

NTN+B5G integration architectures – second release

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Abbreviations

3GPP	3rd Generation Partnership Project	NBI	Northbound Interface
5G	5th generation mobile access (3GPP specifications)	NB-IoT	Narrowband IoT (Internet of Things)
5QI	5G Quality of Service Identifier	NETCONF	Network Configuration Protocol
6G	6th generation mobile access (3GPP specifications)	NF	Network Function
AC	Attachment Circuit	NGSO	Non-Geostationary Orbit
ACaaS	Attachment Circuit as a Service	NMS	Network Management System
ACM	Adaptive Coding and Modulation	NR	New Radio
AI/ML	Artificial Intelligence / Machine Learning	NRM	Network Resource Model
API	Application Programming Interface	NSaaS	Network Slice as a Service
AWS	Amazon Web Services	NSC	Network Slice Controller
B2B	Business to Business	NSMF	Network Slice Management Function
B2C	Business to Consumer	NSSaaS	Network Slice Subnet as a Service
BGP	Border Gateway Protocol	NTN	Non-Terrestrial Networks
BH	Backhaul	OAM	Operation and Management
BSS	Business Support Systems	ODL	OpenDaylight
BW	Bandwidth	O-RAN	Open Radio Access Network
CAPIF	Common API Framework	OS	Operating System
CD-SSB	Cell-Defining Synchronization Signal Block	OSS	Operation Support Systems
CE	Customer Edge	OTN	Optical Transport Network
CIR	Committed Information Rate	PCE	Path Computation Element
CN	Core Network	PE	Provider Edge
C-NSSMF	Core Network Slice Subnet Management Function	PIR	Peak Information Rate
CPE	Customer Premises Equipment	PLMN	Public Land Mobile Network
CSMF	Communication Service Management Function	PM	Performance Management
CU	Central Unit	PoC	Proof of Concept

D2D	Direct-to-Device	PoP	Point of presence
DSCP	Differentiated Services Code Point	QCI	Quality of Service Class Identifier
DTC	Direct to Cell	QoE	Quality of Experience
DU	Digital Unit	QoS	Quality of Service
DVB-S2	Digital Video Broadcasting - Satellite - Second Generation	R17/18/19/20	Release 17/18/19/20 (3GPP technical specifications)
DVB-S2X	Digital Video Broadcasting - Satellite - Second Generation Extension	RAN	Radio Access Network
E2E	End-to-End	rAPP	Non-real-time application, O-RAN RIC
EGMF	Exposure Governance Management Function	RESTCONF	RESTful Configuration Protocol
EHPMLMN	Equivalent Home Public Land Mobile Network	RF	Radio Frequency
EIR	Excess Information Rate	RFC	Request for Comments
EMF	Exposure Management Function	RIC	Radio Access Network Intelligent Controller
eNB	evolved Node B (4G LTE terminology)	RU	Radio Unit
EPC	Evolved Packet Core	SA	Standalone
EU	European union	SAP	Service Access Point
FDD	Frequency Division Duplex	SBA	Service-Based Architecture
FEC	Forward Error Correction	SBI	Southbound Interface
FM	Fault Management	SCPC	Single Channel Per Carrier
FR1	Frequency Range 1	SDO	Standard Definition Organization
FWA	Fixed Wireless Access	SDP	Slice (or Service) Demarcation Point
GEO	Geostationary Orbit	SD-WAN	Software-Defined Wide Area Networking
gNB	Next generation Node B (3GPP 5G terminology)	SIB19	System Information Block 19
GNSS	Global Navigation Satellite System	SID	Segment Identifier
gRPC	gRPC Remote Procedure Calls	SINR	Signal-to-Interference-plus-Noise Ratio
GSMA	GSM Association	SLA	Service Level Agreement
GST	Generic Slice Template	SLE	Service Level Expectation

GST/NEST	Generic Slice Template / Network Slice Type.	SLO	Service Level Objective
GTP	Generic Tunneling Protocol	SMO	Service Management and Orchestration
HAPS	High Altitude Platforms	SMOF	Service Management and Orchestration Function
HARQ	Hybrid Automatic Repeat Request	SMOS	Service Management and Orchestration Service
HE	Horizon Europe	SMS	Short Messaging Service
HPLMN	Home Public Land Mobile Network	SNMP	Simple Network Management Protocol
HTS	High Throughput Satellite	SNO	Satellite Network Operator
HW	Hardware	SNS	Smart Networks and Services
IAB	Integrated Access and Backhaul	S-NSSAI	Single Network Slice Selection Assistance Information
IETF	Internet Engineering Task Force	SRv6	Segment Routing v6
IF	Intermediate Frequency	SS-SINR	Secondary Synchronization Signal - Signal-to-Interference-plus-Noise Ratio
IGP	Interior Gateway Protocol	SW	Software
IMS	IP Multimedia Subsystem	TA	Timing Advance
IoT	Internet of Things	T-API	Transport API (ONF, now Linux Foundation)
IP	Internet protocol	TDM/MF-TDMA	Time Division Multiplexing / Multi-Frequency Time Division Multiple Access
ISL	Inter-Satellite Link	TMF	TM Forum
KPI	Key Performance Indicator	TN	Terrestrial Network
L/S	L and S frequency bands - Mobile Satellite Service	TR	Technical Report
L2/L3	Layer 2 / Layer 3	TrN	Transport Network
LEO	Low Earth Orbit	UE	User Equipment
LOS	Line of Sight	UE	User Equipment

LSO	Lifecycle Service Orchestration	UL	Uplink
MBSR	Mobile Base Station Relay	UPF	User Plane Function
MDM	Mobile Device Management	VHTS	Very High Throughput Satellite
MEF	Metro Ethernet Forum	VLAN	Virtual Local Area Network
MEO	Medium Earth Orbit	VPN	Virtual Private Network
MHz	MegaHertz	VSAT	Very Small Aperture Terminal
MNO	Mobile Network Operator	WG	Working group
MPLS	Multi-Protocol Label Swapping	WRED	Weighted Random Early Detection
MSS	Mobile Satellite Services	xAPP	Near-real-time application, O-RAN RIC
MW	Microwave	YANG	Yet Another Generation (modelling language)
MWAB	Moving Wireless Access Base Station		

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1. Introduction

This document constitutes the second deliverable **6G-INTEGRATION-02-E6** of the 6G-INTEGRATION-2 project, building on top of the work consolidated in the previous **6G-INTEGRATION-02-E5**, which covered generally:

- General mobile network technical and architectural definitions about network slicing, and foreseen evolutionary roadmap in the different mobile network domains that form the overall service E2E.
- Relevant standardization work and specifications about network slicing, with a focus on 3GPP and O-RAN for the radio access network (RAN), core network (CN) and E2E management and orchestration, IETF for the specific considerations related to the transport network domain (TrN), and other relevant organizations as GSMA related to the slicing ecosystem definitions (for example including key slicing topics as service template, device rules or roaming implementation).
- NTN use cases, typical architectures and system capabilities considering satellite solutions already commercialized or developing in the market, and the foreseen evolution of 3GPP standardization, which is shaping the new wave of future 5G NTN systems.
- Relevant functionalities needed in satellite systems to provide incremental flexibility and resources for slicing support, as well as primary needs in terms of integration into E2E service orchestration and management architectures as those set as a reference in terrestrial networks to implement slicing.
- A first definition of a set of relevant integration architectures and their main characteristics, including key necessary interfaces, identified gaps and foreseen evolution.

One of the key challenges in the architectural definitions of the project relates to the numerous NTN systems and their corresponding system architectures, with existing differentiation evident in relation to the type of application (e.g., transport vs. direct to device), service (e.g., IoT vs. mobile broadband in D2D systems), radio access network function deployment architecture (e.g., fully integrated gNBs vs. RAN splits), or standard support (e.g., DVB-S2X transport vs. 5G NR over VSAT). This also leads to side effects on standardization fragmentation and the overall pace of evolution and roadmap of the solutions.

This broadens the space of solutions too much in practice, making their analysis difficult, especially when moving to higher-detail solution proposals and related concept validations. So, in practice, only a subset (those with higher maturity and availability of components to integrate PoCs) will be subject to a lower-level specification.

This document then aims to extend the previous work, focusing principally on:

- Summarising the relevant progress and gaps in the standardization groups already within scope, especially in areas which can impact or require refinement or variation of the already proposed high-level integration architectures. This will be mainly covered in section 2.
- Reviewing the currently deployed and developing NTN systems (and their system architectures) to establish a prioritization for the definition of solutions at a lower level linked to the view on standardization evolutionary roadmaps. This will be consolidated in section 3.

- Updating and refining the general integration architectures reflected in the first deliverable and providing a more detailed solution specification for the prioritised cases, focused on the use of NTN solutions as transport in 5G environments. These will also serve as the basis for concept demonstrations in the last stage of the project. Section 4 will address all these.

The content in this deliverable includes this way, according to plan, results coming from the work carried out in the next tasks of the project:

- 6G-INTEGRATION-02-A3
- 6G-INTEGRATION-02-A4.

2. Standardization progress

This section aims to provide a general overview of the progress of key SDOs, already identified and used as a reference in the project's first period. It focuses specifically on covering those aspects that are more relevant, considering the identified architectures and their potential evolution in time linked to standardization progress. The final section will also include additional considerations related to the status of slicing implementation in terrestrial networks, which serve as the reference for the future integration of NTN.

2.1 3GPP NTN standardization evolution

The first deliverable release on integration architectures **6G-INTEGRATION-02-E5** already included a first review of the main adaptations required in the 3GPP standards to support NTNs, which constituted the main area of focus in the initial stage of the standardization process, with the results from the main studies already consolidated in R17 and R18 technical specifications. These essentially deal with the specifics of satellite connectivity, such as large or variable latency, high Doppler shifts, large coverage areas, recurrent satellite user and feeder link handovers, etc. New SIB19 and continuous update, configurable timers and TA offsets, adaptations of HARQ (more processes, no wait for feedback or deactivation), doppler estimation and compensation at UE and adjustment of UE time synchronization, SS-SINR in channel state indication and ACM based on SINR are some of the most relevant ones to enable the 5G NTN support. Although in most cases the critical adaptations focus on using the 5G network as access solutions, additional adaptations have also been made to support using satellites as a backhauling solution (e.g., notification of NTN to core NFs to handle latency, etc.).

Besides these, from R17 3GPP has followed a phased approach aiming at developing support for additional functionality through releases gaining in flexibility and suitability for larger sets of NTN use cases, starting from simpler architectures and a reduced set of bands and end devices, to progressively extend to higher frequency bands, multiple types of terminals and developing enhancements to maximize applicability, integration and performance.

2.1.1 R17 and R18 high level summary

As a brief recap from the incremental functionality already developed in R17 & R18:

- **Release 17** constituted the first 3GPP release with support of NTN systems, including work related to both NR (higher capacity use cases) and IoT.
 - Specifications consider operation in MSS L/S bands (FR1 FDD) to handheld devices (so, direct to device as baseline for 3GPP), including GEO and NGSO (LEO, MEO).
 - Devices must support GNSS to work with the NTN solution, which is necessary for the required protocol and procedure adaptations to aspects like latency, Doppler shifts and periodic variations.
 - From all the foreseen satellite network architectures (transparent, with the gNBs or RAN NFs at the gateway side or regenerative, with the RAN NFs distributed in the satellites), R17 only supports transparent payloads.

- While NR NTN is supported with 5G SA core, IoT is defined with EPC and allows for other case-specific functionality, as optimizations and adaptations to support of discontinuous coverage.
- R18 extended the functionality and flexibility of R17 definitions including aspects as:
 - Addition of new channels within MSS L/S band, both for NR and IoT and addition of NTN support in Ka-band for VSAT devices (FR2 FDD), with different device category specifications, including both mechanically and electronically steered antennas to support GEO (fixed or moving VSATs) and NGSO (fixed VSATs).
 - Introduction of UL coverage enhancements, mobility enhancements for signalling, power consumption optimization and network verified UE location
 - Specific enhancements for IoT as HARQ disabling, mobility and discontinuous coverage, IoT over NR with in-band and guard-band, etc.
 - Enhancements to satellite backhaul type notification to CN, including QoS monitoring for dynamic satellite backhaul, and support for UE-UE local switch and edge with satellite UPF in GEO

2.1.2 R19 and R20 work

With R17 and R18 already complete, work in 3GPP is now focused on completing and freezing R19 specifications while kicking off two new parallel work streams as part of R20, with the first focused on new release functionality within 5G-advanced and the second on developing the first studies for longer term 6G 3GPP standard definition, both of them with content related to NTNs.

As for the R19 and R20, the next figure shows the current 3GPP standardization timeline.

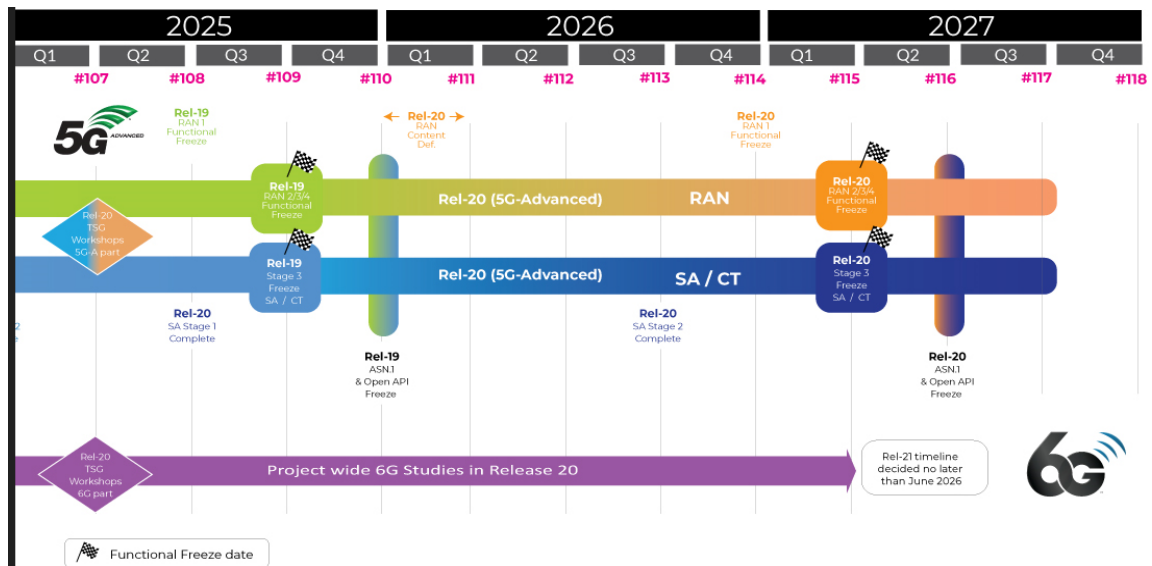


Figure 1: 3GPP R19 (end) and R20 (new) standardization timeline

Release 19 brings relevant functionality in relation to NTN, including support of additional bands (additional channels in L/S and support for Ku-band) and, especially, enabling the support of regenerative payloads (gNBs or split RAN NFs deployed on the

satellites), bringing higher flexibility to develop NTN use cases. As a brief summary of the main topics under consolidation in the final R19 specifications:

- Support of NTN architecture with regenerative payloads, hosting 5G system functions (e.g., RAN, UPF) on board the satellite, including the support of inter-satellite links (ISL).
- New MSS L/S channel definitions for NR and IoT and support of Ku-band (FR1/FR2 FDD) in NR, for VSAT devices. Support for fixed and moving VSAT in GEO and NGSO in Ku and Ka bands.
- Store & Forward (S&F) operation based on regenerative payload to support non-complete constellations (e.g. IoT) and support of direct UE-sat-UE communications.
- Downlink Coverage Enhancements at the link and system levels to accommodate power or feeder link limitations in satellites, such as CD-SSB periodicity relaxation and enhanced beam-hopping support.
- Uplink capacity enhancements through multiplexing techniques to optimise UL performance in resource-limited conditions, with prioritization of service types.
- Support of RedCap devices within FR1 NTN.
- Other specific enhancements for NTN IoT, as uplink capacity enhancements, support for half duplex operation in TDD and FDD scenarios, higher transmit power in selected bands and cell broadcast for public warning systems.

As for R20 NTN enhancements, preliminary work has focused on specifying the reference use cases and consolidating the requirements which will serve to define subsequent studies by the relevant working groups and further normative work as part of the release timeline. Although it is early and work has recently started, it is important to identify the key areas targeted for enhancing the NTN definitions, as some of them can potentially impact the long-term architectures under consideration in this project. In this respect, 3GPP TR 22.887 [1] consolidates the work so far, including a large set of use cases, which focus on key areas like:

- Developing support for IMS voice for GEO satellites
- Emergency, disaster recovery and public safety, including resilient notifications, public warning services
- Communications with mobile base station relays for different scenarios
- Multi-connectivity, multi-orbit NTN and joint TN and NTN scenarios

There is a clear focus in R20 towards multi-orbit NTN operations and integration with the TN, becoming a common component in most of the reference cases in this initial stage. This includes cases relevant for slicing implementation, such as considering the intelligent distribution of different types of traffic across different NTNs (e.g., different orbit systems) and in coordination with the TN and also including consideration of multiple tenants or operators (satellite and terrestrial) for the different TN and NTN parts. The latter was a clearly identified aspect (being a relevant source of complexity in terms of system orchestration for complex cases like slicing support) in the previous **6G-INTEGRATION-02-E5** for all scenarios, including those achievable in shorter term via existing satellite systems for transport applications (e.g., backhaul), which receive within the project a larger focus linked to their higher maturity and availability of the solutions.

The initial scenarios for 6G network studies are still under definition, and the target is shaping the definition in the longer term of the 6G system architecture and specifications. Work ongoing is becoming consolidated in 3GPP TR 22.870 [2], which includes a set for ubiquitous connectivity focused on NTNs and TN-NTN cases, including cases focused on service continuity and resiliency, QoE enhancement and disaster recovery, as well as a specific focus on positioning services, both with satellite technology and hybrid TN-NTN approaches. It must be noted that, besides satellites, new use cases focused on HAPS or drones are already starting to be proposed as future enhancements to define requirements for the future 3GPP 6G specification.

Another topic under study in R20 related to NTN is indirect network sharing, generally introduced for terrestrial networks as part of R19, with pending normative work. This will be introduced in section 4.3.2, as it might open some variations around the integration scenarios.

