the MNO by a satellite service provider.

In case of GEO, this began to become a typical case as already introduced with the rising capacity and complexity of HTSs and later, of VHTSs. This has become a need also in constellations, where it can be seen nowadays (from the perspective of a large terrestrial mobile operator) as the only option due to the complexity, capacity, global approach, and costs to deploy a LEO system. The next figure shows the same case but considering a LEO constellation providing transport services.

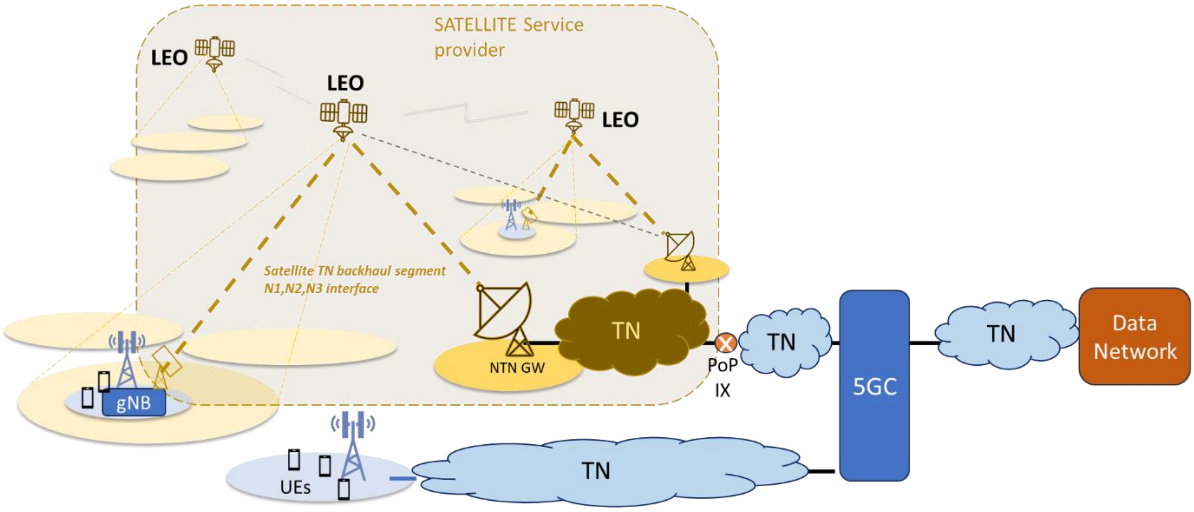

Figure 55. general representation: GEO NTN backhaul – managed service to the MNO by a satellite service provider.

In both cases, traffic will we delivered to the MNO in one or several interconnection points (IX). It must be noted that as HTS/VHTS and MEO/LEO have multiple ground gateways, a transport network needs to be owned and operated -or leased to terrestrial network provider- by the satellite service provider.

As pre-condition, similar considerations to those already made in the case 1 are applicable here. The MNO will have RAN and CN devices implementing the functionality as required in the R17 and R18 3GPP specifications. In relation to backhauling, R18 (a specific study TR. 23.700-27 analyzes and provides normative recommendations integrated later on in specifications as 23.501 and 23.502) extends the previously introduced modifications with some aspects that are relevant specifically for the LEO case as, on top of the QoS aware procedures (supported by AMF, SMF, UPC, PCF) relying on backhaul class indications by the AMF and processes established for the rest, support of dynamic QoS is introduced, in part extending the aforementioned backhaul classes with dynamic ones to trigger specific procedures to adapt to a potentially varying QoS in satellite backhaul enabled (as for example in LEOs implementing ISLs). Other updated to R18 system architecture and procedures related to satellite connectivity are more related to regenerative access satellite systems).

It will be also assumed here that, even meaning a much larger step in terms of extra complexity, with inherent challenges to solve (as dynamic time variable routing, latency variations, etc.) in LEO systems, a basic networking toolset to implement the general procedures introduced to map transport slices to external domains (RAN or CN composition with other TN domains) would be available similarly to GEO, not being at the time as a potential hard blocker (although it remains for in-depth study depending on use case prioritization).

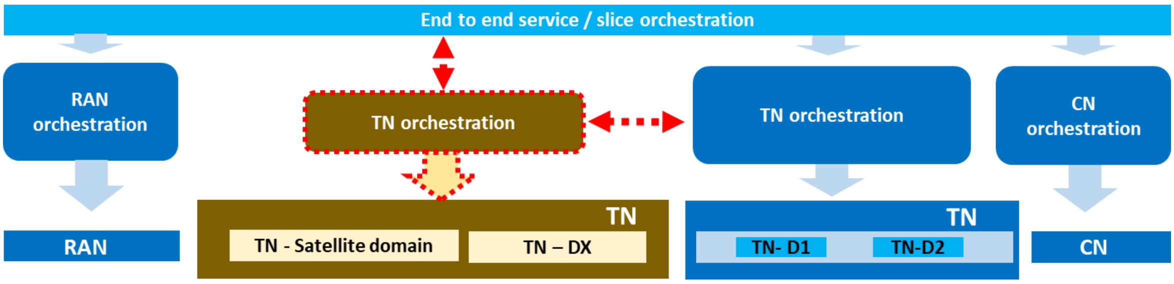

Figure 56. End-to-end slicing management overview – case 2.

In terms of integration, even if the end connectivity cases are similar, there is a significative difference of the integration in the end-to-end service orchestration, which shifts toward a potential integration of orchestration platforms between the satellite service provider (transport slice provider and manager) and the MNO (mobile service provider requiring the end-to-end slice) which might need to happen also at higher layer OSS/BSS systems. For the specific case of slicing, the MNO can orchestrate its network using the presented reference architecture, including the RAN domain, the CN domain, and its own section of TN relevant to the slice definition. To complete the end-to-end, it will need to request a transport slice to the satellite service provider through an established process.

In the worst case –no integration– the different steps of the full slicing lifecycle management will not be automatic but requested explicitly by the MNO, for example in terms of a satellite connection using a specific satellite type and minimum SLA (e.g., guaranteed throughput and availability to a given gNB) able to support the requirements for the planned end-to-end slice. The satellite service provider will provision the connection according to the request agnostic to other end-to-end requirements aside the specific terms in the SLA. Other steps like termination, or modification would be equally static. Dynamic operation (in terms of automatic service modifications linked to the end-to-end slice performance) will not be supported either, only monitoring of the satellite connection SLA will be possible but normally through a proprietary interface / API exposed by the satellite provider.

For higher integration, interconnection at management level of the different orchestration platforms used by the satellite provider and the MNO will need to be considered. Here there is a direct dependency on the way in which the satellite provider manages and orchestrates (and exposes capabilities, etc. offering the possibility of managing transport slices. This is also dependent on how many solutions the satellite provider manages as well as their nature. For example:

1. The provider can just work with a single solution (GEO VHTS or LEO), which is under its direct management. Section 3.3 covers the specifics around the trends and challenges of the satellite domain management in both GEO/(V)HTS and LEO. An API exposed by either an NMS or an internal orchestrator (not standard as of today, and not covering slicing specifics) will be available for interconnection.

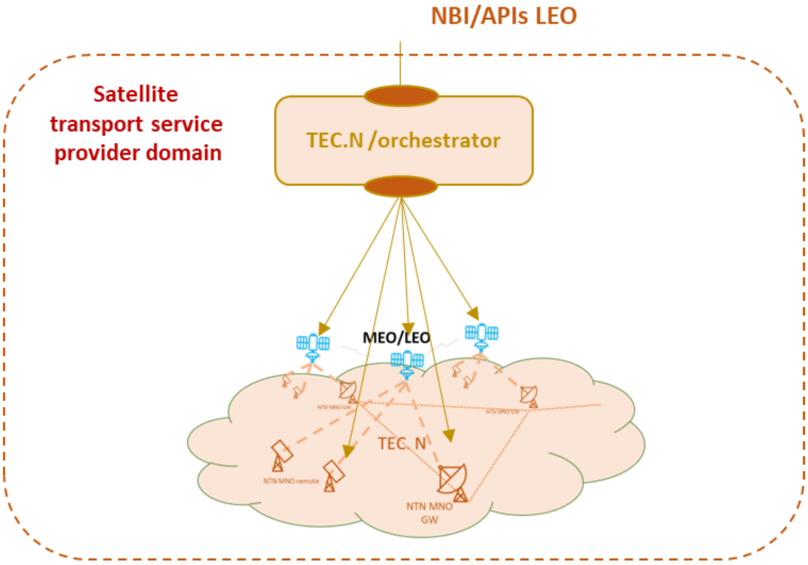

Figure 57. LEO managed service – API exposure.

2. The provider can be an integrator of multiple solutions. In this case, within its own domain, the integrator will face a similar case in terms of management to that presented in the previous section 4.1.1, extended to the case of including not only GEO satellites, but might also include LEO systems. Here, it is likely that a system to expose a single NBI/API (still not standardized and not covering slicing) for provisioning, monitoring, management, etc. to the MNO or other transport service customers is implemented by the provider.

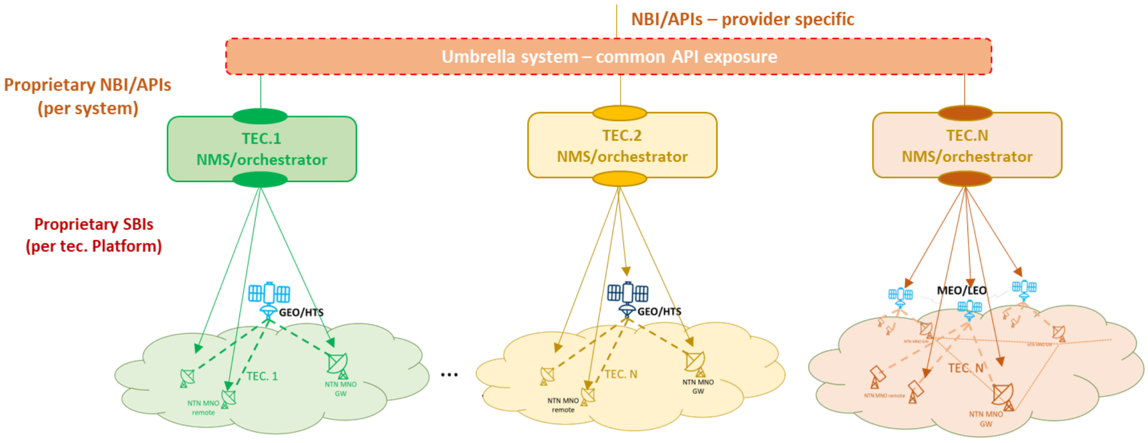

Figure 58. Satellite system integrator managed service – API exposure.

Some of the challenges and gaps in this case are in this case this way common to the case 1:

- Within the satellite domain, the provider faces the problem already presented in the case 1 and might decide to implement an orchestration solution -agnostic or per technology- with similar considerations and challenges. In this case, it would be outside the scope of the service MNO.

- Integration of solutions via managed service still cannot rely on a standard API, which would be desirable as identified in case 1, for the same reasons. Exposure and openness for the customer management will be limited to the decision of the satellite service provider, but a minimum set of new functionalities will be needed to support transport slicing provisioning and the rest of necessary steps within the slice lifecycle.

An additional consideration to be made in this case is at which level the interconnection between management and orchestration platforms should exist, considering a standard or proprietary NBI exposed by the satellite service provider is available. We will focus here on this stage in options based on technical aspects, but in many cases, considering derived aspects of the service provision as charging, billing, etc., interconnection and interfacing at higher layers as OSS/BSS might be needed.

If non-standard interfaces (be them one defined by a service integrator or multiple differentiated ones) are the only available options, the case remains quite similar to the case 1, and the SDTN can be the element interfacing the third-party APIs. However, following similar considerations to those already done, to avoid vendor/domain specific developments in the SDTN an adaptation layer to translate from common NBIs (for the different relevant use cases in terms of management -topology exposure, monitoring, fault, configuration- and slice specific -transport slice provisioning, monitoring, dynamic management, etc.) to the specific APIs exposed by the service provider(s) will be required. Again, in comparison to case 1, functionality in this APIs restricted in this case to that subset enabled by the service provider.

Adoption of standard interfaces, similar to those applicable for the terrestrial network, can favor the integration of the non-terrestrial network within the end-to-end orchestration architecture. Two potentially interesting cases would be:

- The Satellite service provider implements a similar interface in its orchestration/management system to that used by the SDTN controller (in the reference scenario set to IETF transport slicing service, under development). Internally, using a similar transport slicing interface than the terrestrial domain, the satellite provider will need to manage within its network the slice creation, monitoring, etc. between the inter-domain SDPs according to the requested SLA. In this case, the MNO end-to-end service orchestrator can interface the satellite provider transport orchestrator with a technology agnostic interface.
- The Satellite provider can implement an interface in its orchestration and management system that requires some domain specific parameters (not a totally domain/technology-abstract interface as in the previous case), similar in terms of functionality to those applicable at the SDNT SBI towards the domain controllers (as those already under development now in IETF for other transport domains as. This can be for example augments of the IETF service interface, which can add a minimum of required parameters to enrich the definitions. This of course is domain specific and would require harmonization work in standardization forums.

Both options were already depicted in Figure 56 schematically. Depending on the potential evolution of the adoption of open management architectures by non-terrestrial providers, different options can materialize in different term. In more detail below, assuming a transition towards the adoption of slicing service NBIs by the satellite provider for different cases within the satellite domain: in Figure 59, the case in which the service provider does expose a common interface but without open SDN architecture within its management domain; in Figure 60 the same situation but where the satellite provider adopts a similar orchestration architecture to that employed in the TN, including and end-to-end transport management, exposing only a fully agnostic transport slicing service interface towards the MNO end-to-end orchestrator, with fully SDN agnostic management within its domain; in Figure 61 finally, a case where the satellite operator exposes a standard interface towards a satellite domain orchestrator supporting cases other than abstract transport slice service implementation, and fully agnostic domain is possible in the satellite domain.