2.1.3 Main impacts on INTEGRATION2 architectures

A high-level summary of the main additions to 3GPP NTN standard releases is shown in the following figure:



Figure 2: Satellite architectures, device types and bands in 3GPP NTN release evolution

2.1.3.1 Use of 5G NTN NR for broadband applications with VSAT devices

A first element relevant to consider with respect to the base architectures is the extension in 3GPP R18 and R19 to Ku and Ka operation (FDD, with FR1 or FR2 for Ku and FR2 for Ka so far) with fixed and moving VSATs (both mechanically or electronically steerable¹). This impacts potential service architectures, opening the potential implementation of a range of applications being served today as transport applications with proprietary devices and specific satellite transmission standards (e.g., DVB-S2X or others adapted) via its integration with 3GPP radio access, using NR and 3GPP compliant standard devices. Figure 3 represents² a simplification showing the two cases.

Beyond technical aspects (slicing implementation based on RAN domain functionality instead of transport functionality) and the potential differentiation between the two options, impacts in this case extend to the service management and orchestration layer, with the service management corresponding to the RAN domain control architecture. This will be presented as part of the architectural variations presented in section 4.

¹ There are 5 device types overall, as reflected in 3GPP TS38.101-05 (R19 work ongoing)

² The figure shows a backhaul case, others as fixed access are also possible with simpler 3GPP VSATs.

Beyond VSATs (where a typical use case would be residential fixed broadband access, connecting to a user CPE like in terrestrial FWA applications), other types of VSAT-based devices might also be considered in the future for the provision of mobile services, integrating satellite transmission and reception capabilities as well as mobile access connectivity to users including mobile operation (e.g., installation on moving elements as cars, boats, etc.) as IAB fixed ground nodes, MBSR repeaters (which rely on IAB functionality) or MWAB nodes, which may extend the potential use cases relevant for this implementation depending on standardization evolution.

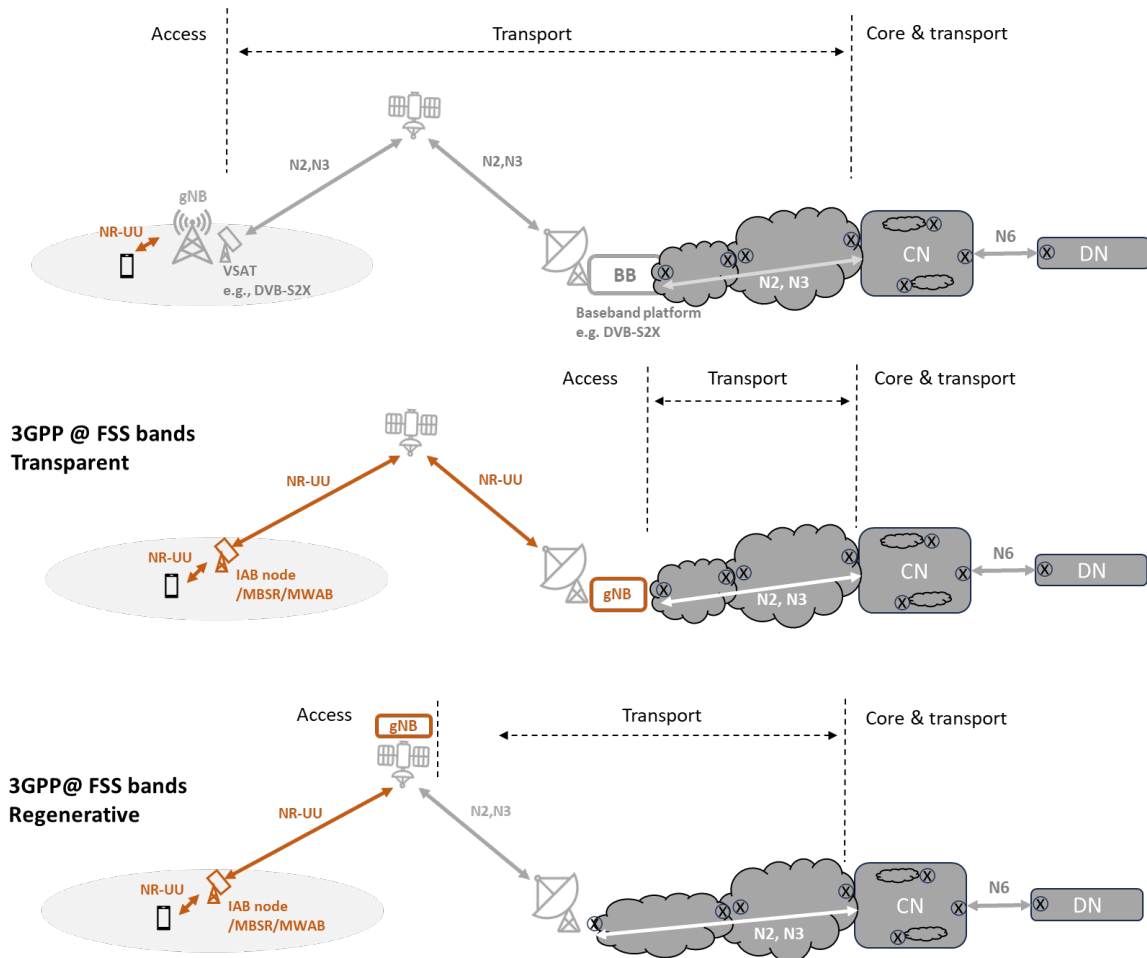


Figure 3: Satellite transport vs. 3GPP NTN broadband applications with VSAT or VSAT-like devices.

In terms of timeline though, it must be noted that it will still take some time for these options to become available. As main impacting factors:

- Limitations in terms of performance in NR based operation with respect to current satellite transport applications. It must be noted that NR physical layer and protocols are optimised for terrestrial network operation and radio environments. In contrast, satellite transmission standards as DVB-S2X or other proprietary ones used by LEO constellation providers have been optimised for typical operational conditions (high packet loss and latency, LOS operation, etc.). Currently, there is much focus in research around this topic, with many initial lab-based and in-orbit experiences to assess performance, comparability and identification of potential enhancements in standards.

- As some examples linked to the previous statement, it seems desirable for satellite operators to work with FR1 specifications in Ka-band (for now, as per R18 it is limited to FR2 NR parameters) which besides technical aspects also impacts the availability of low-priced chipsets (mass market for terrestrial devices lies mainly on mid-band FR1). To enhance performance, considering that FR1 has lower allowed channel bandwidths, carrier aggregation specifications for NTN will also be required.
- Linked to the previous aspect, the unavailability of generally available commercial VSAT devices compliant with 3GPP specifications for NTN with appropriate price points. This, of course, will evolve.
- Besides VSAT devices to connect to user CPEs or remote gNBs, more advanced nodes as IAB, MBSR and MWAB are still not specified within 3GPP to support NTN applicability³ and lack the necessary adaptations, being anyway a typical area of research in EU funded projects.
- In the case of regenerative architectures, which provide higher flexibility for implementation, there are no existing constellations with regenerative satellites compliant to 3GPP R19 NTN specifications. The main constellation targeting this would be as of now the EU-backed project IRIS², planned for operation in 2030. Before regenerative constellations meeting this requirement become available, applicability will be limited to transparent constellations or GEO satellites.

2.1.3.2 Regenerative payloads

The second key element with impact on integration architecture and end to end service orchestration comes linked to the addition of regenerative payloads. Regenerative payloads have already been considered generally in the architectural definitions in the deliverable **6G-INTEGRATION-02-E5**, being already supported in non 5G NTN compliant systems already reaching the market (as SpaceX D2D Starlink constellation). The main additional aspect to be considered here is the impact coming from the potential separation of radio access network functions, considered a general architectural option in 3GPP (and being the conceptual base of other relevant groups such as O-RAN, which will be covered in the next section).

Leveraging inter-satellite links, regenerative architectures open additional possibilities for the placement of different radio access NFs (and also CN NFs as UPF, etc.) in different parts of the satellite segment, including spreading different functions between satellites or satellites and the ground segment gateway(s). The next **Figure 4** shows two potential options, centralising CUs in gateways while distributing the DUs and the radio frequency units (RUs) in the satellites or using also satellites within the constellation to distribute CUs serving each multiple satellites with distributed DU and RUs.

The distribution of RAN network functions can provide different benefits at the radio access layer and flexibility for the constellation design, reducing the amount of functionality required for implementation in the satellites (which are inherently size, power and resource limited to maintain complexity and costs within reasonable limits).

³ As per latest R19 system architecture TS 23.501 [4] (still not available RAN corresponding specifications for R19), it seems that MWAB nodes will be considered for compatibility with NTN NR links on their connection to the BH NG-RAN.

However, there are also impacts to the interfaces and procedures, especially considering the specifics of satellite systems and constellations (constant relative movement in NGSO systems, high latency with respect to terrestrial networks, etc.) as for example the need for DU-CU handovers.

There exists additionally an extra degree of flexibility in terms of RAN NF centralization, which is the separation between the RU and the DU. The interface between RU and DU is outside 3GPP scope and constitutes one of the main areas of focus in O-RAN, which will be covered in the next section. The fronthaul interface between RU and DU poses significant additional challenges for satellite implementation.

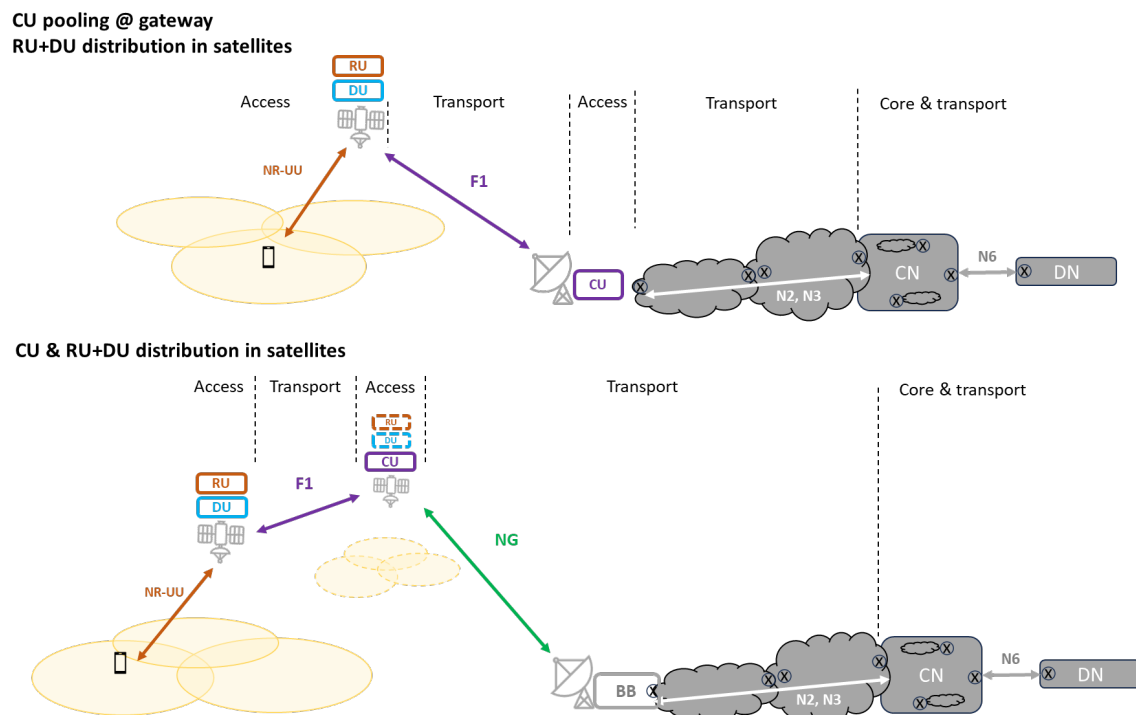


Figure 4: Distribution of RAN network functions leveraging 3GPP NTN R19 regenerative architectures

Besides viability for implementation, challenges and potential performance, it must be noted, as depicted in **Figure 4** that this scenarios also create impact to the E2E service management and orchestration, interleaving interfaces and functions which typically are included in different network domains (which means also that are defined by other standardization groups and managed by different systems within service orchestration architectures). While the CU-DU F1 interface is part of 3GPP specifications (messages, procedures, requirements), the technology implementation (physical and transport layer) is not mandated within 3GPP scope, being a similar case to other interfaces as N3 (user plane backhaul from a gNB or a CU to the corresponding CN UPF), so it is managed within the transport network domain. The same happens with the RU-DU fronthaul interface within O-RAN. This will be reflected in the updated architectures in section 4.

Considering the recent integration of regenerative payloads in the latest R19 developing specifications and the aforementioned impacts, this topic constitutes an open field of research in the satellite industry and can still be seen as developing, which reflects in the work and future PoCs planned within different funded research

projects part of the different EU programmes as Horizon Europe or SNS. This will also be reinforced in the next section covering O-RAN, where this topic has just started to be under consideration in initial studies related to NTNs. So, it becomes a potentially longer-term impactful topic.

2.1.3.3 Future R20 topics

Beyond R19, the uncertainty in terms of specifications and timeline increases, as already presented before. However, the previous aspects will gain additional relevance considering the initial studies in 3GPP, as reflected in the main reference use cases considered so far. MBSR/MWAB applications for emergency and other cases are within this initial set, with also a large focus on multi-orbit scenarios (that in most cases rely on ISLs between satellite systems), leveraging regenerative architectures.

Besides this, a larger relevance opens for multi-tenancy aspects where, besides the differentiation between the MNO and SNO in scenarios considering the integration and coordination between the TN and NTN, cases leveraging connectivity to multiple systems operated by multiple SNOs (e.g., multi-connectivity, load balancing for different traffic types -or network slices-) are also introduced.

Although multi-tenancy was already considered in the LEO backhaul scenarios presented in **6G-INTEGRATION-02-E5**, additional considerations and variations will be introduced in section 4, given that this is a current field of research and focus in 3GPP. On top of aspects as multi-connectivity or seamless continuity between networks, which will require additional considerations on top of those mechanisms already integrated within 3GPP specifications so far, there is also a significant impact into service orchestration, which moving to multi-tenancy (with a larger number of tenant) reinforces the need to define system interconnection architectures leveraging standards.

The next figure shows one of the cases introduced as reference for study in [1] where the terrestrial network and the satellite systems might be owned and operated by different companies, requiring interfacing between their management & orchestration and OSS/BSS platforms in order to achieve operational automation in processes like service (and slice) provisioning, assurance, etc.

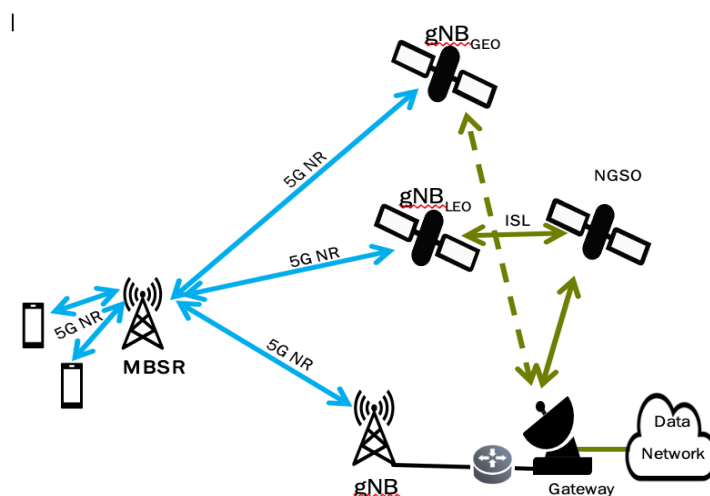


Figure 5: combined terrestrial and MO satellite access for connecting MBSR and 5GC [1]

2.2 O-RAN standardization evolution

As presented in the first project deliverable, O-RAN is a relevant SDO focused on radio access disaggregation and virtualization, looking for SW and HW interoperability between radio access network element and functions (which extends also to service management and orchestration systems), with alignment to 3GPP and other SDOs as IETF for specific transport network aspects outside 3GPP scope.

During the past months, besides progressing into the different working group specifications, with new study items related to the transport network which have relevance for the work within scope in INTEGRATION-2, O-RAN has also recently started two study items targeting the integration of NTN into the O-RAN ecosystem. This section will present the main advances related to the architectural specifications in INTEGRATION-2 and the new NTN work, to be considered in the proposed architectures and solutions updates, part of the following sections.

2.2.1 Progress on architecture, slicing and service orchestration

The general O-RAN architecture principles, blocks and interfaces remain mostly unchanged, as represented in **Figure 6** and **Figure 7** [3].

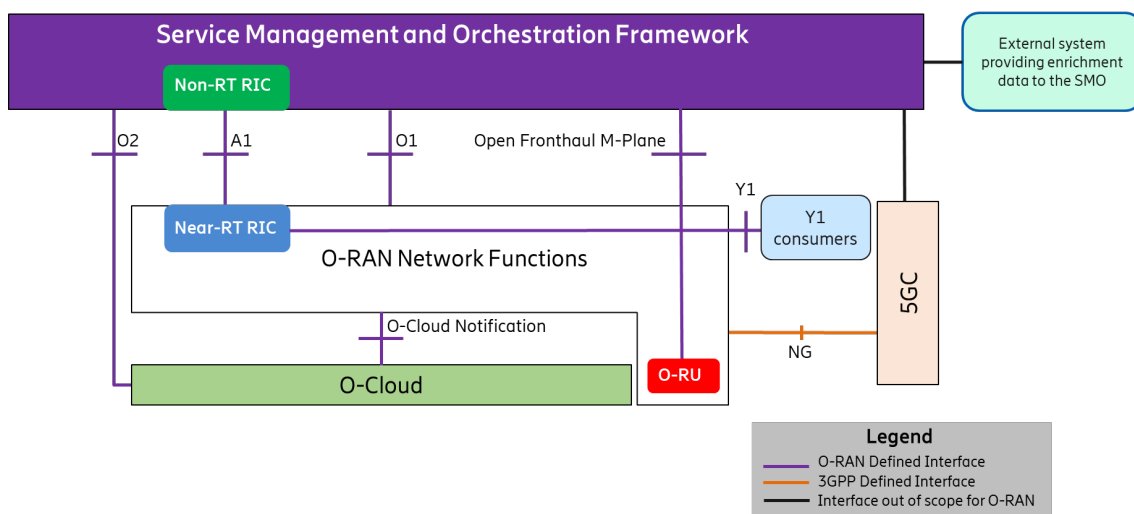


Figure 6: O-RAN high-level architecture [3]

support for NTN use cases is included within O-RAN, a case adopted by SNOs working with O-RAN network elements in the access side.