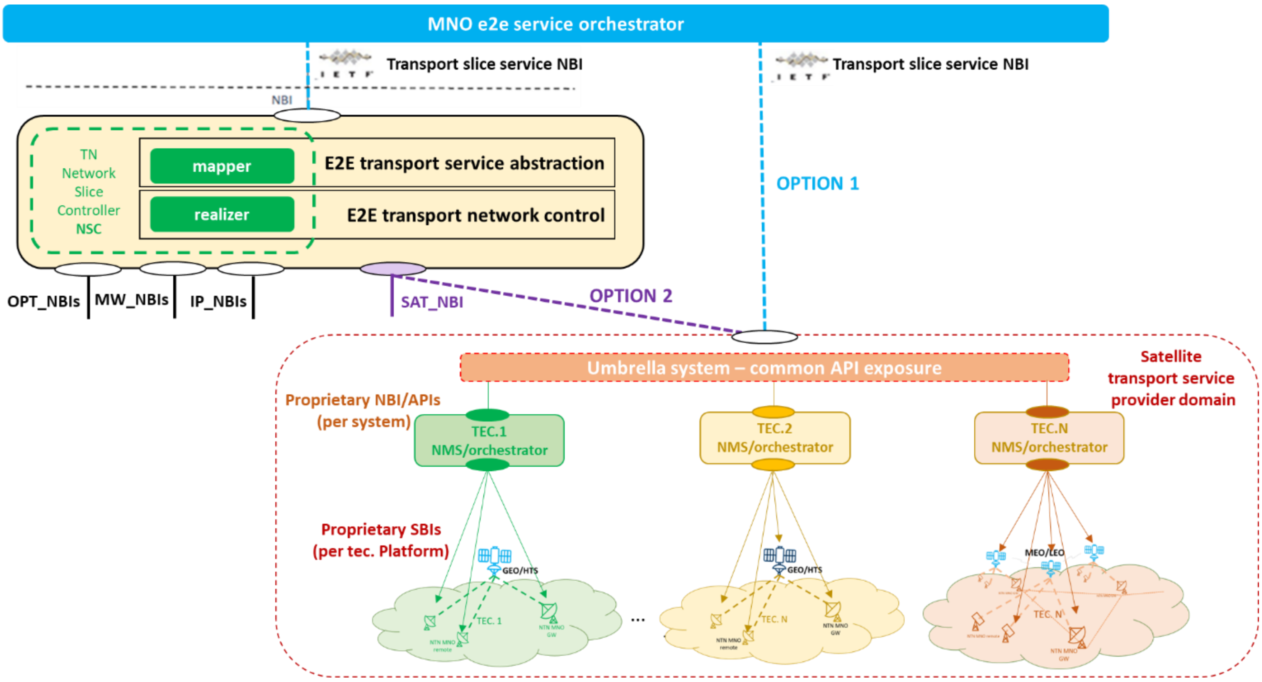

Figure 59. TN-NTN management integration architecture – satellite domain with proprietary management, exposing standard transport slicing interface.

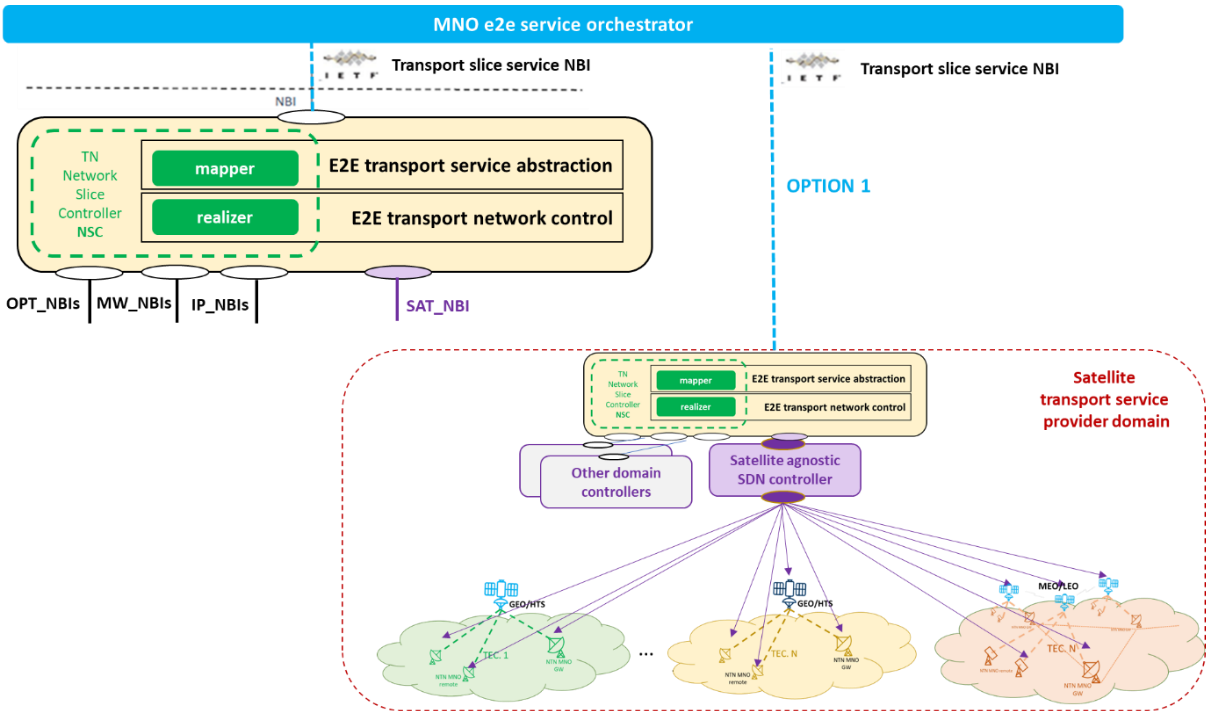

Figure 60.TN-NTN management integration architecture – satellite domain with fully agnostic SDN management, exposing standard transport slicing service interface.

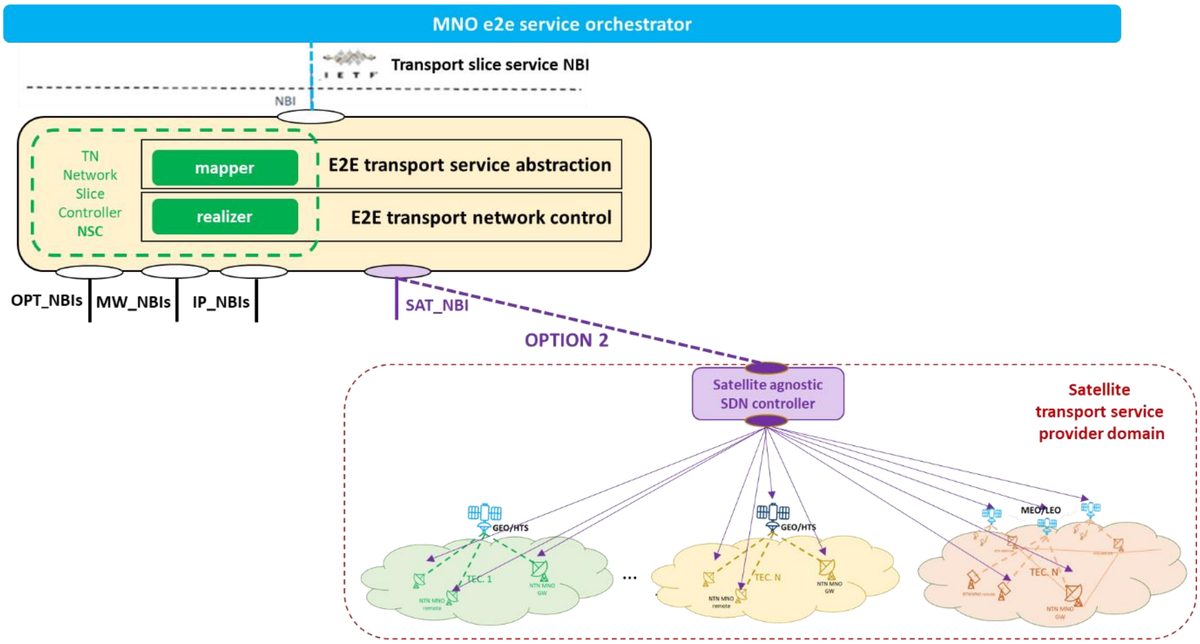

Figure 61. TN-NTN management integration architecture – satellite domain with fully agnostic SDN management, exposing standard transport slicing service interface.

So, in this general managed service backhaul case, on top of the common ones already highlighted in case 1, the specific gaps to cover come related to the implementation of inter-platform standard interfaces where the satellite provider opens and exposes management functionality to the MNO.

4.1.2.1 Case 2b: 5G multi-orbit GEO/MEO/LEO

This case can also be seen as extension of the previous one, where multiple satellites, as for example combining GEO and LEO offer connectivity to a given gNB (assuming it has the right ground devices to support that on the satellite side, be them dual carrier modems and a planar array or dedicated infrastructure per solution). It can also be extended as 4.1.1.1 to also support terrestrial connectivity, permanent or temporal.

This case (which is starting to get adopted in the industry for specific cases) is similarly left for further study linked to its extra complexity. As in the GEO + TN multi-connectivity case, 3GPP standard R17 studies were not conclusive and normative work need to be analyzed in greater detail.

However, in terms of implementation, solutions based on SD-WAN are similarly seen as feasible option here, compatible with the support and implementation of TN slices by the satellite service provider in its transport service domain. Implementation of multi-orbit GEO/LEO would be responsibility of the satellite provider, with the main open point of how to expose potential management of this part -if seen as needed- to the MNO, on top of the rest of interfaces for the slice provisioning, etc. mentioned in the previous section. Bringing multi-orbit together with TN operation -using for example an SD-WAN based solution- would open the main question of setting the flow policies together between TN and NTN and which partner -if not both- manages the SD-WAN logic on top of the combined TN and NTN underlay.

4.2 NTN providing mobile access

Complementing the cases in the 5G mobile network service provision scenario where satellites are used as a transport solution, this section targets analyzing applications where satellites are used to provide mobile access, in line with 3GPP normative architectures and the architectural references found also in early projects developing in the satellite industry. The main focus will be kept on new constellations able to support multiple services for simplicity because, as already introduced in section 3.1.2.2 there can be different options and alternatives impacting system architecture).

LEO constellations providing direct access to devices constitute a relevant area of development in the satellite industry and can constitute a good opportunity to complement terrestrial networks in uncovered areas avoiding the deployment of a ground mobile RAN in remote low-density regions where the terrestrial mobile access can be difficult or too expensive to deploy (and operate). Typical use cases for this category are:

- Ubiquitous basic messaging services, SMS and broadcast in uncovered areas or in cases of emergency and disaster recovery, when the terrestrial network is down.
- IoT services (sensing, asset tracking, etc.) in areas where a terrestrial network cannot provide them due to lack of infrastructure.
- Voice and basic broadband in underserved or uncovered areas, with low user density filling terrestrial network gaps, or in cases of emergency and network recovery, serving as a permanent solution in low density areas till the terrestrial mobile network is restored or in any other scenario as an immediate basic solution till a temporal higher capacity network is set-up on the ground.

In this category, although multi-connectivity cases can be considered (although restricted to dual UEs, as simultaneous PRBs in s single device using different RATs is not considered within 3GPP NTN specifications), the main typical use of the satellite networks aside providing mobile services in areas isolated from the terrestrial network is mainly provide service continuity, allowing for handover between the terrestrial access and non-terrestrial mobile access networks.

As already presented in section 3.1.2.2, these systems are in a more immature state, currently developing, and although definitions in 3GPP to incorporate non-terrestrial access in 3GPP starts in 5G, from R17, initial systems to reach the market will most probably start operating targeting 4G service provision, adapted to the nature of the areas where the services are required.

This, in addition to these solutions constituting a complete or partial parallel 3GPP network, with mixed sharing or roaming approaches (less mature in the specific case or network slicing normative specifications and network implementations) make more difficult to enter at this stage in more detailed definitions. In any case, the main considerations in terms of potential integration architecture will be covered, to identify the key areas which will need to develop further targeting a full support of network slicing.

4.2.1 Case 3: 5G access transparent LEO- managed service

The first general category of solutions is, as introduced in section 3, the first reflected in terms of 3GPP release support (R17). In this case, a 5G FDD access network can be deployed relying on a non-terrestrial LEO constellation keeping the RAN gNBs on the ground, and having the satellite as a transparent bent-pipe solution that supports the NR-Uu interface to devices (changing frequency from the feeder link, typically in very high frequencies -Ka, or Q/V- to the user frequencies (3GPP defined ranges or MNO terrestrial ones, typically in low or mid-bands), generating also the beam patterns that form the ground cells -normally static- and mapping also to the different desired beams the cell channels coming from the gateways. The use of this solutions anyway needs to be planned in coordination with the terrestrial network to avoid interference, being the typical critical aspects the impact from the UL terrestrial network signals to the satellite UL, which if using the same spectrum might require the use of exclusion areas (these areas can be needed also in country borders, etc.), and the potential interference than the satellite users or the satellite signal causes to the terrestrial network in its UL and DL respectively. Depending on the method of spectrum sharing, different coordination or planning mechanisms can be required, which for now are considered to be statically planned prior to the satellite network deployment and operation.

Considering the analysis from projects developing and 3GPP architecture definitions, different cases can be considered:

- First, the case (3a) in which the satellite provider takes responsibility of the deployment and operation of the satellite segment only, providing a connectivity service for gNBs placed on the GW locations, but responsibility -management included- of the MNO, and with a core network of the MNO as well.

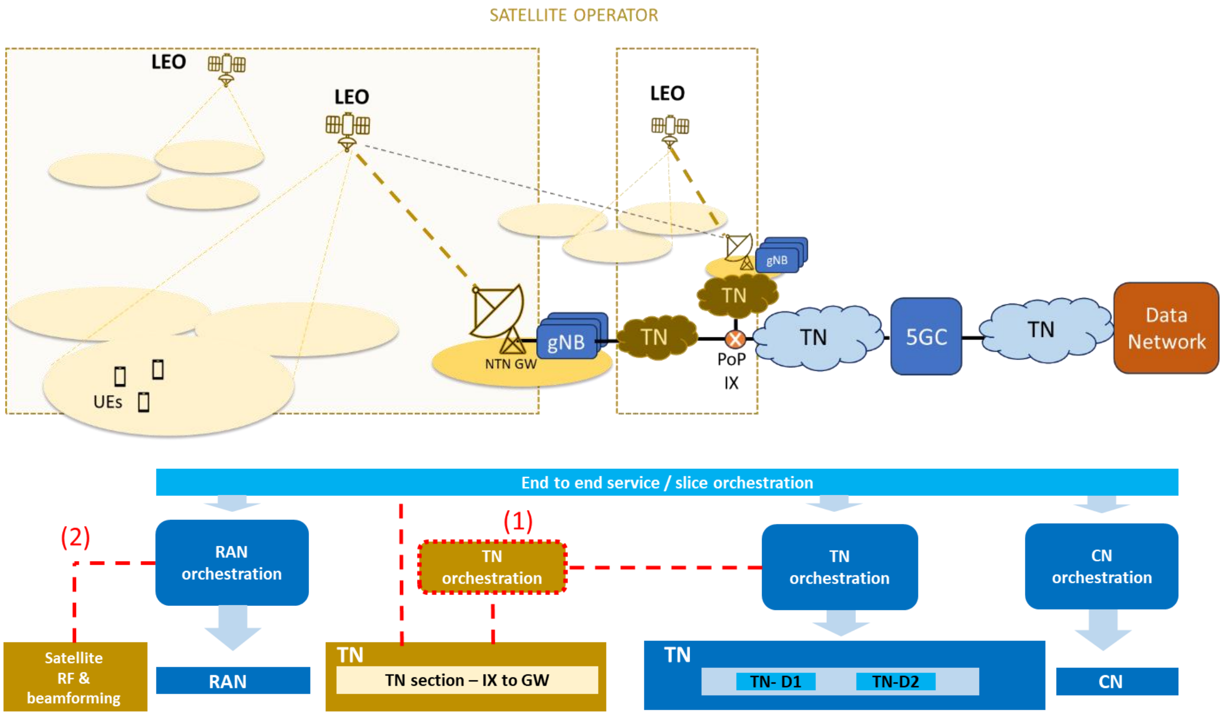

Figure 62. End-to-end slicing management overview – case 3a.