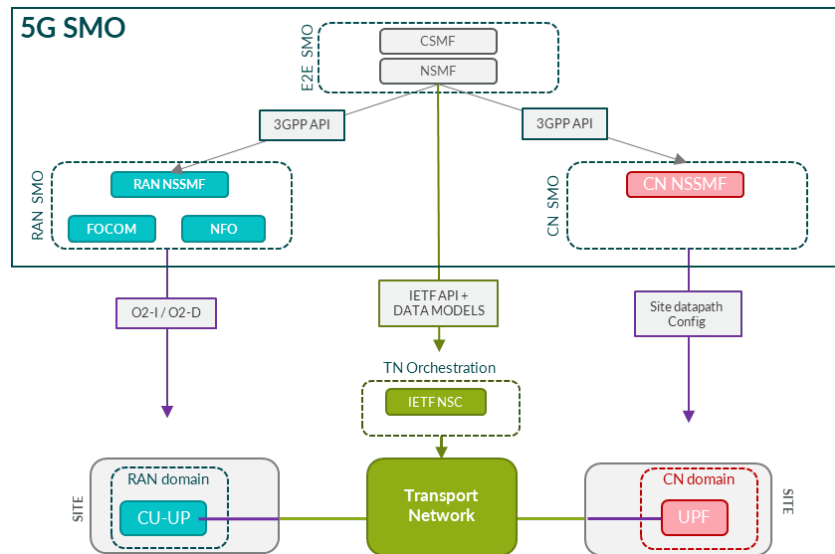


Figure 8: Potential extension for RAN SMO in O-RAN architecture [4].

However, it must be noted that, as already reflected in the base proposed architectures in the previous **6G-INTEGRATION-02-E5**, the transport network domain in large scale networks (there is recent work in O-RAN as well related to the inclusion of the transport network in the SMO scope, as introduced in section 2.2.1.1) is left to be handled by external transport service orchestration systems through proper standardized interfacing, adopting IETF principles concerning transport slicing.

The SMO in O-RAN follows an SBA with service producers, consumers and standardized service-based interfaces like 3GPP in the 5G system architecture. Within the SMO, O-RAN defines SMO services (SMOS) as a standardized cohesive set of management, orchestration and automation capabilities offered by an SMO Function (SMOF). In terms of implementation, a given SMOF can produce and/or consume any combination of one or more SMOSs, provided that the SMOF complies with the O-RAN specifications of the interfaces exposing the SMOSs. There is a specific line of work in O-RAN related to SMOF decoupling [5], to allow for the implementation of different functions within the SMO scope by different vendors, support differentiation of development lifecycles or to allow for combination and integration with operator legacy systems already covering part of the SMO functions, etc.

The following figure shows relevant SMOs represented in the SBA architecture. Within the SMO scope, it must be noted that besides those explicitly referencing network slicing, such as the service and slice subnet orchestration and assurance SMOs, many others are relevant to support slicing cases, such as the RAN OAM, the topology and inventory, the RIC and its rAPPs, the AI/ML workflow, and those related to the exposure to external consumers (for the integration with higher-layer consumers).

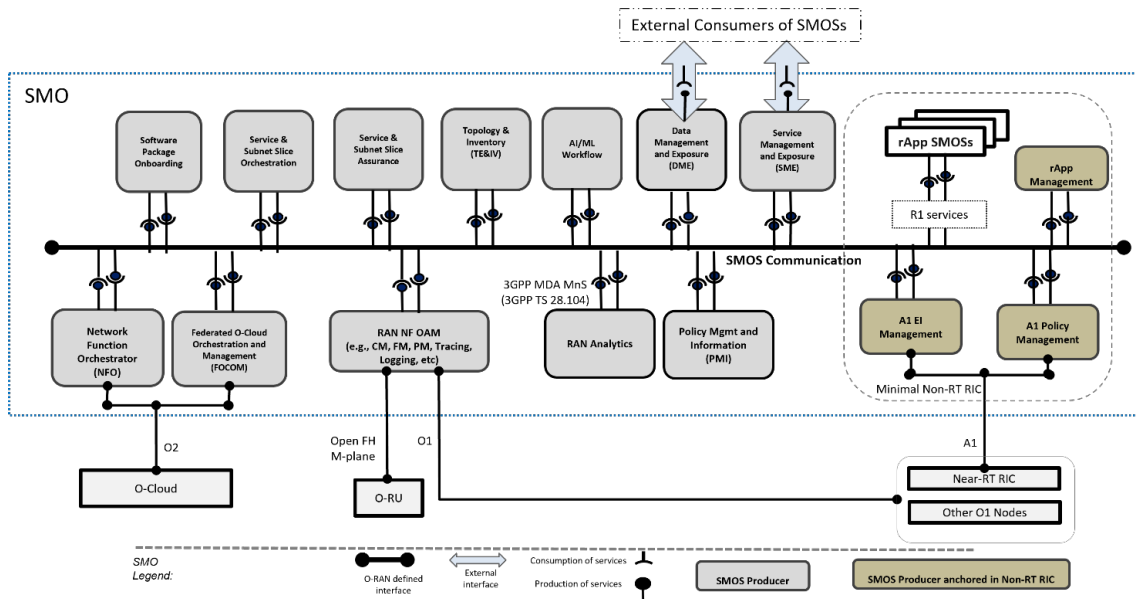


Figure 9: Relevant SMOs and SBA representation. Source [5]

The SMO architecture and the potential decoupling of SMOFs provide additional flexibility for the SMO implementation. Together with the inherent RAN network function separation in O-RAN, the decoupling and the differentiation between RAN orchestration controllers (RICs) and their control loops (real-time and non-real-time) open a wide range of implementation options. In case of applicability to NTNs, placement of SMOFs (and RICs) adapting to the architecture of the satellite system constitutes another open field of study.

2.2.1.1 SMO transport network inclusion

As already introduced, the separation between RAN network functions requires the definition of new interfaces between them.

- F1 interface (also defined in 3GPP) between O-CU and O-DU (also referred to as Midhaul)
- Open fronthaul interface between O-DU and O-RU, defined with the 7.2x low-level layer split (also referred to as Fronthaul)

Implementing these interfaces is typically achieved with transport technologies, lying within the scope of the mobile network transport domain.

The next figure shows the typical multi-domain hierarchical E2E service orchestration architectures for a large mobile network (which was already set as a reference for service management and orchestration architecture in the terrestrial networks in **6G-INTEGRATION-02-E5**) in an O-RAN access environment, with separation of the access NFs. It must be noted that, although it is not depicted in the figure, the same happens within the CN domain, where there can be transport connectivity between physically separated core network functions (and to the data networks interfaced by the core functions).

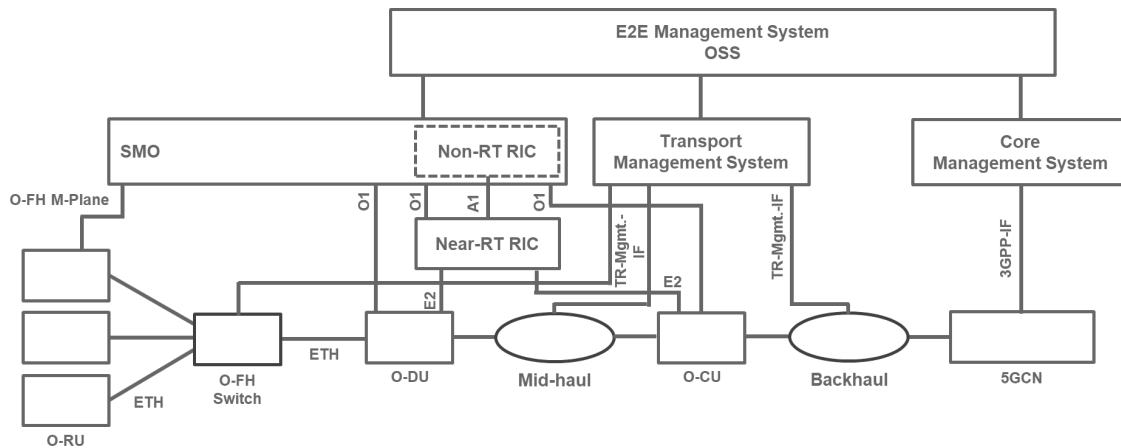


Figure 10: Hierarchical multi-domain service orchestration in MNO large O-RAN network deployment [4].

New use cases in mobile network deployment, including network slicing, have led to the identification within O-RAN work about the need for tighter integration between the RAN and Transport domains, through sharing of information (inventory, PM, etc.) and coordinating operations & orchestration. Functionality gaps have been identified in cases like slicing, NTN, energy saving or network resource optimization, showing the challenges and lack of maturity of the extended SMO for the overall E2E service orchestration.

As a result, a new study item has been created for the analysis of this topic, which will span to mid-2025, and might lead to the creation of additional work items between the relevant groups in O-RAN to derive normative work. The main objectives in the current phase focus on:

- Research on Transport Network Management systems and the best ways for integration with the O-RAN architecture.
- Identification of gaps within already available specifications and necessary new requirements.

Two main options for the inclusion have been identified within O-RAN:

- First, a direct integration of transport within the SMO, which might benefit smaller-scale network deployments like private networks, reducing the number of orchestration systems and flattening the overall architecture. Here, the modification of existing components within the SMO and the creation of rApps within the non-real-time RIC is considered, relying on the uniform network modelling concept already described in the previous deliverable
- Second, even in large-scale deployment cases that maintain a separate transport service orchestrator external to the MNO, direct interfacing between them using standards is seen as a benefit for multiple use cases. In relation to transport, the main reference for O-RAN is the IETF.

It must be noted that direct interfacing between RAN and TrN orchestrators is more straightforward when both elements lie within a single operator scope. Interfacing between orchestrators becomes more complex (even if the technical benefits still hold) when the elements correspond to different operators, which might be the case in some of the already identified TN-NTN integration scenarios. Higher-layer interfaces (E2E or OSS/BSS level) are typically required for multiple reasons, such as security, billing, etc.

2.2.2 New NTN studies

During the second half of 2024 O-RAN kicked off specific work related to NTNs. The two initial study items are currently open, the first (extending in principle up to mid-2025) focused on the RIC as enabler for NTNs and restricted in to 3GPP R17 and R18 transparent satellite architectures and a subsequent one (proposed in the beginning of 2025 and extending to early 2026) to open consideration and analysis for the support of NTN regenerative architectures including 3GPP R19 and beyond.

Considerations extend to how the TN and NTN segments will intelligently coexist (integration between TN and NTN) and the specifics of intra-NTN domain optimization, considering O-RAN adoption (where the RIC controllers typically play a main role). In this respect, the ways of enhancing (or adding new) O-RAN interfaces and components to support NTNs and connecting RIC control elements from both MNO and SNOs are within the scope of the analysis. The study items' targets are identifying architectural aspects and feasibility, state of the art in industry, gaps in specifications and deriving requirements for further phases, which would address enhancements in architectures, interfaces, new capabilities and optimization use cases and will lead to new specification work.

The running studies focus on using NTNs as a mobile access solution. However, there is already an identified need to extend NTN work to WG9 (the one specific for transport technology and management within O-RAN), not just to deal with the need for making definitions for fronthaul and midhaul interfaces in NTN scenarios having RAN NF disaggregation, but also to cover the case of using NTNs as a backhauling solution, which is a case already having focus on INTEGRATION-2. The scope of potential new activity might extend from specific requirements for NTN-based transport to security framework definition, including architectural work (redundancy and resiliency, multi-tenancy in NTN and TN-NTN scenarios, E2E service integration, already part of this project's scope).

As relevant impacts already identified in the initial stage of these studies (especially related to the most advanced one, focused on transparent NTNs and RIC-based integration and optimization):

- The inherent NTN latency and its variation, depending on the NTN solution and the distribution of control functions can impact the O-RAN control loops (fast in the case of near-real-time RIC and slower in the case of non-real time RIC within the SMO) and can motivate specific considerations for the deployment of the real-time RIC controller, as an example.
- Non-standard implementation so far of several interfaces in the NTNs as for example, the feeder links (as already introduced in the previous section for 3GPP) or the management functions for the non-RAN NTN specific elements (which was something already identified in the **6G-INTEGRATION-02-E5** deliverable for the access cases).
- New interfaces are required to integrate satellite-specific information for the NTN RIC operation and allow for tighter interaction between the MNO and SNO orchestration systems (e.g., SMOs) if the focus is on the RAN.

In terms of high-level architecture and modifications, it is still too soon to make precise definitions or to anticipate final scenarios. For now, as some potential adaptations:

- Interfacing between the SNO and MNO SMO systems and controllers is seen as a need to achieve tighter integration in TN+NTN scenarios. The specific components and level at which the interfaces are feasible are to be explored, although it is typically simpler to conceive this type of connection at the highest hierarchical levels (in this case, at the SNO, via east-west direct interface between SNOs or through NBIs to higher-level systems).
- Inclusion of specific NTN OAM functions or rApps within the SMO to support NTN use cases and parallel enhancements to interfaces like O1, A1 and E2, depending on decisions on the near-real-time RIC.

Others might arise from the work already ongoing, which is also based on different driving use cases, including, for example, resource, quality or mobility optimizations in the SNO relying on NTN xAPPs, which might take advantage of the predictability of orbits to support these types of procedures, even in multi-orbit NTN solutions.

2.2.3 Transport network slicing

Besides the general relevance of the transport network domain as part of the full mobile service E2E in cases like network slicing (e.g., as backhaul between RAN and CN), in O-RAN, the disaggregation of access network functions provides additional relevance to transport technologies due their interleaving between the RAN NFs supporting midhaul and fronthaul links. Network slicing constitutes a base use case in O-RAN, with WG1 specifications reflected in [6] and then spread between the rest of the working groups to ensure support in the full O-RAN architecture, which includes WG9, which deals with the specifics of the transport technologies. A general description was already made in the first released project deliverable, which will be complemented here by some updates, essentially within the scope of the WG9 specifications [4] and [7]. The main relevance of this topic comes from the focus given in the project to the cases considering the use of NTNs as 5G backhaul, due to the larger maturity and availability of solutions, while still limited by the existence of relevant gaps to support E2E slicing.

Within [7], WG9 focuses on the architecture of transport networks and the technologies serving as the base for O-RAN implementation. Here, while O-RAN does not yet include any specific consideration about NTN technologies, it provides content that serves as a reference for network slicing implementation in terrestrial transport networks. All the identified cases for integration between TN and NTNs (even if one would consider the case of a standalone NTN for access cases entirely operated by an SNO) include a terrestrial transport network, where all the content related to the transport network is then directly applicable. Besides, many of the concepts are also applicable as a baseline to the satellite transport part (but in this case, the applicability of the concepts is directly related to the type of architecture and, in many cases, will require adaptations or will be subject to specific requirements or restrictions linked to it).

The following figure shows two examples of the already studied TN-NTN integration architectures, showing the sections for generic IP/MPLS and satellite transport and the tenancy (MNO / SNO) across the E2E service domain.

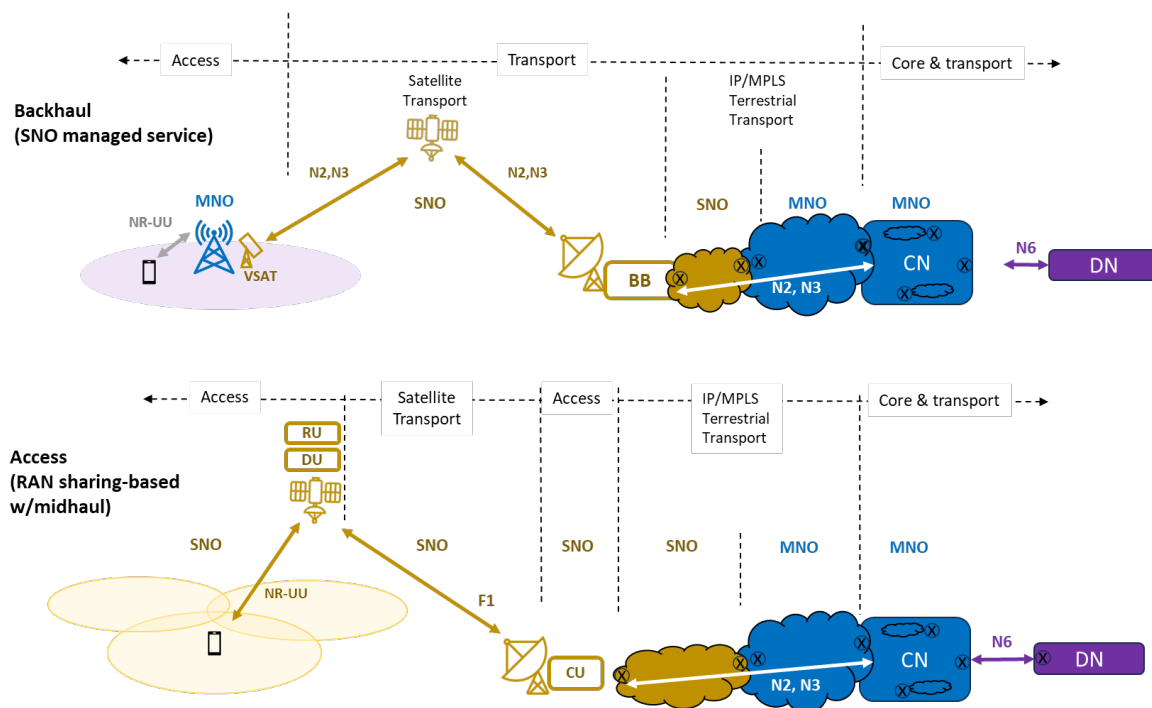


Figure 11: Examples of integration architectures showing satellite and general IP/MPLS transport sections.

A packet-switched infrastructure, as defined in O-RAN, relies on underlay forwarding solutions, Quality of Service (QoS) and services as VPNs to allow a mobile network operator to partition the transport network to support hard and soft slicing. Many of these aspects apply to NTN, with the necessary additional considerations linked to the specifics of the NTN wireless transmission and the specific capabilities and resources (beams, bandwidth, power, etc.) in satellite systems.