Here, most of the scenario is within full MNO responsibility, so the reference architecture applies, wi.th all related considerations done in this document. It must also be noted that as precondition the MNO deploys, as it was the case in the backhaul cases 1 and 2, all the necessary RAN and CN network functions with the functionality to support NTNs as defined at least in R17 5G release (this extends also in this case to the necessary extensions impacting the NRM and the 3GPP management functionality). Although there are not that many NTN-slicing specific definitions aside those already covered in 3.2, it is assumed that the use of NFs that meet the general 3GPP requirements specified in relation to slicing for the RAN and CN support the slicing cases also in the NTN domain.

For the elements under responsibility of the satellite provider, first, if there is a transport network section responsibility of the satellite service provider between the interconnection with the MNO and the gateway where the gNB (typically a pool) is implemented, this section -shown as (1) in the Figure 62- can be considered similar to the case already studied in 4.1.2 in relation to the creation and management of transport slices, although in this case only applicable to the transport resources managed by the satellite operator. It must be noted that this segment might not be orchestrated and just provisioned as connectivity service with a guaranteed SLA to support the traffic and requirements coming from the needs of the MNO.

The main differential is then the final (2) section of the figure. This in principle is outside the service end-to-end domain of the operator, which can be considered finished in the RAN node. However, from the RAN node to the UE, the NR-Uu interface is implemented on top of the satellite physical connectivity layer. Beam configuration needs to be managed and prepared according to the geographical situation of the non-terrestrial cell, and characteristics of the gNB cell and the service requirements from the MNO -which can include a minimum set of functionalities to support the planned slices in the RAN and end-to-end scope.

3GPP definitions (e.g. [48]), in fact, consider the complete terrestrial gNB functionality and the satellite infrastructure supporting the physical connectivity -including the satellite- as the full NTN gNB, identifying the need for O&M and data connectivity[9] between both.

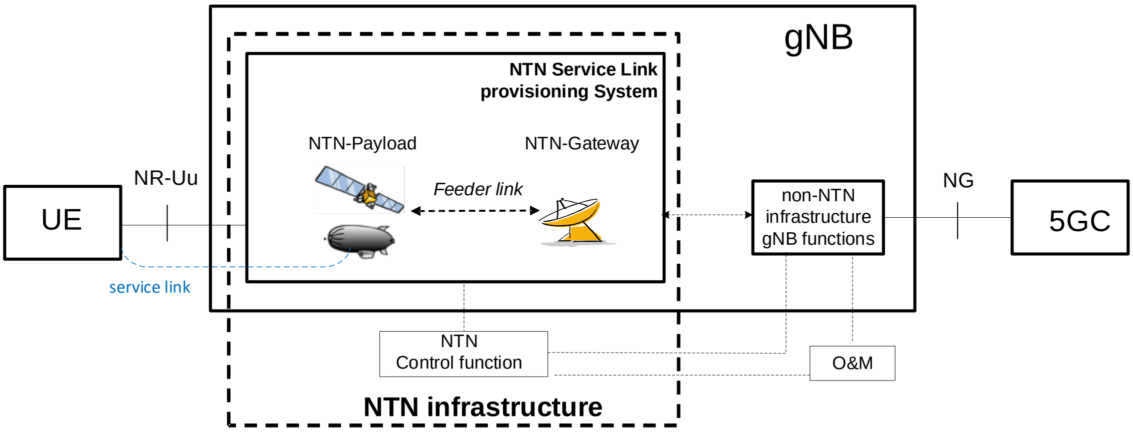

Figure 63. full NTN gNB, transparent NTN access solution. Reference TS 38.300 [35].

This interface is reported as outside 3GPP scope, and it is dependent on the satellite provider definitions and non-standard as of today, so this is a gap that requires further definition in order to accomplish a direct integration within the orchestration architecture of the MNO (as for the transport part, in an initial stage it can be provisioned statically separately from the MNO E2E orchestration to meet the specific requirements of its planned network slices.

Considering that this last section is totally RAN specific (and quite specific to the satellite part), as a candidate option to enable a higher integration and match the potential variation of slice definitions by the MNO in the overall E2E an interface between RAN orchestration and the NTN infrastructure control and management blocks is considered. This is the option depicted in Figure 62. It is still uncertain at this stage how standardized (at least for the cases related to the presented mobile service slice lifecycle) an interface like this can be, as there is a strong dependency on the satellite system specifics, and for now there is not a large available reference about implementation options.

- The second identified representative case (3b) considers that the RAN section, and transport towards the interconnection points with the MNO network is under direct responsibility (for management as well) of the satellite service provider. The CN will be the own core network of the MNO. This can be seen then as a network sharing case (it will be a typical situation that the satellite provider manages connectivity for more than one MNO in a given country), more specifically a MOCN scenario with active RAN sharing. Non-specific NTN studies,

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[9] The minimum information is dependent on the type of cells generated by the satellites (fixed beams, moving cells,etc.) including, depending on that, cell identifiers, location, pass windows, etc.

as already introduced in 2.2 were conducted as part of R17 work [14], with others still open as part of R18 specifications [49]. It is a requirement for the 5G systems that a 5G satellite access network shall support NG-RAN sharing as expressed in 3GPP TS 22.261, and a satellite provider can therefore act also as VISP, allowing access to the satellite components to the MNOs (network operator role) including the management of slice configurations in the shared satellite RAN. However, slicing in network sharing scenarios is in a lower maturity stage in term of implementation and as commented, even more in NTN access systems, which in this first wave of constellations starts in practice with an initial 4G focus (which will evolve towards 5G). At this stage, only the main identified key aspects in relation to potential architectures will then be introduced.

The Figure 14 depicted a general diagram showing a typical MOCN case. This scenario, with participating operators (POP) and a Master operator (MOP) in the shared zone, that provides the shared RAN components, was studied analyzed for a different set of cases in [14] (differentiation of Cell id in the shared RAN or common PLMN ids). In terms of management roles, the next figure depicts the general architecture:

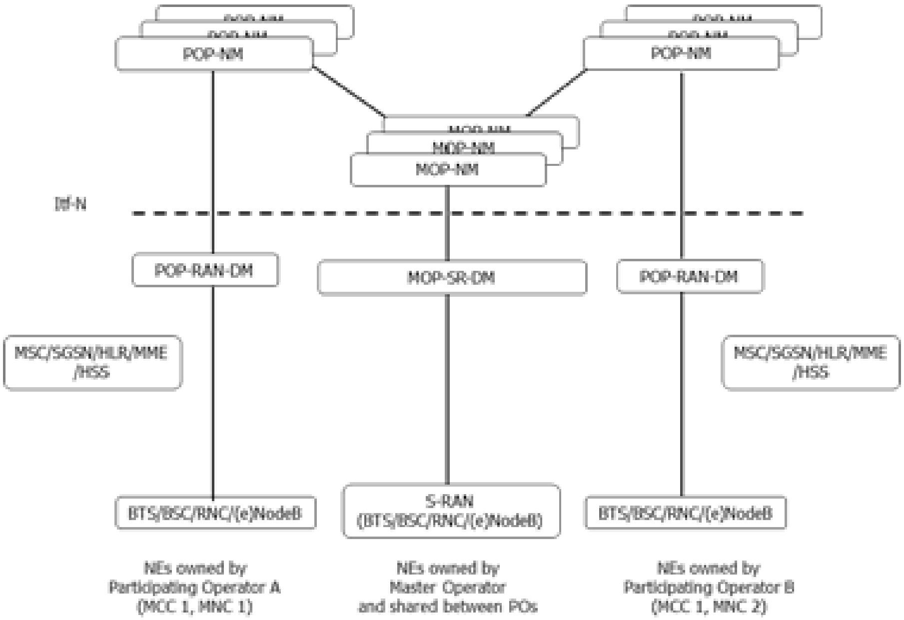

Figure 64. MOCN network sharing – management roles. Reference [50].

The satellite operator can act as MOP in this case, providing services and managing the shared radio part with other operators. As some basic requirements, the 3GPP management system of the satellite operator (the MOP) needs to enable:

- Configuration of the PLMN-IdentityInfo (including PLMN Id, CellIid, TAC) individually for each supported network operator.
- Collection and reporting of measurements (e.g. active UEs measurements, packet delay measurements) in PLMN granularity for the different MNOs.
- The 3GPP management system of the MOP shall support several capabilities to:
    - manage the shared network elements.

- configure the NG-RAN network element to start/stop the sharing
- configure the POP(MNO)-specific attributes of the shared NG-RAN individually based on the POPs' requirements.

To enable all this, as a result of the studies, different objects were added to the 3GPP NRM to support sharing (OperatorDU, NROperatorCellDU) to represent the operator specific part, keeping existing IOCs for the common one.

A general diagram showing the overall integration architecture in this case is depicted in the next figure:

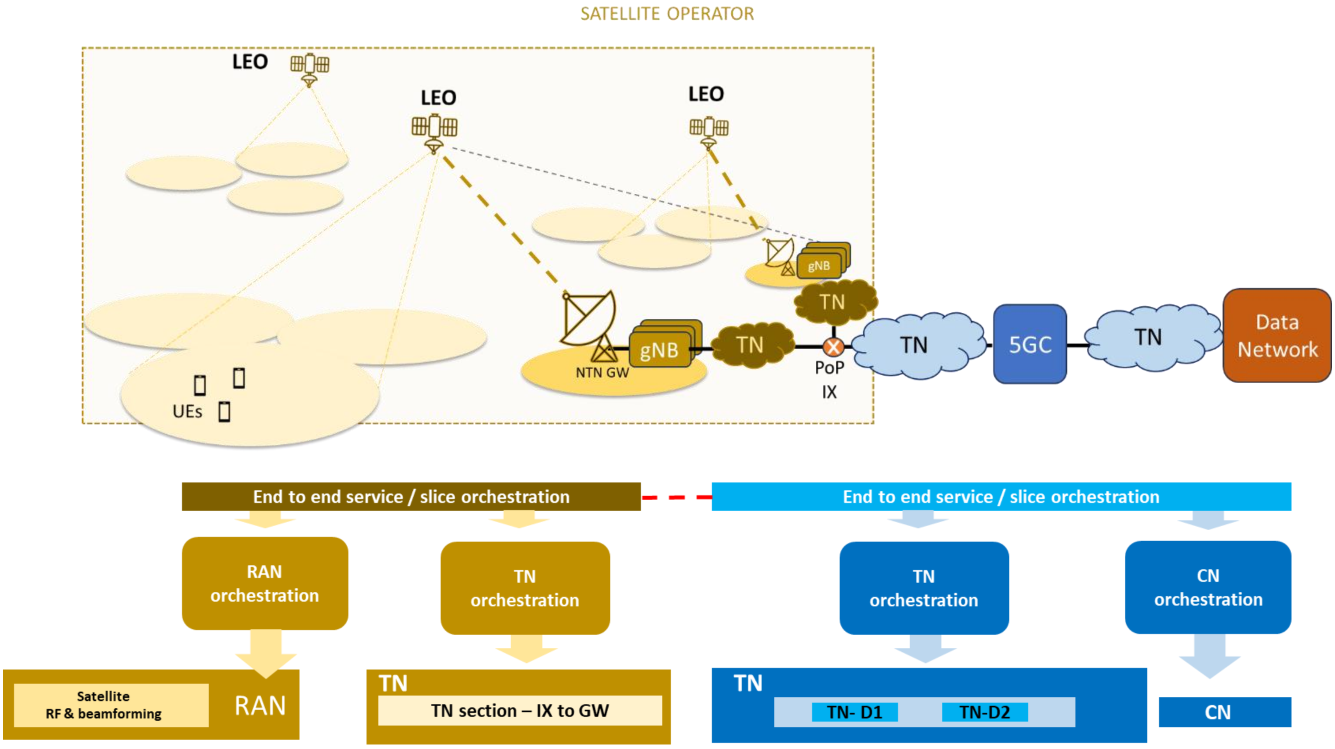

Figure 65. End-to-end slicing management overview – case 3b, network sharing.

In this case, the satellite provider will implement a 3GPP management and orchestration system as per 3GPP specifications to support slicing management. This can extend to transport network orchestration within its domain as well, in a similar way to that considered for the terrestrial network architectures. Inter-management system interfaces need to be developed to support the case, which also is on a less mature state, but will develop linked to the slicing as a service (NSaaS[10]) path and capability exposure and intent-based management work in 3GPP (see section 2.2.2). It is recognized by 3GPP that the definitions so far are not meeting a service-based management architecture requirements (already introduced in 2.2.2, and further work is then being conducted in R18. Aside recommendations to shift towards the desired service based management, R18

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[10] A dedicated study in R17 [13] already identified the need to develop NSaaS definitions to multi-operator cases like network sharing and national roaming, which can be relevant for NTN cases, also linked to capability exposure topics. Impacts on 3GPP NRM were envisaged with recommendations triggering work in technical specifications by different TSGs and new specific studies in R17 and further releases.

work related to MOCN and network sharing [49] focuses on aspects like enabling the MOP reporting operator specific configuration and performance/alarms, enable granularity at PLMN id, enable management specific actions and configuration of operator-specific 5QIs. For most of the new topics, recommendations are not conclusive, and options and specifications are still open. Release 19 has also opened lately a new study [51] focused on new general network sharing aspects -not specific of non-terrestrial-, focused on feasibility analysis of relevant topics applicable for this non-terrestrial scenario, as mobile access control and mobility management between partners, service continuity and roaming between networks participating from the sharing, which will develop in mid-term.