Transport slicing in O-RAN is addressed in several phases through use cases with growing complexity (and considering in parallel the progressive development in terms of capabilities of O-RAN nodes and the underlying packet-switched network, which allows for their implementation). The base scenario considers that only the backhaul segment is slicing aware (meaning that even RU/DU/CU are disaggregated, the fronthaul and midhaul part constitute a common network resource where slice differentiation is not possible) to then grow in complexity adding slicing support in midhaul in phase 2 and 3 and adding extra complexity in longer term cases as network sharing in phase 4 and slicing aware fronthauling in the latest phase 5.

A key aspect applicable to all the phases, which will be taken as a reference in INTEGRATION-2, is that the delineation of RAN and CN user plane interfaces will be based on physical interface or VLAN+IP separation (which applies to all phases for transport network slicing within O-RAN), with DSCP marking linked to 5QI also potentially available for the backhaul and midhaul segments⁴. This requires specific procedures for transport network element provisioning in line with RAN/CN elements.

⁴ This assumes that RAN and CN NFs as UPF have the possibility to reflect a DSCP value in the GTP IP headers, mapping 5QI/QCI values to DSCP which can be processed by the

Different options are considered possible for implementing network slicing (soft and hard) in a packet-switched transport network, depending on the transport element capabilities and the operator's preferences. For example,

- Single transport plane for soft slicing, exploiting QoS capabilities in transport elements to support slice SLAs
- Differentiated transport planes, per type of service, per slice customer or per 5QI group (if DSCP marking is available) using VPN services and traffic steering (through different protocols in the transport network depending on the network capabilities). Here, L2 and L3VPN services (relying on standard transport protocols as BGP, SRv6, etc.) are the common option for the segregation of planes.

All of them rely on the exploitation of QoS mechanisms available in transport network devices (which are also common in satellite network devices, so will be part of the “toolset” considered for the INTEGRATION-2 architectures and potential implementations).

The general approach proposed in O-RAN is to exploit common traffic classification and marking and congestion avoidance mechanisms available in transport network elements (e.g., ingress policing, egress scheduling and shaping, WRED, etc.) linked to VLAN and DSCP, and differentiating edge nodes (facing RAN and CN NFs), where fine-grained QoS management is to be applied and core nodes where more coarse-grained QoS and per-hop behaviour settings (reduced number of queues, higher interface capacity aggregating traffic from many edge nodes, etc.). The use of dedicated queues or links (hard slicing) is also within consideration in combination with this.

Considerations related to transport management (through standard-based solutions and interfaces) in O-RAN [4], which reviews specific standard interfaces for user and control plane management for different technologies in the transport networks, with a particular focus on the slicing case. No specific work related to satellite technologies is included in the specification, reflecting one relevant observation already done in the first released INTEGRATION-2 deliverable is the absence of common / harmonised YANG models for satellite devices in the ground network or for the satellite themselves as part of an NTN network used as transport. Potential progress in the NTN work initiated recently in O-RAN, as introduced in section 2.2.2 might lead to future inclusion as part of WG9 work.

The content related to microwave and IP/Ethernet technologies can serve in any case as reference for satellite networks, which have somehow capabilities related to both, as radio resource related configuration, PM, FM in microwave devices (bandwidth, power, modulation control, etc...) or QoS/networking configuration, etc. in both (there is indeed an overlap as microwave devices can be used as L2 (typically) or L3 devices with similar capabilities (although more constrained or less scalable) that general IP devices as routers. Separate YANG models exist for NETCONF-based management for both microwave and IP devices, with some commonalities for the capabilities related to

transport network elements (which is assumed from phase 1 for backhaul and phase 2 for midhaul)

networking. To consider as a reference for satellite networks (which would require new specific models), it must be noted that there might be a dependency on the NTN network architecture and use. For example, GEO point to point backhaul applications might be a simpler case where microwave models can serve as a first reference for ground devices (with adaptations), while in LEO regenerative solutions for transport applications, ground and satellite nodes might at some point be seen as closer to IP routing devices (but still including specifics linked to the wireless transmission).

In relation to the specific case of managing network slices (for example, provisioning), O-RAN scope so far integrates 3GPP and IETF content already part of the terrestrial network orchestration framework, which were set as a relevant part of the initial architecture proposed in the previous **6G-INTEGRATION-02-E5** deliverable. There have not been impacting changes from what was already presented there, which essentially considered relying on 3GPP NRM object specifications in 3GPP TS 28.541 in R15/R16/R17 versions as *EP_RP* (*EP_NgU*, *EP_NgC*, *EP_F1U*, *EP_F1C* linked to the RAN and CN network functions) and their related *EP_TRANSPORT* objects to link to the connected transport network to make the inter-domain stitching in the overall E2E.

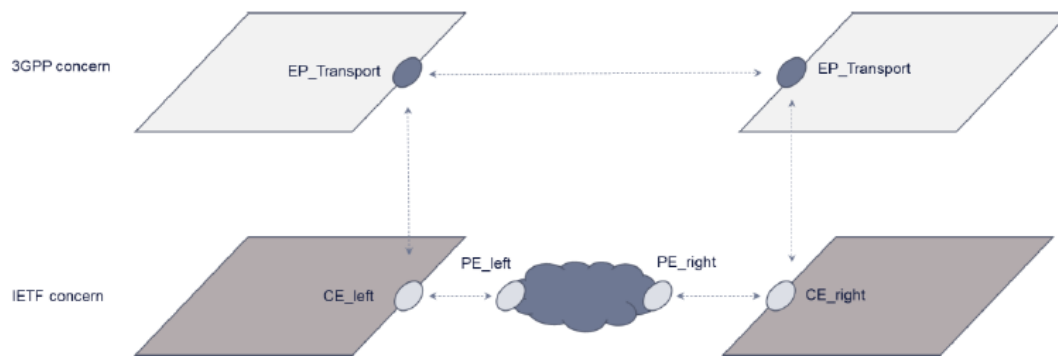


Figure 12: inter-domain stitching between RAN/CN objects (3GPP) and transport domain (IETF) for implementation of transport network slicing supporting the full E2E

The procedure follows the specifications established by the IETF based on slice demarcation points in the CEs (RAN/CN elements), PEs (transport network elements), and attachment circuits between them. It relies on two main models to support network slices in the transport segments defined in [8], [9].

Since the provisioning of endpoints is achieved with different orchestrators (e.g. RAN orchestrator and transport orchestrator), there is a need to synchronise on the data path network resources to provision network devices. Up to 3GPP R17, O-RAN (linked to IETF work) considered the *nexthopinfolist* field within the *EP_TRANSPORT* object to propagate all network data path resources for the configuration of the Transport Network. However, analysis from O-RAN (linked to IETF parallel analysis as well) showed gaps, and requests to 3GPP were made to achieve lower ambiguity (using *nexthopinfolist* as a string field creates practical problems for the inter-domain connection). As a result, 3GPP NRM R18 [10] introduces changes in *EP_TRANSPORT* to address this, linked to parallel requests and gap analysis from IETF transport slicing work, as will be reflected in the next section.

2.2.4 Main impacts on INTEGRATION2 architecture

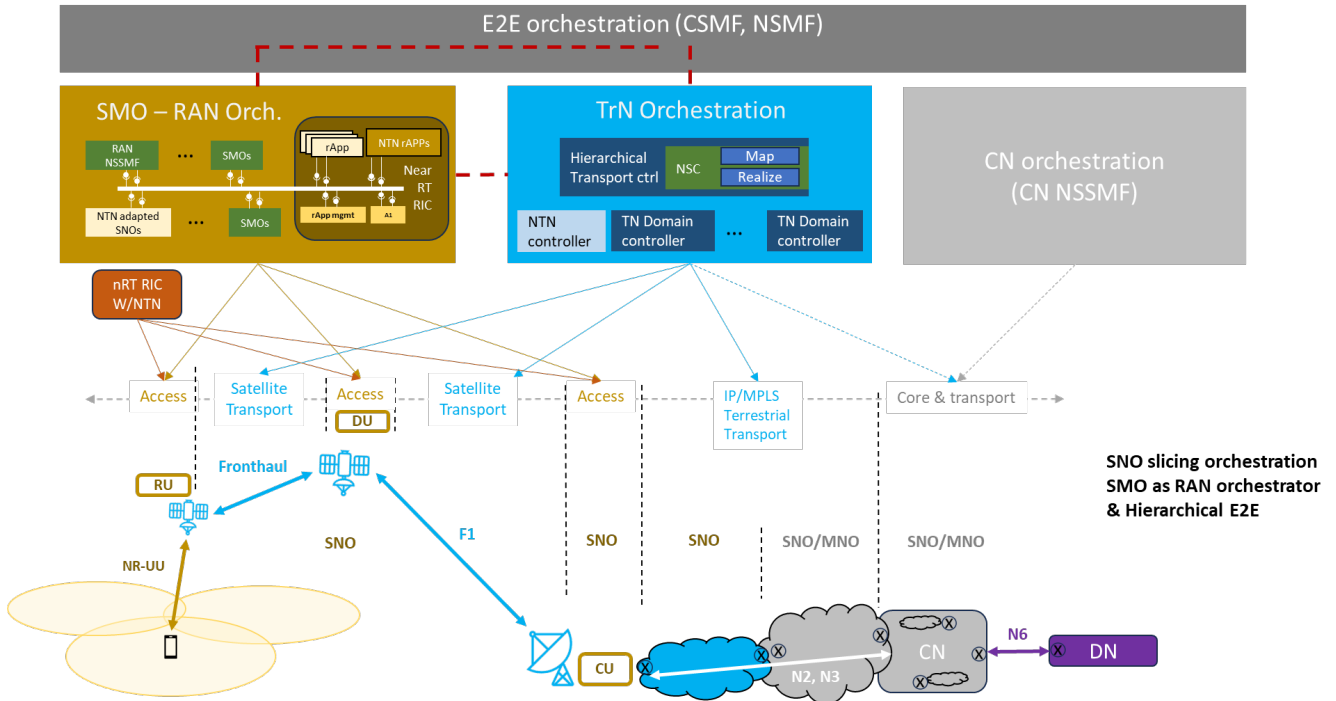
Progress in O-RAN work during the second period of the project does not impact the general aspects considered for the integration architectures during the first part. The recent opening of specific NTN (RIC enhancements for transparent NTN architectures and the more recent study item on regenerative ones) is the main aspect that opens potential for impacts in the future as work progresses. However, the initial considerations and work so far are in line with the high-level architecture, and the main impacts might occur at a lower (e.g., interface) level, with modifications and additions to adapt to the specifics of the NTN segment in the overall architecture.

O-RAN is mainly about RAN disaggregation and virtualization, ensuring interoperability between SW and HW from different providers. CU / DU centralization and distribution of RUs is a typical targeted scenario. Linked to the evolution in satellite technology, 3GPP parallel standardization (including regenerative architectures) and longer-term research work (as that ongoing in NTN SNS or HE projects, which address in many cases this topic), a first relevant aspect to consider is that within O-RAN ecosystem there might develop a wider set of architectures for the NTN systems, including those with distribution of the RUs in part of all the satellites forming an NTN constellation. However, as commented, it is still quite uncertain how feasible or convenient these “more extreme” disaggregated architectures might be (this will be a topic of study in O-RAN), especially when considering fronthauling interfaces between satellites or in the feeder links.

In parallel, in O-RAN, as explained, the SMO can be considered as the RAN orchestrator in a hierarchical service orchestration architecture like those in terrestrial networks or potentially extended in the future to integrate management of the transport network as well, taking advantage of the transport network inclusion work presented before. This probably fits better in lower-scale mobile networks, which might benefit from a flatter service orchestration architecture.

The following **Figure 13** shows, for an example considering DU and RU distribution at different level within an NTN regenerative mobile access system, the E2E orchestration view for an SNO adopting an architecture that uses the SNO as RAN orchestrator, with the NTN orchestration shared between the RAN (for example for the particular NTN RAN NF related functionality and the transport (for example, for the satellite/gateway transmission specific functionality) domains. A tighter integration between the RAN and transport domains is considered in this case, either via direct interfacing or through an NBI, as options represented in the figure. It must be noted that in some cases, TN-NTN integration (e.g., sharing) might mean that the CN part and part of the transport network correspond to another tenant (the TN MNO), while others, as standalone service by the SNO or roaming-based integration, require that the SNO covers a full E2E scope.

A second option (**Figure 14**) for the SNO would be a flattened architecture, where the SMO deals with the full service E2E, including (e.g. via rApps, xApps, adaptations of the general SMOs for the NTN and transport parts, specific NTN SMOs) the NTN (access and transport) and the terrestrial transport control. The adoption of one or the



other (there might be also options “in-between”) can influence the way in which the interaction with the TN orchestration architecture develops or vice-versa, for systems addressing some use cases or considering a given NTN architecture for the integration (e.g., network sharing, etc.) one option might become a better or simpler fit than the other.

It must be noted that the priority for discussion and integration of NTN functions on the SMO architecture bases on the RAN NF related functionality, and it is considered that some other management NTN functionality (gateways, satellites, etc.) may be left to an external system to O-RAN, with proprietary interfaces (or outside O-RAN scope for

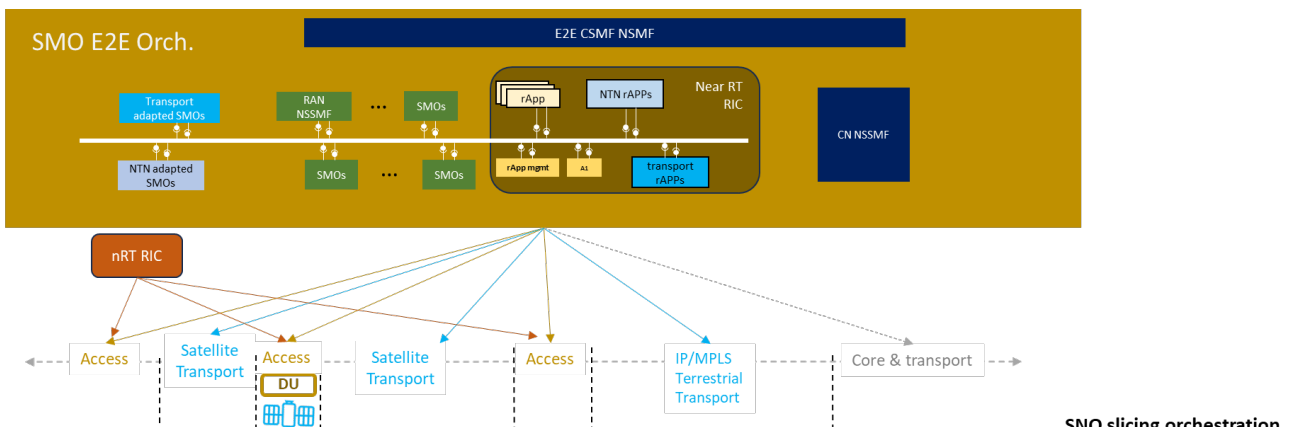


Figure 13: Service/slice E2E orchestration for SNO – hierarchical (similar to TN architecture)

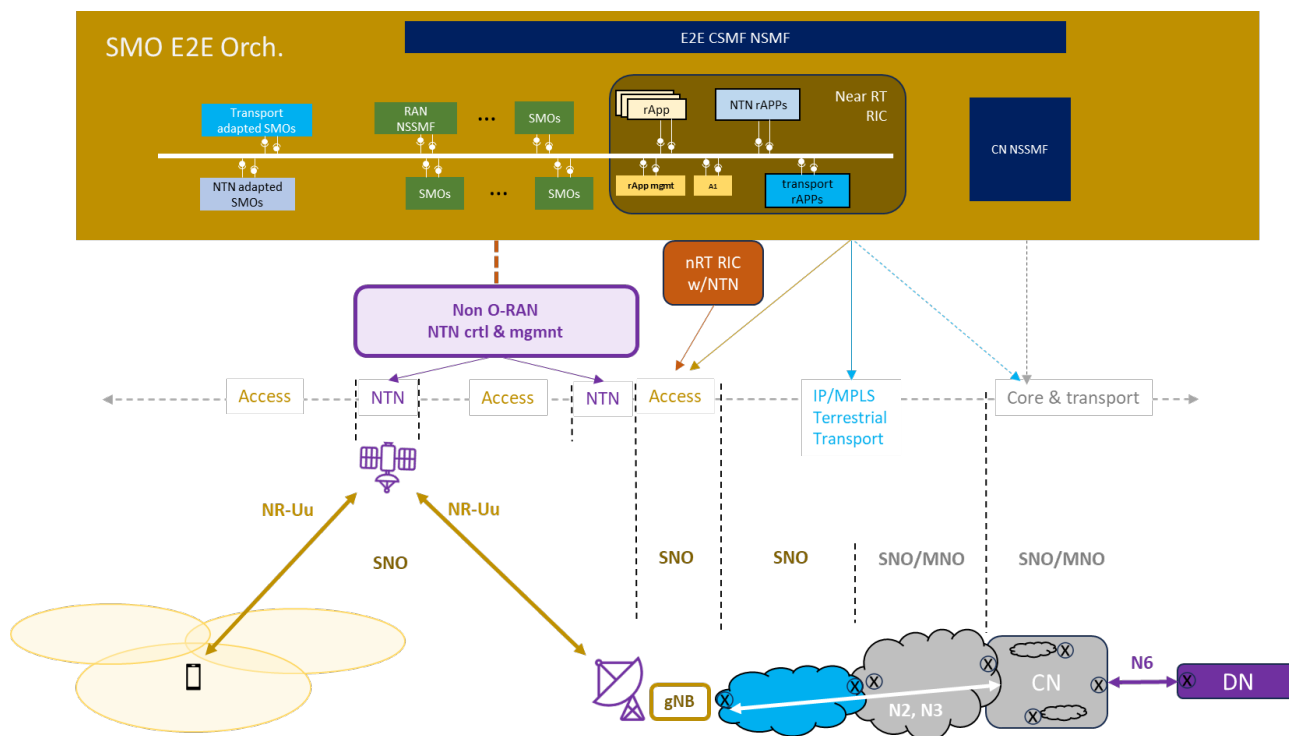
Figure 14: Service/slice E2E orchestration for SNO – flattened (SMO covers E2E)



definition). In the previous figures, this has not been depicted assuming that, at some point, the non-RAN related NTN part can be integrated for management and orchestration as well as part of the transport domain orchestration (either in the transport domain or through its potential integration in SMO via rAPPs and adaptations), although challenges related to that (lack of standard interfaces, differentiation between satellite constellation architectures, baseband platforms and devices, etc.) were already identified in 6G-INTEGRATION-02-E5, being a relevant area of focus for the solution implementation analysis.