4.2.2 Case 4: 5G access regenerative LEO- managed service

NTN mobile services with regenerative LEO fits similar use cases as those already introduced in the previous section, extending mobile connectivity in low density areas with the same benefit of not requiring deploying RAN terrestrial nodes in remote locations. The main difference here is that, in regenerative architectures, the access nodes (gNBs or gNB DUs) and even parts of the CN are deployed within the satellites of the constellations. Additionally, inter-satellite links can be employed, routing dynamically the signals across the satellites, providing extra flexibility but also an extra degree of complexity. This way, this type of systems has been considered in 3GPP from R18 onwards, for the different applications which can be feasible depending on the satellite type[11], although there also exist some systems within this category already developing in the industry (with current focus on 4G, but will evolve over time to 5G), which have also be taken as reference for the analysis of the integration scenarios.

Like in transparent solutions, feeder link frequencies typically are implemented in high FSS frequencies -Ku, Ka, or Q/V-, although in this case, the link towards the gateway matches an N3 backhaul interface (or F1 if the satellite has only the DU). In the user, frequencies as those in specification by the 3GPP or MNO terrestrial ones can be used, typically in low or mid-bands. In the latter case, like in the transparent category, the use of the NTN solution needs to be planned in coordination with the terrestrial network to avoid interference and depending on the method of spectrum sharing, different coordination or planning mechanisms can be required, which for now are considered to be statically planned prior to the satellite network deployment and operation.

As in the rest of scenarios, we will consider here as pre-condition, although in this case 5G status is more immature, with work ongoing around some topics, having been addressed at a later stage than transparent systems, that both the NTN provider deploy a network with components in the RAN and the CN which are meeting the specifications of R18, to effectively support the NTN operation. New features and enhancements linked to R18 studies and work, presented already in previous sections have already been

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[11] As in other parts of the document, we will focus specifically on aspects or systems which are specific of a given service type as IoT, but better on general systems and definitions which can be considered general and applicable for any service type.

introduced in specifications, for example to handle dynamic latency linked to the satellite movement and inter satellite beams, or the deployment of edge functionality or local traffic switching for different use cases in the regenerative satellites. In the following, the focus as in previous sections will be on the high-level analysis of the foreseen integration architecture to also help identify the main related challenges or open aspects in 3GPP work. Detailed specifications, considered the lower maturity in this space are left for further study in subsequent phases, depending on use case prioritization.

Taking as a reference projects under development (general or IoT service specific) the most typical case identified (although others can develop) is that in which the satellite constellation constitutes a complete mobile network on its own, where connection via roaming is implemented with the MNO which might want to complement its terrestrial networks to deliver the type of use cases already introduced. The next figure shown a general diagram of the reference case in this category.

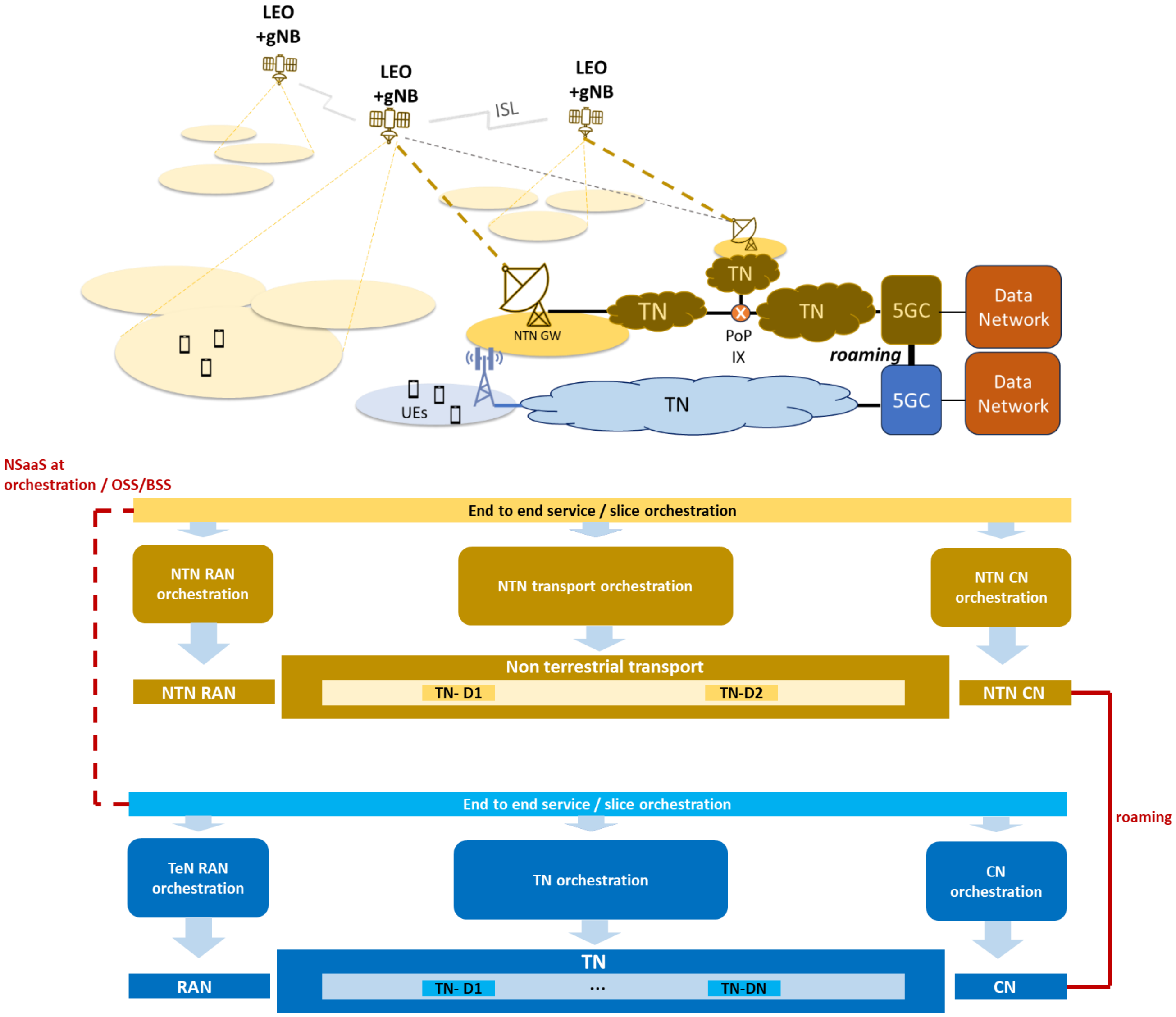

Figure 66. End-to-end slicing management overview – case 3b, network sharing

As depicted in the figure, in this case the NTN constitutes an independent parallel network, interconnected via roaming but under the direct control, operation and management from the satellite provider. It will be assumed that aside the appropriate RAN and CN NFs the satellite operator implements similarly a 3GPP management and orchestration system like that implemented by the network operator (R18 functionality will be needed).

Roaming and slicing support in RAN, CN and UE have been considered from initial definitions of 5G in R15. TS 23.501 includes in the system architecture description dedicated definitions around roaming and slicing, and guidelines for implementation were also studied and defined by GSMA, consolidated in [52]. Slicing in roaming brings additional complexity because, aside the technical implementation aspects, it needs to base on negotiations and agreements between operators, and also can get impacted by regulation. In current terrestrial networks, where slicing support and implementation by MNOs is advancing, as introduced in the second chapter, currently definitions of specific generic slices for roamers are under definition and agreement.