The next figure shows a simpler case for an SNO considering a flattened management and orchestration considering a single orbit transparent NTN solution, and non-RAN NTN functions integrated through proprietary interfaces.

Figure 15: Service/slice E2E orchestration for SNO – flattened (SMO covers E2E) with transparent satellites and proprietary NTN management.



Complementing the possibility to distribute RAN NFs and the different orchestration architectures, the distribution of SMOs and SMOFs within the implementation of the architecture is also a relevant topic of research which might evolve and with direct dependency on the NTN system architecture, as use cases served by components operated by different control loops might impose de-location and distribution of functions as the RIC controllers, etc.

Finally, work related to transport slicing (relevant for scenarios in which satellite systems are used as mobile backhaul) has kept in line with previous specifications and in line with IETF transport slicing progress (presented in the next section), so there is no impact on the considerations already made in the INTEGRATION-2 related architectures.

2.3 IETF standardization evolution

2.3.1 IETF transport network slicing

In the previous **6G-INTEGRATION-02-E5** deliverable, the IETF general framework and drafts related to transport network slicing were presented. Work within IETF is relevant for INTEGRATION-2 not only as it will be taken as a reference for implementation of E2E slicing in NTN backhaul scenarios, but also for the potential that it has to become part as well of the overall service orchestration in other architectures for NTN integration, as those related to using NTNs as access solutions (IETF work is serving as a reference for O-RAN as presented before, and adaptations in 3GPP NRM are also developing for the stitching between access (RAN and CN, within 3GPP scope) and transport network sections (outside 3GPP scope).

The general framework for transport slicing in IETF has already progressed from IETF draft to the final RFC9543 [11]. An IETF network slice represents a logical partition of an underlay network that enables connectivity between a set of slice 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 security, etc.). 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 with flexibility to define SDPs within the customer CEs or the provider PEs, depending on operational responsibilities of the slice provider. Slicing management considers an implementation in three levels with an E2E service orchestrator, a network slice controller (NSC) which will be the entity within the transport network management and orchestration layer to manage the slices, interfacing the E2E orchestrator above (NBI) and the technology-specific network controllers below (SBI) via its network configuration interface to realize the slice in each of the managed domains composing the transport network (network controllers will use their device configuration interface for that).

In parallel, open drafts related to IETF transport slices have progressed, providing additional tools and references for implementing IETF transport slices within 5G communication networks. A summary follows summarizing the main references considered in the INTEGRATION-2 scope.

The teas group document *draft-ietf-teas-ns-controller-models-04* [12] extends content about the network slice controller and its role within the general framework. IETF considers that the basic NSC scope needs to include two key functions:

- Mapper, which processes the customer requests and puts them within the context (provider view) of the IETF Network Slices in the provider transport network, maintaining the relationship among customer IETF Network Slice request and the managed transport slices and resources. It shall also provide performance notifications in relation with the SLOs set by the customer request and maintain the view of network resource partitions (resources) with the data provided by the realizer.
- Realizer, which processes the complete view of transport slices and decides the proper technologies for realising the IETF Network Slice and triggers its realization via the underlying network controller layer. It also generates filtered topologies with the network data available via the underlying network controller layer and provides the performance, telemetry, etc., to the mapper for the assurance mechanisms at the slice and service level.

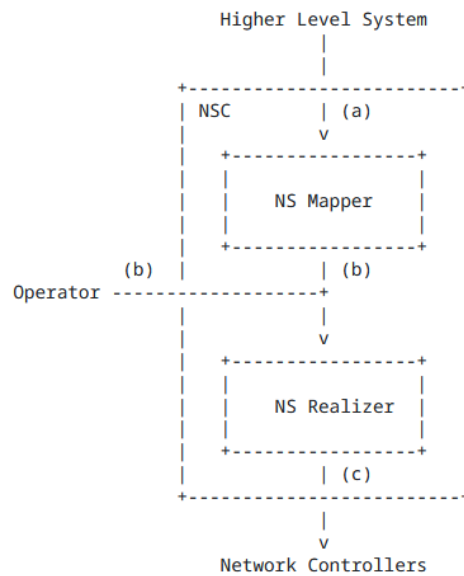


Figure 16: Three-level IETF transport slice architecture, and NSC roles.

The NSC exposes service-level NBIs to the higher-level systems (as a 3GPP 5G E2E orchestrator). For slice requests at customer level, IETF defines the slicing service NBI yang data model (to consider, for example, in RESTCONF/YANG interfaces at the NSC NBI level) in *draft-ietf-teas-ietf-network-slice-nbi-yang-22* [8], already close to becoming a final RFC, and aligned with the RFC9543 framework. Besides this, also at the customer / E2E orchestrator level, IETF also considers a complementary YANG model for the implementation of an interface that helps enable the automation of the attachment circuits and underlying bearers between the transport slice customer and the provider (which can also be organizational entities within the same company). This is defined in *draft-ietf-opsawg-teas-attachment-circuit-20* [9]. This way, upon a new service request (e.g. new slice provisioning), the service can be bound to existing attachment circuits or trigger the instantiation of new ones through coordination of the provisioning in endpoints that might not belong to the same administrative entity (customer and provider, etc.), simplifying the provisioning of services. It must be noted that this model has a relation to others, such as [13], which have relevance also within the slice provider domain.

Complementing the general framework and the slice controller architecture, *draft-ietf-teas-5g-network-slice-application-04* [14] constitutes a key reference for INTEGRATION-2, as it centers on the application of IETF transport slices for 5G network slicing, with its primary focus on the mapping between 5G network slices and IETF-defined network slices in the underlying transport (outside 3GPP scope) networks. The realization within the transport domain of the transport slice depends on the functionality and capabilities of the devices and architectures forming the transport network. Considering also that the transport network might not just be a continuous domain between the RAN and CN but also interleaved between de-located RAN or CN NFs and that the different domains might correspond to various tenants, stitching the different domains together to achieve becomes one of the key aspects for the implementation of the overall E2E 5G slices.

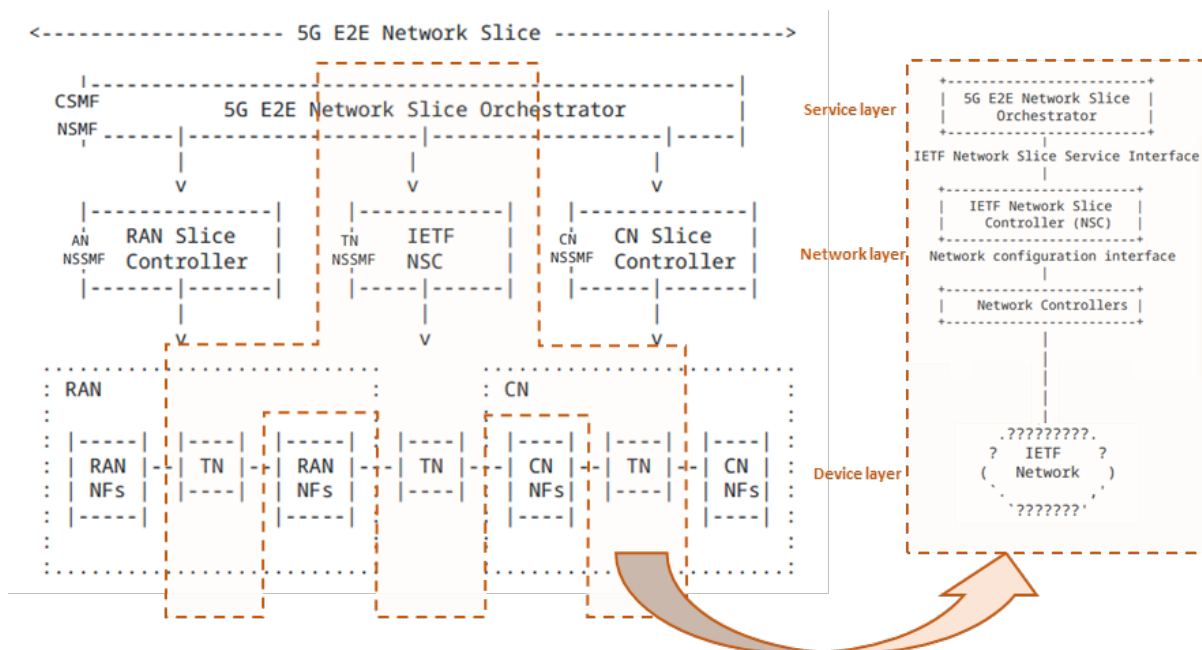


Figure 17: 5G E2E slice and hierarchical architecture, including IETF NSC within the transport domain orchestration layer

The mapping needs to be aligned at several levels as depicted in the previous **Figure 12**, including the 3GPP slice side to the customer edge (CE) endpoint that faces the IETF provider edge (PE) endpoint of the transport slice and the CE to PE endpoint match, with 3GPP objects in the 3GPP TS 28.541 NRM (as *EP_TRANSPORT* or *EP_RP*) serving as the base to provide the necessary info to the transport domain to map the slices (although with identified gaps up to R17 that pose limitations to the more complex scenarios). The slicing service NBI also serves as a vehicle to pass the NSC the necessary information for the 3GPP to IETF transport slice mapping.

From all the referenced mapping options, we will consider that based on VLAN ID (assuming that the RAN and CN domain present slices to the transport network through separated physical interfaces or logical ones relying on VLANs. To the already existing alternatives, the latest draft updates reflect a new one (valid for 3GPP R18) leveraging on the 3GPP updates in the 3GPP R18 NRM [10] linked to a joint O-RAN and IETF liaison. This option is based on interface identifiers created through the use of the previously introduced attachment-circuit service interface. In the 3GPP R18 NRM:

- The *EP_TRANSPORT* field *nextHopInfoList* (which served as a string including several parameters as the IP address of the ingress transport node, the IP address and mask of the attachment circuit, port name and VLAN identifier, etc.) is replaced by a list called *externalEndPointRefList*, to be used as identifier of connection points external to 3GPP, linking to the IETF data model. The list corresponds to a *ConnectionPointInfo* datatype that includes the identifier of the connection (*connectionPointId*, which identifies a transport network object) and its type (*connectionPointType*, which can have values like VLAN, MPLS or ATTACHMENT_CIRCUIT).
- The *localLogicalInterfaceInfo* represents a 3GPP class with transport network-related parameters related to a given 3GPP object (as *EP_NgU*, etc.) and includes information like the interface identifier and type (VLAN, MPLS, etc.), the system name, port name and routing protocol.

The attachment circuit model is then used together with the NBI slice service model to reflect the connectivity from the transport network to the 3GPP system, including the bearer's physical parameters, location information, logical connectivity parameters, and routing protocols.

For the realization of the transport slices, IETF work has progressed as well with the drafts proposing reference implementation of slices in different transport domains as *draft-ietf-teas-5g-ns-ip-mpls-18* [15], focused on IP/MPLS networks considering their current capabilities, *draft-ietf-teas-ns-ip-mpls-05* [16], which proposes another alternative concept, based on a slice-flow aggregate concept and resource partitions and partition policies, or *draft-ietf-ccamp-yang-otn-slicing-08* [17] which focuses on OTN network slicing and defines YANG data models with OTN technology-specific augments deployed at both the north and south bound of the OTN network slice controller. While no specific work has been identified in IETF for the realization of transport slices using NTN network technologies, besides the general and 5G frameworks, the content in the previous references serves as a base for the research in INTEGRATION-2. Especially, that corresponding to the realization of transport slices in IP/MPLS with current technologies, which, as introduced before, has also been adopted as a reference by O-RAN WG1 and WG9.

While not all the content is of course applicable to NTN transport scenarios, slice mapping procedures as VLAN-based handoff, QoS management with fine-grained control (policing, shaping, scheduling control, etc.) in the network edges to support the slice service SLOs (exploiting 5QI to DSCP mappings when available) or OAM mechanisms can apply to satellite transport network slice realizations. Even others exploiting more complex functionalities and protocols of the IP/MPLS networks related to the transport underlay (as L3 VPNs with SRv6, FlexAlgo for traffic steering, etc.) might at some point become relevant as well in the context of NTNs (especially in the case of regenerative architectures adopting terrestrial routing functionalities) although in most cases a direct exploitation is not possible and adaptations to NTN constraints would be needed.

Complementing all of the above other RFCs and progressing drafts extend the set of available tools for the realization and automation of IETF transport slices, as *draft-ietf-teas-network-slice-topology-yang-00* [18], which serves to provide the option to express topology intents in the transport slice requests, complementing the IETF slice service NBI, the RFC 9408 [19], also related to the topology, in this case for the exposure (augmenting the base IETF topology model in RFC8345 [20]) in an abstract way of the potential attachment points for services and *draft-ietf-teas-nrp-yang-03* [21], which provides a data model for network resource partitions, in case the provider works with them as specified within the general IETF transport slice framework. An additional open draft *draft-ietf-teas-ns-models-applicability-00* [22] provides a consolidated reference around how the different IETF data models within IETF can be combined in the context of network slices, at the different architectural levels.

2.3.2 NTN-related work

IETF work has also recently included specific work concerning satellite networks, in most cases personal drafts spread among different groups, as the time variant routing group (*tvr*), transport and services working group (*tsvwg*), routing area working group (*rtgwg*), locator/id separation protocol working group (*lisp*) and several others. In most

cases, the drafts reflect the research work in the global community and focus on identifying requirements and challenges faced in adapting transport protocols and routing solutions for LEO (regenerative) satellite networks and on proposing potential alternatives and solutions.

Most of the reviewed work identifies a common set of challenges, motivated mainly by the potential high scale of satellites in LEO satellite constellations, the high mobility of the satellites and the specifics of the satellite design and radio propagation. As a summary:

- Frequent handovers and connection switching between LEO satellites and ground stations and between LEO satellites in the orbits forming the constellation (complexity increases in case of multi-orbit solutions), which impact routing protocols as the network topology changes constantly. ISLs between different orbital planes can have high temporal variability depending on orbits. In addition, collision avoidance procedures might involve sporadic changes on top of the orbital movement.
- High packet loss environments (which impact transport protocols), linked to the previous point (fast mobility and handovers) and the nature of the radio propagation in the different frequencies used for satellite transmission (which include typical FSS bands but also Q/V/E-band and even optical frequencies in ISLs), which might also suppose variations in capacity in both user and feeder links. Additionally, solar or magnetic interference can be a source of impact.
- Satellites are constrained in weight, size and available power, which limits the complexity and processing power of the payload, and where the satellite movement also impacts dynamics, as satellites spend part of their time in orbit without sun exposure. Solutions for adapting routing protocols must consider keeping the satellites' complexity and processing limited within reasonable limits.

It must be noted that current satellite networks are proprietary so far, and little information is generally available to analyze the specificities of resource allocation and routing dynamics⁵.

Most of the work oriented to the proposal of solutions considers, besides the challenges, that the movement of the satellites (leaving aside sporadic cases) is predictable, following a predefined orbit that can be projected. This can be exploited to adapt protocols and solutions for routing, as the future positions of the satellites can be pre-determined, and a large part of the complexity can be offloaded to the ground-supporting network.

The recent informational RFC9717 [23], derived from an original draft from the TVR group (which identified satellite networks as a relevant use case as part of the initial group work compiled in RFC9657 [24]), analyses the topic and proposes a potential approach which is proposed openly for future validation by satellite operators. The approach bases on segment routing with an MPLS data plane and IS-IS as IGP (with

⁵ Existing systems are known to work with periodic (e.g., several seconds) satellite and resource allocation adapting to satellite movement with relation to the ground stations (user and gateways) traffic demand (volume and type) variation.

intelligent partitioning with nodes being L1L2 plus some specific considerations as the use of Area Proxy to achieve scalability, avoiding that topological changes within a L1 area become visible in others) where each satellite is assigned a node segment identifier (SID).

A path through the network can then be expressed as a label stack of node SIDs, with IP forwarding not used within the satellite network and limiting the label stack to include the main waypoints along the path. The IGP will accommodate unexpected topology changes, and gateways can also carry out traffic engineering procedures using differentiated label stacks for different traffic flows (relevant for the potential implementation of slices, like in terrestrial networks). Other mechanisms typically used in terrestrial transport networks, like traffic engineering or Path Computation Element (PCE) can also be added in the overall solution.

Scheduled topology changes are then necessary to define the routing in the satellite network, and a proposal is to follow YANG modelling as reflected in the YANG model [25]. Scheduling information is needed in all the nodes, which will define routing to handle link additions and deletions as the topology changes.

2.3.3 Main impacts on INTEGRATION2 architecture

Progress by IETF is not impacting the proposed architectures for integration, which consider the general IETF transport slice framework and application to 5G slicing implementation in some of the sections of the overall E2E, especially in those where satellite connectivity is used as transport solution. IETF transport slicing keeps being a reference for O-RAN standardization, and enhancements in the 3GPP NRM have already been introduced to ease the linkage between RAN/CN objects and IETF transport network objects, reinforcing the relevance of its consideration.

Specific work related to NTNs in IETF is less mature, although on evolution, taking as example the content presented before, can provide a good reference of the viability as well for adoption of adapted standard transport and routing protocols to the LEO regenerative systems under development, where so far proprietary solutions are the typical case. This is an area of quite active research with multiple solutions under consideration, which extends to the use of ML/AI or the implementation of SDN techniques⁶.

Although the development of NTN-domain routing solutions is not the focus of INTEGRATION-2, the potentially viable solutions and protocol extensions can provide a reference for additional capabilities in satellite networks, which can be exploited to implement network slices in satellite networks. While a relevant part of the focus about end to end quality typically relies on the radio resource allocation and QoS mechanisms and their relation with achievable performance, a key high-level service

⁶ As example, work in 5G-STARBUCK project, as reflected in D5.2: Preliminary Report on Multi-Connectivity and Software Defined Network Control:

https://www.5g-stardust.eu/download/5g-stardust_d5-2_1-0-f/?wpdmdl=941&masterkey=r_uQTqJd3E3vQJ5Op0FiJRfe2Mwe5Sc39dDpFk3iJ9TmbfOEUC3wnfXdBADu-9wl9hScq4YXcM_54zrWgnQy7-JyTY1AknBueJ2RtKc3KxA

requirement part of slice SLAs is normally latency so, in regenerative systems, dynamic routing and traffic engineering component in the satellite segment becomes key as well on evolution.

2.4 MEF LSO ecosystem and NTNs

MEF LSO (Lifecycle Service Orchestration) is a framework developed to enable the orchestration of connectivity services (e.g., Carrier Ethernet, IP, SD-WAN) across multiple providers, network domains and underlying technologies. LSO defines reference points between functions and roles (including customer, provider, etc.) in an E2E service provision and orchestration architecture, standardising APIs, information models, and operational flows to support end-to-end service delivery automation and lifecycle management. and developing tools to support each reference point.

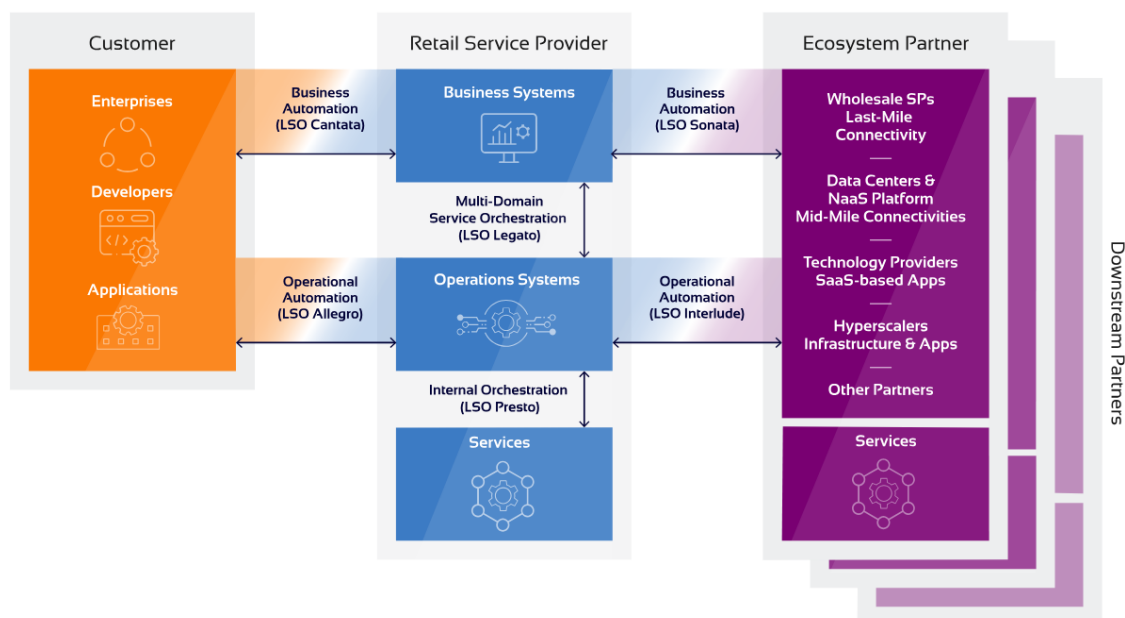


Figure 18: MEF LSO ecosystem, including reference points and APIs

- **Sonata:** Standardizes inter-provider service ordering, quoting, inventory, etc.
- **Legato:** Northbound API for service intent/order from business layer.
- **Interlude:** Peer orchestration between service orchestrators.
- **Presto:** Abstract domain-level service provisioning and topology.
- **Adagio:** Maps domain requests to actual device configurations. It must be noted in this case that MEF has not progressed with these API definitions, left as device/technology specific.
- **Allegro / Cantata / Intermezzo:** Optional interfaces for control, telemetry, analytics.

As the previous figure depicts, there are similarities with respect to the presented service orchestration architectures adopted by large MNOs providing 5G services. A hierarchical, standard API-based ecosystem with different levels of abstraction (high at the BSS/OSS and lower when closer to the network domain orchestrators and devices) is similarly considered in MEF, and there exist as well some commonalities and

synergies in terms of API adoption, especially at the higher layers with TM Forum APIs being part of Sonata or Legato APIs for example (although T-API from Linux Foundation is also part of MEF API definitions). Although MEF historically has focused on carrier Ethernet services, specifications are technology-agnostic, supporting IP, optical transport, and SD-WAN services.

The lowest level in the architecture is defined by Presto, targeting service orchestration through a high-level RESTCONF/YANG (and gRPC) interface that would match somehow that on top of the transport technology domain controllers in the reference network orchestration E2E reference architectures considered within INTEGRATION-2.

Although not being the focus of many large MNOs in the context of the provision of 5G services and the overall E2E service orchestration, where we will continue taking as reference the already presented architectures to support network slicing, MEF LSO ecosystem has become adopted or is a potential reference for adoption by companies in the satellite service provisioning chain (including satellite operators as Intelsat, SES, Telesat⁷, device providers like iDirect⁸ or service providers like Kratos⁹).

In some of the scenarios, especially those related to using NTNs as a backhaul solution where an MNO with its terrestrial network wants to integrate an NTN segment leveraging on a managed service by an SNO, a MEF-based service orchestration might end up being a piece of the overall multi-tenant architecture, solving the service implementation in the SNO domain driven by the requirements coming from the MNO in terms of service/slice request. An example can be that introduced already in the following **Figure 19**, with the SNO potentially orchestrating its service domain with an MEF LSO-based solution, transparently to the MNO (the focus being in this case on the interface alignment between orchestration systems and the E2E slicing support meeting the required SLA).

It can be noted that although there seems to be convergence towards the adoption of multi-layer hierarchical orchestration architectures both in terrestrial and non-terrestrial networks, there is still some fragmentation in terms of SDO and interfaces, especially to match already adopted ones by large MNOs in their 5G orchestration architectures. In parallel, other satellite service orchestration systems in development (an example would be the SpaceTime platform by Aalyria¹⁰) have been developed so far integrating their own defined interfaces, based on protocols like gRPC / Protobuf¹¹.

⁷ <https://www.mef.net/edge-view-blog/carrier-ethernet-over-satellite-a-new-growth-opportunity-for-telecom/>

⁸ *iDirect includes a large focus on open API adoption (both for service orchestration and also towards SDN satellites e.g., RRC APIs) in their latest Intuition platform*
<https://www.idirect.net/products/intuition/>

⁹ *An example would be their OpenSpace SDN platform:*
<https://www.kratosdefense.com/systems-and-platforms/space-systems/dynamic-ground/platform>

¹⁰ <https://www.aalyria.com/spacetime>

¹¹ <https://github.com/aalyria/api>

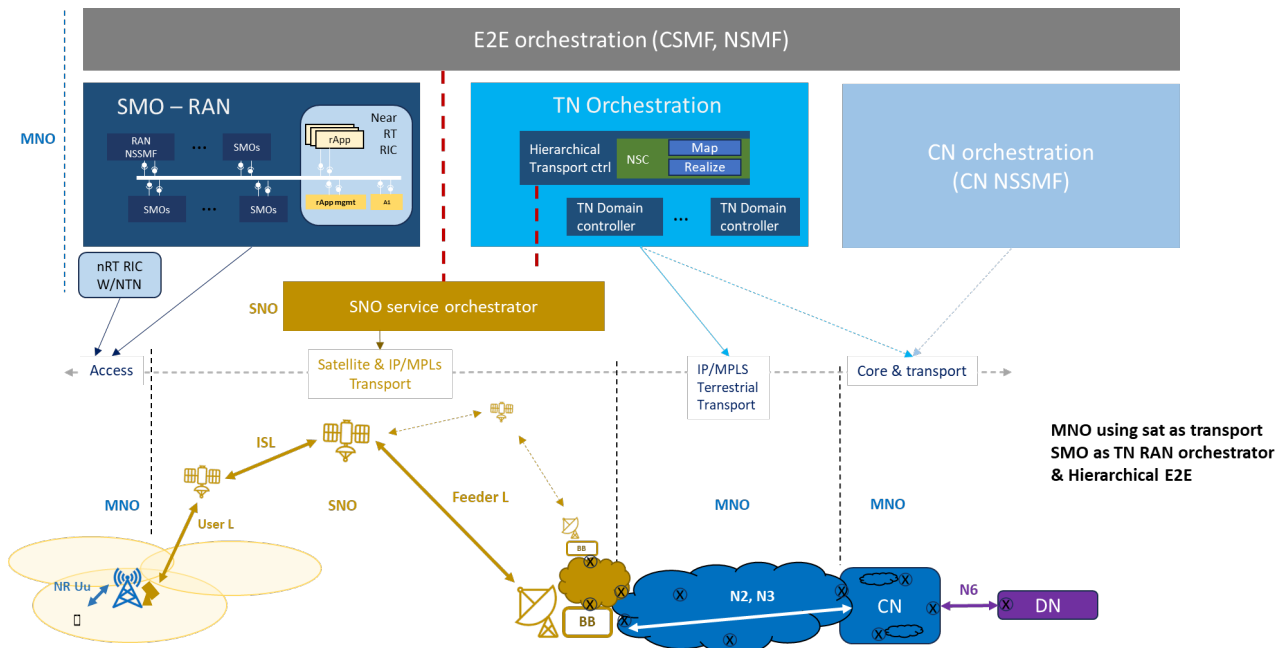


Figure 19: E2E integration architecture – satellite LEO as backhaul with SNO-operated service orchestrator

3. Constellation deployment progress and terrestrial slicing updates

This section focuses first on providing a short update on the latest evolution in LEO constellation deployments and planned systems for broadband and direct-to-device, as well as 3GPP 5G NTN systems, identifying the different satellite system architectures under deployment and their potential evolution. A brief update on the progress of implementing network slices in MNO networks is also provided.

The content is incremental to that already detailed in 6G-INTEGRATION-02-E5, with the main target of identifying relevant changes that can impact the reference integration architectures considered so far.

3.1 LEO/MEO constellation deployment progress

3.1.1 Satellite broadband constellations

In broadband systems (constellations used as transport solution), **Starlink** keeps being the dominant system, with around 6000-7000 active satellites in LEO inclined orbits (the figure varies as they are in the process of decommissioning the first generation of satellites and upgrading the constellation deploying newer Gen2 satellites) evolving now towards higher capacity and lower VLEO orbits. Starlink Gen2 becomes a regenerative system where satellites can communicate with each other using optical ISLs, still relying on the already deployed global ground network composed of gateways and PoPs for traffic interchange, which will need capacity expansions. Leveraging ISLs Starlink might have the flexibility to route traffic between satellites and decide which ground stations need to be upgraded (more antennas, more spectrum) to accommodate traffic growth.

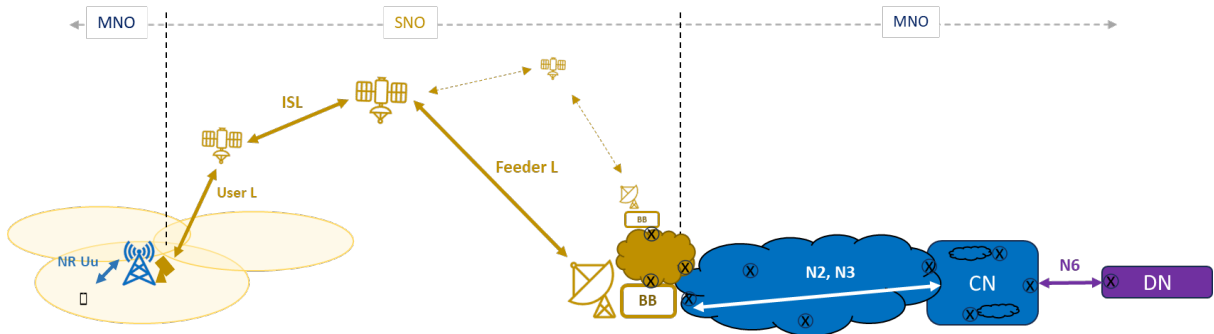


Figure 20: LEO regenerative constellation architecture for 5G backhaul

Starlink uses their own transmission protocols in user and feeder links, and little detail is public concerning the resource allocation protocols and routing mechanisms, which in Gen1 included replanning of resources and connections every 15 seconds to adapt to satellite and earth mobility. Starlink provides both internet services for B2C and B2B segments with predefined service plans using differentiated user terminals with different specifications, with the option to support L2 services. Service orchestration is managed internally, and APIs are exposed to the clients (e.g. MNOs, which can resell the products). Still, these are typically restricted for statistics and reporting, activation or basic configuration of the terminal, with limited flexibility for the targeted service configuration aspects within INTEGRATION-2, as would be a dynamic service provisioning by third party (MNO) request. The latter being a common limitation in all the other systems presented next, with some variation across solutions.

Oneweb is an already deployed global (but lower scale) system, with around 650 operational satellites deployed in higher LEO polar orbits. The main progress has been on the further development of their ground network, where global services are not yet fully available, linked to deployment aspects related to the supporting ground infrastructure. Oneweb considers SLA-backed L2/L3 services which match predefined plans within service categories that, depending on specification, include single or multiple classes of service. In terms of architecture, the system is transparent with no ISLs, and traffic from users is landed in the ground gateways and delivered to customers in different ways, ranging from Oneweb PoPs, e.g., via dedicated ethernet circuits, or optionally through public cloud. The high-level end-to-end architecture is depicted in the next figure, with the main difference with respect to Starlink being a simpler satellite segment in the overall architecture, with a transparent architecture. Longer-term design evolution is uncertain as of now, although replacement of the satellites needs to be realized in the coming years due to lifetime constraints.

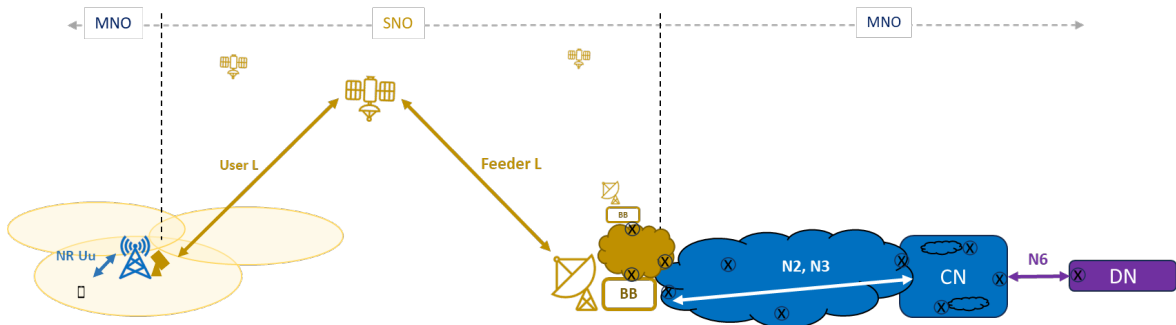


Figure 21: LEO/MEO transparent constellation architecture for 5G backhaul

Another constellation that has advanced towards the service phase is **SES Mpower**. In this case, it is an MEO system in equatorial orbit, targeting 12 satellites (and potentially evolving later to a larger scale with other orbits and ISLs). However, satellite problems have impacted the timeline and might affect the final number of satellites and system capacity. In any case, re-designed satellites are already being launched, and at some point, global services in the supported latitudes will become available. This is a highly reconfigurable system (e.g., with high granularity in terms of BW per-beam bandwidth allocations) with large capacity per satellite that also has a transparent architecture fitting the general representation depicted in the previous **Figure 21**. Traffic can be delivered to clients in SES PoPs or client premises, leveraging the terrestrial transport network of the SNO. SLA-backed services are also available in several categories, with MEF definitions for parameters like PIR/CIR/EIR and QoS management (with multiple classes of service) by the service management layer to back the SLAs, exposing APIs for integration with clients, and allowing flexibility for per-device service parameters (as throughput) with some restrictions and limitations (as the frequency of reconfigurations or maximum time period to accommodate the service reconfiguration requests).

Amazon Kuiper has also progressed, launching the first test satellites to validate aspects of the system design. The deployment phase is just starting, targeting around 3300 satellites in LEO inclined orbits, with half required in mid-2026 to meet licensing compromises. Kuiper is planned as a system similar to Starlink Gen2, with large-scale, high-capacity per satellite and an architecture with inter-satellite links and a supporting global ground network and PoPs to deliver traffic to clients, in a similar way depicted in **Figure 20**. SLA-backed services are planned with at least three types of user devices with differentiated capabilities. The system includes a global SDN controller responsible for the resource allocation of beams for customers and gateways, doing a long-term allocation of resources based on traffic demand and service types, plus short-term adjustment of resources based on capacity peaks, etc., optimising the network among multiple satellites. However, there are still not many lower-level details in relation to the services, resource management, QoS handling or APIs for clients. A main differentiation for this system will be the tight integration with the AWS cloud.

Other large-scale systems have started deploying, as several Chinese constellations (e.g., **Guowang, Qianfan**), with little detail in this case related to payloads, system design and architecture. In contrast, other lower-scale ones, such as **Telesat Lightspeed** (a LEO regenerative system, matching the high-level architecture of those presented before), will probably become operational as well in the 2027-2029 window. This gives a clear reference about the rising maturity and incremental market offer in this category (although with dominance so far from Starlink linked to the much earlier service entry), which is directly applicable for transport and mobile network backhauling applications.

It must also be noted that, in many cases, the LEO/MEO systems are already exploited (or plan to be exploited in the case of solutions reaching the commercial phase now) in a **multi-orbit configuration with GEO**. In this case, the main option consolidating so

far is combining separated satellite solutions¹² with dedicated infrastructure for each satellite type (GEO and LEO constellation) with SD-WAN. The next figure depicts the high-level architecture in this case. Starlink LEO + GEO, Oneweb LEO + GEO or SES O3B / Mpower + GEO are some examples already exploited and commercialized typically by GEO operators or satellite service integrators. In these cases, the commercialising company typically manages the overall solution, providing a fully integrated and managed service with the necessary APIs to the clients, linked to the individual service API of the composing solutions and the scope of the integration, which brings extra variability to the available APIs for integration with MNO systems.