Aside this, the main open aspects in relation to slicing in the presented multi-operator scenario which derives from the integration between the terrestrial and non-terrestrial network in this case is related to slicing management, which, to enable complete lifecycle management, assurance support, dynamic management or even flexibility in the definition of user requested slices of a given capability and performance, requires further development in NSaaS, NSSaaS, capability exposure and intent based management, which are current topics subject to further work in terms of study and / or specification.

In R17, within a specific study related to slicing management enhancements [13], the national roaming case (which can apply in cases for this scenario) was analyzed to look for further enhancements. The Satellite operator would need to determine which network slices are allowed to be used by inbound roamers from the mobile operator and, if needed, will configure its network to support mapping of S-NSSAI according to the general system architecture specifications. In the specific case of national roaming, the 3GPP management system needs to enable the consumer to provide S-NSSAI(s) information to map to the Satellite provider S-NSSAI(s) to the MNO S-NSSAI(s), and having as pre-condition that a roaming agreement exists.

Another relevant study was triggered in R17, with work still ongoing as part of R18 focused on capability exposure [15]. Here, different scenarios to analyze slicing management gaps in capability exposure for NSaaS (also applicable to the case 3a). Within them, the simpler scenario fits the potential integration set in this case:

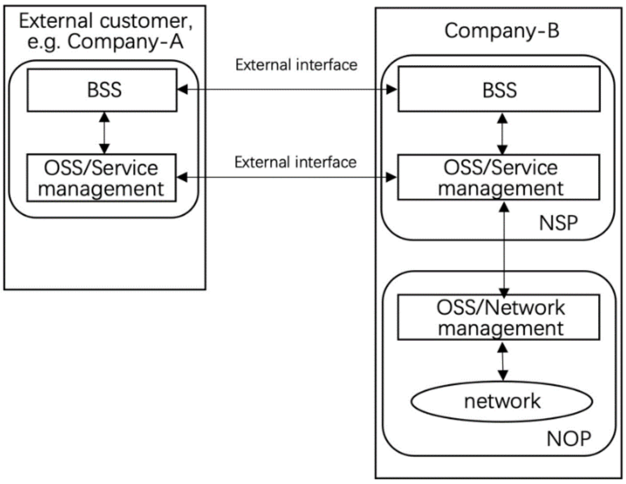

Figure 67. Network slicing capability exposure, satellite operator as NOP/NSP, MNO as customer ([15] - R17)

The target is having interfaces available during the whole lifecycle of network slice, including ordering, provisioning, operation phases and, in this case an (East-West) interface between OSS/BSS layers is considered, spanning -for provisioning- the creation, retrieval of information, update or deletion of a network slice service order. Reference to candidate potential APIs as TMF622 are given, being outside scope of 3GPP definitions.

The study provides insight on some of the identified issues which required enhancements and new definitions as, for example, the different types of slice customers (this type of scenarios is also of applicability in non-public networks for enterprise verticals) or the different type of capabilities, which are many at different layers (application – management – network), while having a single common exposure layer is desired (to simplify aspects as system integrations, etc.). Also, the service interactions via the inter-system(s) interfacing, or the level in which the interfaces can be available (OSS aside only BSS requires identifying and addressing the service producers by the slice provider at the consumer side).

R18 work focuses on specific proposals to address issues and gaps, proposing actions for further normative work, which is ongoing. A final reference architecture for network slice ordering, provisioning, and assurance (covering different cases involving more roles to provide flexibility -customer, provider, partner- is defined as part of the R18 updates.

Inter-organization interfaces, relevant to the present case as inter-BSS/OSS system interfaces would be ITF1 (candidate TM622, focused on the creation, modification, update, or deletion of slice service orders) and ITF-2 at OSS or service orchestration layer (candidates for implementation including specifications within TS 28.531, TS 28.532, TS 28.545, TS 28.550 and opening larger capabilities including management of NRM objects as the NetworkSlice, and having the EGMF with enhanced definitions governing the exposure process. This architecture, shown in Figure 68 is the one that has been recommended for the specifications normative phase for network slice ordering, provisioning, and assurance. It is left open to complement the referenced candidate interfaces by 3GPP to be extended by other organizations or open-source projects, etc.

Other relevant conclusions and recommendations, impacting subsequent work are the solutions to expose Management service support for discovery systems and filtering, to provide access control to service consumers to specific services, all this supporting the consumption via OSS layer, as well as the definition of alternative solutions for slicing capability exposure via CAPIF.

As a final note in relation to exposure, being this a field that impacts the case under consideration and that needs to develop, it must be noted that further capability exposure is also being addressed in an ecosystem that goes beyond 3GPP, with TM Forum and GSMA (Open Gateway initiative) also carrying out relevant initiatives in relation to exposure. It is seen as a need in the industry, and within 3GPP, that alignment is needed to avoid creating a fragmented ecosystem, and interwork between organizations is considered to drive the industry forward in this respect.

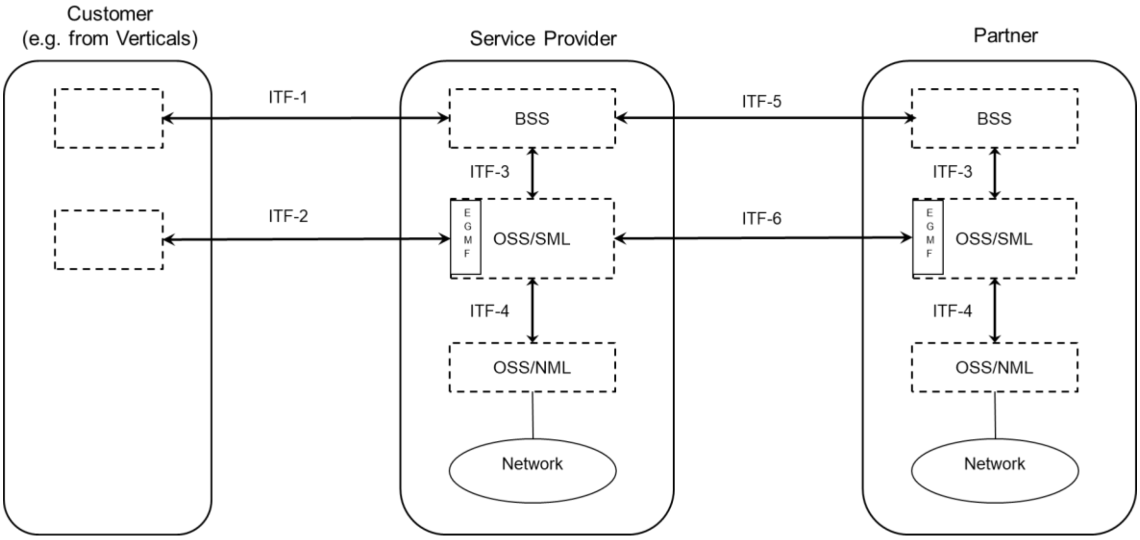

Figure 68. 3GPP reference architecture for network slice ordering, provisioning, and assurance [15]-R18

Finally, another developing topic related to slicing management which might become relevant for access scenarios is that of intents. Intent driven management was specified in TS 28.312 introduced in R17. Intents specify in an abstract way expectations including requirements, goals and constraints for a specific service or network management workflow and can be applicable not only to slices as network internals, but also to slicing as a service, on top or shaping the previously presented work. A specific new study part of R18 work has been conducted in 3GPP TR 28.836 [53], with ongoing analysis of reference cases, requirements and potential solutions to drive further specification work.

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