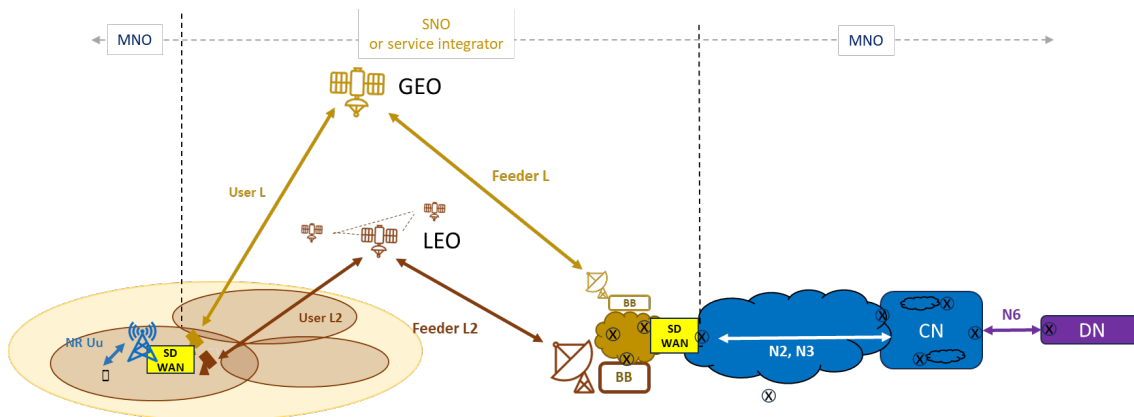


Figure 22: Multi-orbit (e.g., GEO + LEO) system integration with SD-WAN, high level architecture

3.1.2 Satellite D2D constellations (non-3GPP 5G NTN)

Following the development of broadband (transport) constellations, a second wave of systems focused on providing direct mobile access to devices has also developed over the last few years. In this case, being in a less mature state but with the first systems close to reaching (or already initiating) the commercial service stage. This first wave of systems are still not 3GPP 5G NTN compliant and are primarily focused on proprietary or 4G standard services (which anyway will be limited, e.g., messaging, non-continuous light mobile broadband, roadmap for voice). Some systems, as the one proposed by Apple for SOS satellite connectivity, rely on existing constellations (Globalstar) using MSS spectrum and rely on proprietary modifications of the HW of smartphones and developments at OS and application layer to enable and deliver basic services, with no participation of the MNO or integration with 3GPP mobile networks.

Other systems have relied on developing the necessary (proprietary, non-standard) adaptations in the RAN/CN to deal with the specifics of the satellite transmission and achieve compatibility with hardware-unmodified smartphones (modifications in the OS are expected), using IMT frequencies, which will be our focus in this section being the

¹² All the presented LEO/MEO systems have considered so far deploying a single or multiple shells with orbital heights not largely differentiated (although systems like Starlink are beginning to mix deployments in different heights e.g. 550km and 350km). Multi-orbit products reaching the market typically focus on large service performance differentiation and had been typically developed by GEO companies to look for additional applicability of their systems.

ones reaching the market (with general coverage of multiple use cases, not restricted to specific applications like IoT). Here, the developing projects so far have been led by companies which don't have access to their own spectrum, which motivates the collaboration with MNOs and the development of the necessary global and local regulations to allow for the use of IMT terrestrial frequencies for satellite service operation. In this case, there is more differentiation between solutions, which extends to:

- Scale of the projects, in terms of the number of satellites and their orbits (height, inclination)
- Size and complexity of the satellites (number of beams, spectrum per beam, antenna size, etc.)
- Architecture (transparent, regenerative)
- Spectrum (low band FDD, mid-band FDD)
- Integration with the MNO (roaming, sharing, L1 transport)

In parallel, as 3GPP 5G NTN standards develop, MSS compatible user devices become more available it is expected that some existing systems might evolve (when replacing satellites) and that new systems will be deployed supporting 3GPP 5G NTN standards using also MSS spectrum, which is the one considered so far in 3GPP NTN D2D specifications. This will influence the evolution of integration architectures, but it is still a topic with larger uncertainty, especially on the spectrum side.

Like in broadband, **Starlink** constitutes the project with the largest scale, with almost 600 satellites already launched in VLEO orbits, which can provide close to continuous services (continuous if the target elevation angle is relaxed) in some latitudes and services launched commercially (or in beta phase) in several countries. Starlink DTC has a regenerative architecture with Gen2 DTC-specific satellites (and ISLs) including a 4G on-board eNB and a large phased array allowing for D2D mid-band FDD operation. Starlink has its own mobile core, so the interconnection with an MNO is at CN level through standard roaming interfaces. It can then be seen as a full mobile network parallel to that of the MNO. In this first generation, being 4G, slicing is not possible, but on evolution, in future re-deployments, similar architectures might consolidate supporting 5G. The next figure shows the general architecture in this case.

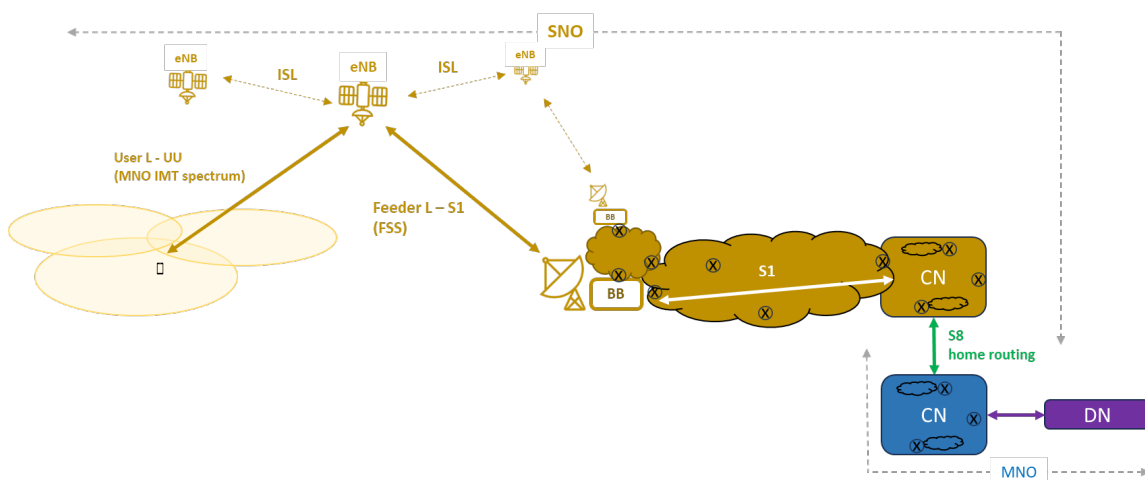


Figure 23: Starlink D2C high-level architecture

AST SpaceMobile is another relevant project in this category, progressing towards commercial services, but in this case, quite limited so far in terms of existing deployment. A large test satellite and five for commercial services have been deployed so far (single orbital plane), with plans to extend towards 40-100 satellites in LEO inclined orbits for 2026-2027. In the case of AST, the satellites are much more complex and larger than those of Starlink, linked to the reduced scale of the constellation, which requires extra complexity. The satellites can generate many beams with reasonably large bandwidth (tens of MHz) to provide mobile broadband services, although, up to a minimum constellation scale, services will be non-continuous. The system follows a transparent architecture, with vendor-specific RAN nodes on the ground that need to be deployed in the ground gateways. A ground gateway is needed within the field of view of any satellite to allow for the provisioning of services. Although in principle the system will start with 4G FDD in low band, with the RAN nodes on the ground, it is simpler to migrate to 5G support (does not require changing the constellation).

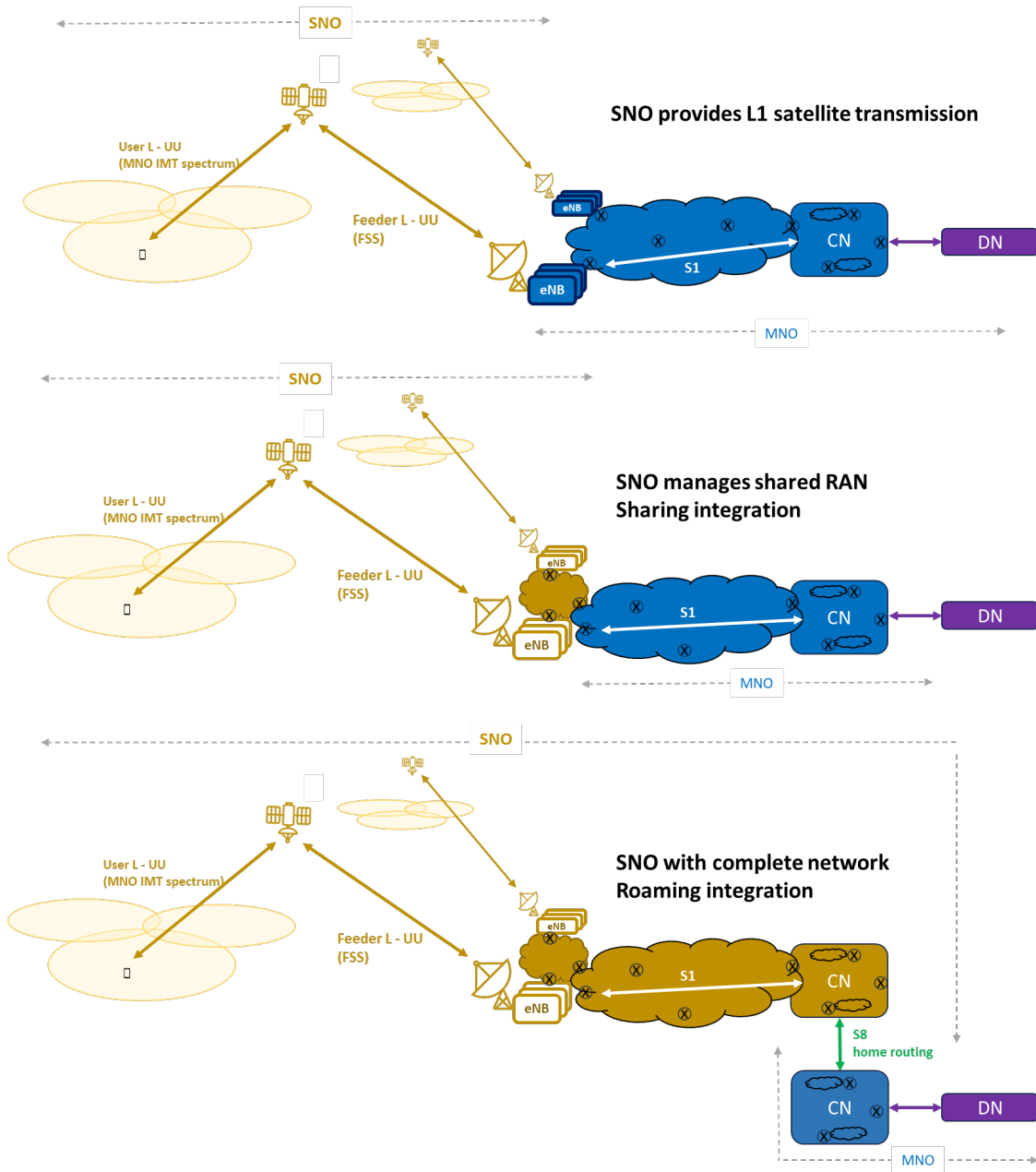


Figure 24: AST high level system architecture and potential options for integration

To integrate with the MNO, AST provides a L1 connectivity solution, with the RAN nodes and CN corresponding to each supported MNO (closer to a MORAN scenario). However, it can extend first to a network sharing approach with the nodes becoming part of the SNO, connecting to different operator CNs (so, evolution to a MOCN-like case) and, depending on their potential access to own MSS spectrum, might migrate over time to a roaming-based approach like that presented before for Starlink. These options are depicted in **Figure 24**. During 1Q2025 AST announced the constitution of a joint company (SatCo) together with Vodafone, opening to commercialize services to other mobile operators in Europe, which might influence the migration towards the latter architectures in specific regions, although specific models have not yet been openly defined.

A third project with satellites already available is that of **Lynk Global**, with five operational in polar LEO orbits and plans for ambitious expansion in the future. The deployed satellites are relatively simple and small compared to the previously introduced systems. Still, services like (non-continuous) broadcast alerts, SMS or voice (between users in the same beam, for a short time) are already possible. The architecture in this case is regenerative (with no ISLs so far) with 4G eNB and CN NFs (network-in-a-box) deployed in the satellites, allowing for store-and-forward services while the ground network grows. The operation considers low-band FDD with bandwidths from a few to potentially tens of MHz. So, the previous figure already reflects the case (considering a future evolution to 5G of course, as the currently deployed system is only 4G capable).

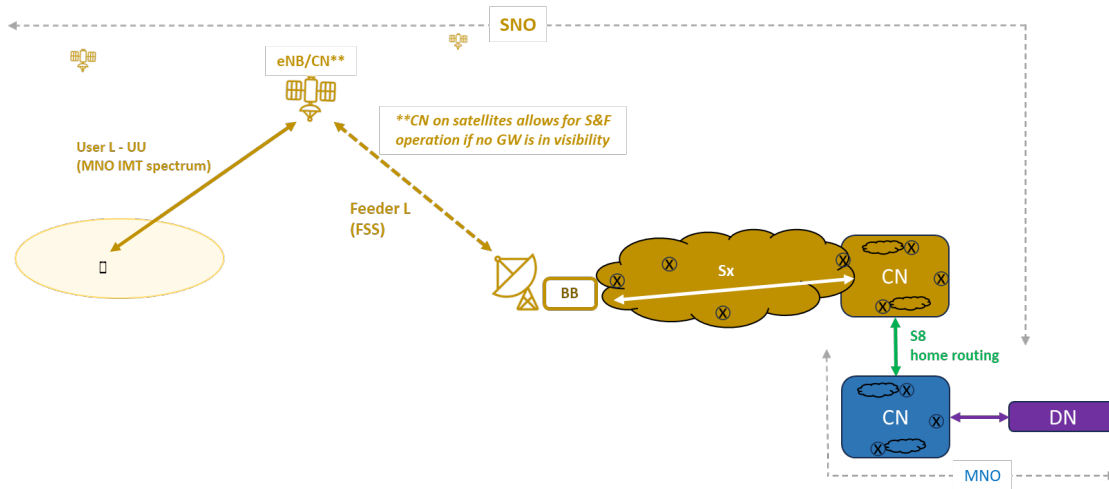


Figure 25: Lynk system architecture

Although it is still a less mature field, mostly focused on 4G, and evolution is expected in different ways (to 5G, architectures for integration, spectrum, etc.), all these will be taken as a reference for refining the potential architectures combined with those already becoming part of the 3GPP 5G NTN and O-RAN standardization work.

3.1.3 3GPP 5G NTN systems

Section 2.1 already presents the evolution in 3GPP standardization and potentially consolidating architectures, complemented by the specific NTN work linked to that evolution within the O-RAN ecosystem in section 2.2.

In terms of systems becoming operational in this category, linked to the progress in the definition of the standards, as already introduced, this is a field with much higher immaturity, and the main options that have recently become available are constrained to direct to device in the area of 5G NTN IoT applications, mainly over existing GEO satellites. However, several systems are progressing in the LEO field. Another blocking element for the progress of more generalist systems (in terms of achievable services) is the unavailability of compatible devices (where again, chipset availability is progressing quicker for IoT and GEO applications, evolving also towards availability for LEO IoT).

In the field of IoT applications, **Skylo** has been the first solution providing commercial 5G NTN IoT R17 services to MNOs (which in 3GPP so far rely on NB-IoT which allows

NB-IoT chipsets to be reused with less impact and firmware updates for NTN) with **Viasat** constituting a similar example. The system in this case follows a transparent architecture with satellite connectivity provided over GEO satellites from satellite operators having global or regional L/S band spectrum assignments (being L/S MSS spectrum the first defined for NTN within R17 specifications) as Viasat or Echostar, and the integration is done at core level (roaming), as Skylo provides a complete mobile network, including the gNBs and their own CN, and validates chipsets and modules as part of an own certification process. Some proprietary modifications are also applied on top of the standard to optimize some specific aspects of IoT applications. Besides IoT services, others like global SOS or SMS are already viable or will be in roadmap, of course for those devices including a compatible 3GPP compliant chipset. In the case of smartphones, Samsung Galaxy 25 or Google Pixel 9¹³ are initial devices supporting NTN functionalities (e.g., global SOS).

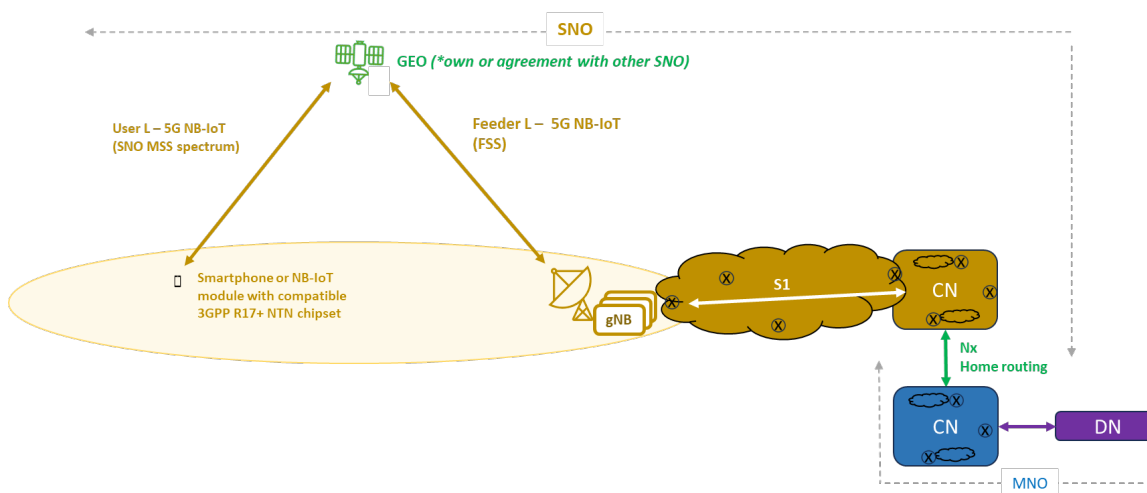


Figure 26: Skylo GEO NB-IoT general architecture

Sateliot and OQ are LEO constellation providers with already deployed LEO satellites (less than 10 in both cases), aiming to build their own constellation for (at least, initially) IoT services, with potential evolution towards support of more advanced ones in the longer term. Both consider a regenerative architecture compliant with 3GPP (R19 in this case, including store and forward functionalities and IoT performance enhancements) to provide services with MSS (both with S-band allocations) with integration via roaming. Considering their current status and plans, their architecture can be represented generally by the **Figure 25**, but considering in this case gNBs and 5G CN NFs in the satellites, and the adapted interfaces between elements to that of 5G.

Finally, as already introduced in section 2.1.3, for more advanced services, or applications beyond D2D in FSS enabled bands within 3GPP (Ka and Ku in R18 and R19) like broadband to VSAT devices, there are not still available 3GPP 5G NTN NR compliant constellations, which will still take some years to consolidate (operation of

¹³ Including compatible chipsets/modems like Qualcomm Snapdragon X80 or Samsung Exynos 5400 modem.

some services in GEOs with transparent architecture will become feasible earlier), and still being a field of research to keep developing the standards.

The main project so far targeting these applications with a dedicated new constellation is **EU IRIS²**, with services targeted for 2030, and conceived as a multi-orbit MEO/high-LEO constellation of around 290 satellites (with potential also to provide transport services to other satellites like GEOs) targeting military and government applications but also open for commercial services. The system, as of now, in this initial phase, targets broadband applications in Ku/Ka and military Ka bands, but it might be extended to D2D as well. While there are not many open details, the publicly available information represents a flexible system considering both transparent and regenerative payloads leveraging ISLs, with the option of implementing meshed (direct communications between users with no gateway) and star topologies, with a 5G underlying CN (which to support all the targets should be compliant with 3GPP R19+). Considering the lack of further details around design at this stage, the longer term of the project, and the potential mixture of government and commercial applications, which might be linked to different exploitation and integration architectures with clients, a reference integration architecture will not be depicted in this case to avoid providing a not accurate view.

3.2 Network slicing progress in MNO terrestrial networks

The first project deliverable **6G-INTEGRATION-02-E5** included a description of network slicing and, more importantly, a view of the foreseen progress of the implementation of network slicing in MNO networks, which needs to be seen as an evolving field gaining in functionality as standards develop, features and capabilities becomes available in the network domain underlays (RAN, Transport and CN), the OSS/BSS systems on top and models for its exploitation develop driving MNO customer adoption.

Operators are already deploying and commercialising network slices, primarily in their own networks, with cases like slicing in network sharing or roaming scenarios still being a less mature field, progressing at a slower pace. Aspects like the required agreements between MNOs, matching definitions of slices by different MNOs in their networks or covering also NSaaS automating the slice lifecycles (exposure¹⁴, provisioning, operation and assurance, defining the interfaces and the proper systems within MNO orchestration architectures allowed for interaction, including security considerations, etc.) require still time to develop further. In any case, at this stage, for scenarios considering NaaS, it seems that interfacing at the BSS/OSS (E2E service orchestrator) levels through TMF and 3GPP interfaces (depending on the level), as considered preliminary in the first project deliverable, seems still a good base assumption at least

¹⁴ *In the first project deliverable, several 3GPP references related to the necessary work around capability exposure were already presented. O-RAN has also identified these developments as enablers for their targeted cases for slicing implementation, which include multi-operator RAN sharing scenarios in advanced phases [6], referring to 3GPP CAPIF (3GPP TS 23.222, 29.222) and EGMF (3GPP 28.533) for the realization SMO external exposure functions, indicating that reaching a higher maturity in EGMF standardization is still necessary.*

for the provisioning (creating, modifying, ending, etc.) cases. This way, in case of NSaaS, high-level slice requests or intents are executed, leaving the low-level implementation details subject to the network slice provider. KPIs related to performance and SLA monitoring are also necessary, with add-ons like slice data exposure (to drive or ease the client requests, providing information like topology, available services, etc.) complementing the typical set of needs. Whether other lower-level interfaces (e.g. east-west between network domain orchestrators) are finally seen as feasible for cases like assurance, etc., is still to be defined.

Within their own networks in simpler scenarios (non-sharing, non-roaming), the commercialization of B2B and B2C segment network slices is a target for most operators, with premium or prioritised slices for B2B segments already being deployed for different clients (e.g., government applications, etc.) and becoming the first type of use case for network slice deployment. Full system automation, with exposure and particularization for clients, is still a work in progress for many operators, as the service orchestration architectures considered become implemented. In the meantime, slices are already implemented mixing automated and manual configuration processes in the different network domains, with multiple options for the configuration, with a roadmap targeting higher automation and system integration as technologies develop.

Besides automation, there are still some practical implementation problems which impact different client segments differently, as how to achieve a device OS independent slice commercialization approach, which somehow constrains the possibilities in this respect, especially in B2C. For example, the first project deliverable presented the details around a relevant “piece” within the E2E slice implementation, which are the URSP rules in the device (defining the mapping between user application traffic flows and PDU sessions), with some gaps already presented there. Currently, descriptors used in URSP rules to classify application traffic flows to PDU sessions and slices are not MNO-defined and are non-homogeneous between different device OS vendors, which limits the possibility to commercialize a common slice service offering to the MNO customers. While some workarounds do exist in B2B, through applications configured in enterprise profile to be mapped to enterprise slices via MDM, other solutions like network-based application tokens are already gaining in definition and progressing in the industry, with forums like GSMA already working on the topic.

4. Updated architectures and solution description for cases 1 and 2

This section targets to provide an update around the TN-NTN integration architectures identified in the first project deliverable, considering the progress in deployments, technology evolution and standardization progress, and to describe in higher detail the solution proposed for the implementation of network slicing in the cases with higher maturity, focused on using NTN solutions as transport section within the mobile networks (cases 1 and 2). For these, planned PoCs for the latest project period, to demonstrate relevant aspects of the solution, will be introduced as well. For cases 3 and 4, where NTN networks are conceived as mobile access solutions (D2D), integration architectures will be refined but kept at a higher level. Descriptions around all the cases were provided in the first project deliverable, which will be taken as the baseline here, trying to minimize repetition.

The architectures and solutions proposed for slicing implementation in all the TN-NTN integration scenarios take as a reference the current reference architecture for its implementation in the 5G mobile terrestrial networks, trying to reuse technology, systems or architectural concepts and to align where possible in terms of interfaces for mobile service orchestration. Although the proposed architectures are generic enough to support the full slice lifecycle, including operation or assurance cases, the main focus in the lower-level solution descriptions and demonstrative PoCs will be put on provisioning.

As a brief recap, prior to describe the cases, the next figure shows the high-level concept of E2E service orchestration architecture to support slicing in terrestrial networks:

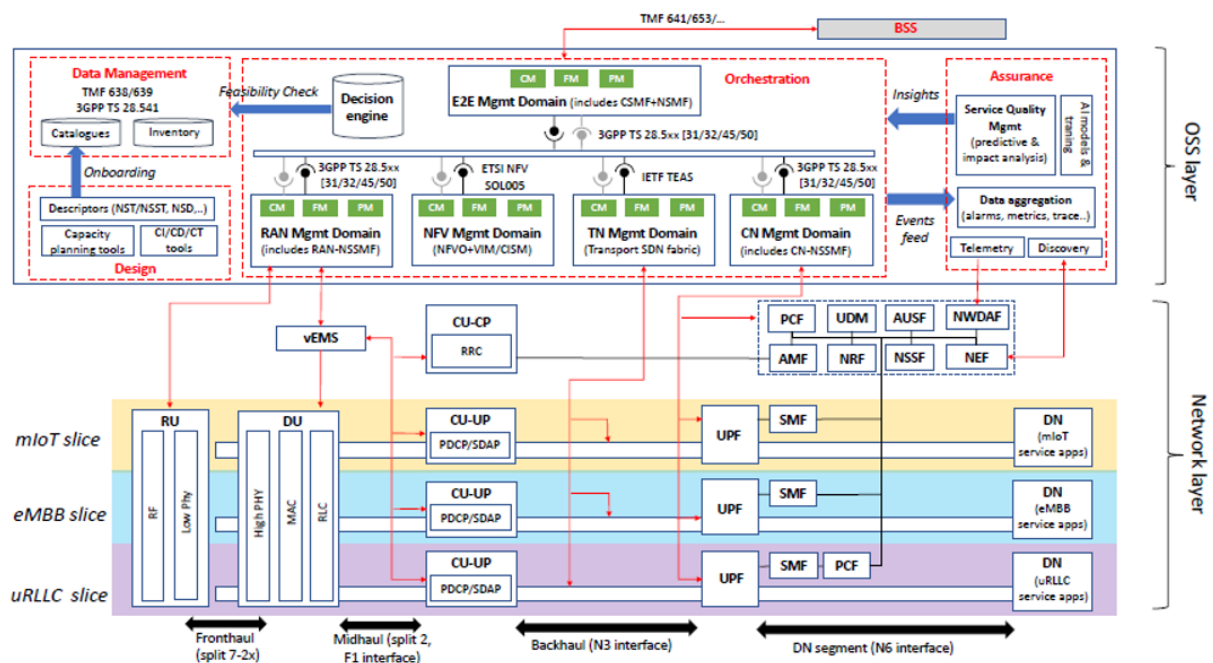


Figure 27: Generic reference E2E slicing orchestration architecture in terrestrial networks

A hierarchical multi-domain open architecture leveraging standardized interfaces is considered for the 5G service orchestration. An E2E orchestrator (OSS layer) interfaces the upper BSS layer using TMF interfaces like TMF-641 for service ordering. It hosts the CSMF and NSMF for E2E slice management and interfaces in its SBI using 3GPP interfaces for domains within 3GPP scope (RAN or CN) and IETF slicing interfaces (as presented in section 2.3.1). NF inventories aligned with the 3GPP NRM are also available to support slice related decision making and inter-domain coordination. Each network domain (RAN, transport, CN) has its service orchestration, with architectures which might also be hierarchical depending on underlying technologies and management complexity (this is the case of the transport network with multiple differentiated technologies in scope). For NSaaS, typically, at OSS and BSS layers, TMF (e.g. TMF-622 for product ordering) and 3GPP interfaces are of applicability, as considered by 3GPP slicing management and capability exposure standardization.

Cases 1 and 2 focus on using NTNs as a transport solution. In these cases, the optimal way to integrate the NTN would be as an additional transport technology domain in the existing TN reference architecture. As already introduced, transport networks are

outside the scope of 3GPP, with standardization specifications driven by other SDOs besides 3GPP and O-RAN as IETF, etc. and the inherent multi-technology nature of the domain makes that a typical reference transport service orchestration architecture (supporting transport slices within the full service E2E) considers also a hierarchical architecture, with a hierarchical top-level element working at a higher abstraction with RESTCONF/YANG service interfaces responsible for the domain E2E (and managing the transport E2E slice implementation) with underlying per-domain controllers responsible for the lower level configuration of the network devices (ideally working with device-agnostic NETCONF/YANG interfaces). The following figure summarizes schematically the architecture taken as a reference for the service orchestration within the terrestrial transport domain.

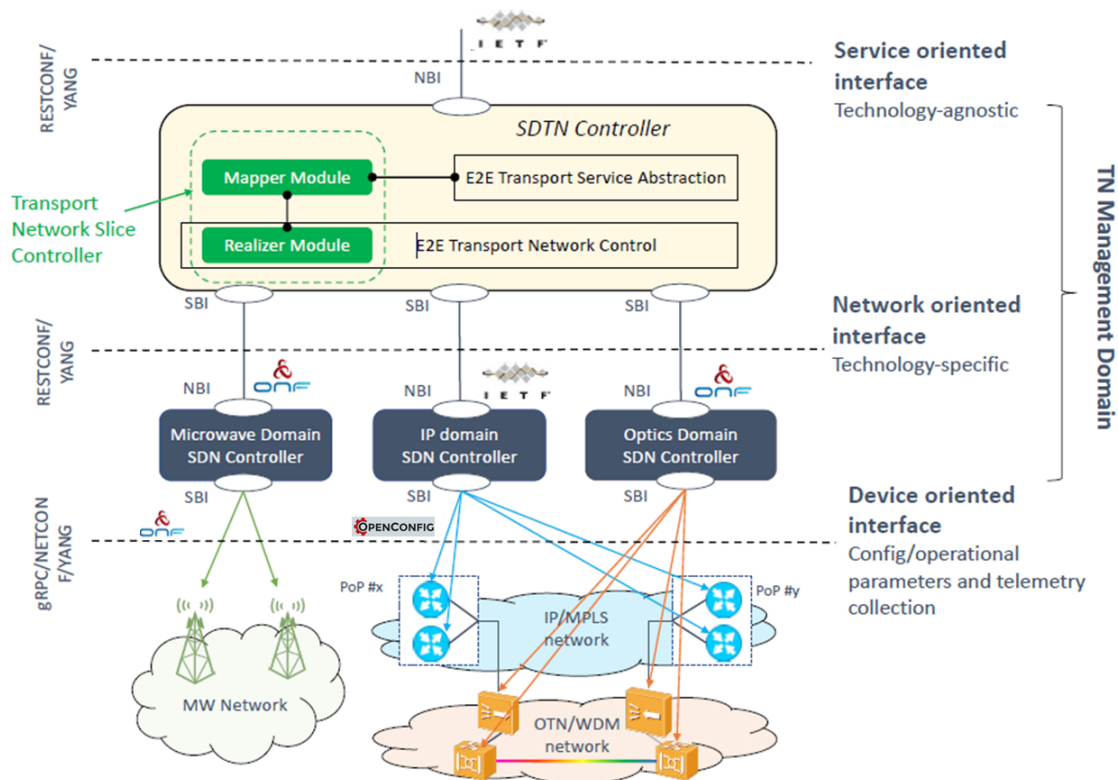


Figure 28: Generic reference service/slicing architecture in the terrestrial transport domain

In all the cases, to fully align with the project targets, for the RAN domain we will assume that O-RAN is adopted and O-RAN orchestration principles and architecture will be applicable (SMO as RAN or multi-domain orchestrator depending on the case, as introduced in 2.2.1). This is not mandatory anyway, and MNOs (or SNOs in the satellite domain) might also use non-O-RAN elements and non-O-RAN RAN orchestrator.

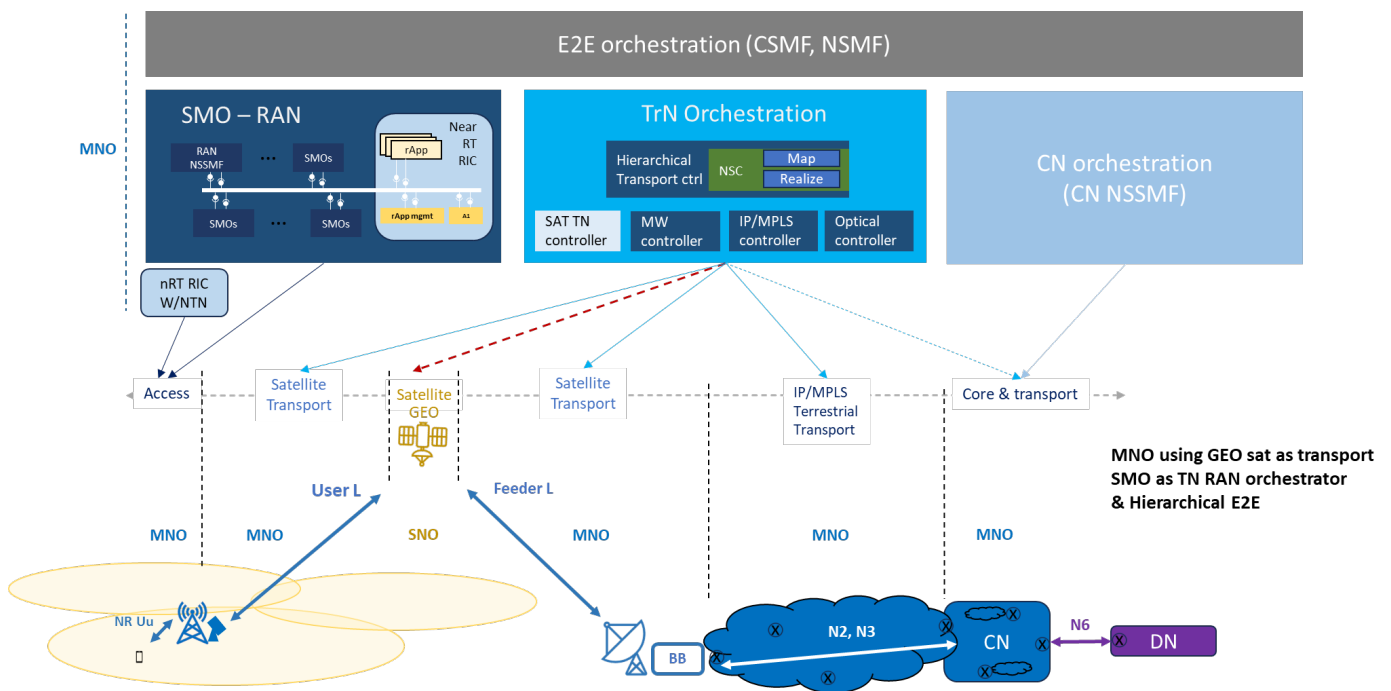
4.1 Case 1: NTN as 5G transport - internal MNO operation

This case, already presented in the first project deliverable, considers the use of a GEO satellite as a transport solution between a remote gNB and the MNO transport network. Although this might not be seen as a representative case of the typical case for an MNO due to the limitations in terms of slice capabilities and especially to the progressive shift of MNOs towards managed services in GEO VHTS or LEO NTN

solutions (case 2), it is studied in higher detail and a solution is proposed, as it constitutes a case in which:

- All the elements but the satellite typically lie within its administrative domain (own baseband platform and gateway HW, own RAN, transport network and CN) which provides simplicity for the management of an E2E slice.
- Many of the considerations to “solve” this case are directly or partially applicable to more complex cases like case 2, showing the problem scope for an SNO that wants to provide transport slices to MNOs integrating their solution into the MNO E2E architecture.

The following figure shows a high-level diagram of the E2E slice orchestration architecture in this case, including the elements under the responsibility of each



network domain orchestrator below the E2E system.

As in any other network scenario, slices are limited in terms of properties, parametrization and SLA metrics to the capabilities of the underlying network. Slices are logical partitions of the resources in the underlying physical network, so the latter constrains the variety of cases or slices that can be supported. In this case, a hard limitation in terms of latency in the E2E will be dictated by the satellite segment, linked to the minimum physical limit imposed by the GEO transmission. As commented before, although not very flexible or representative for the specific case of implementing network slices (which for a case like this will be limited to eMBB/mMTC within the limits of the GEO available capacity and ground platform capabilities), the objective of this case is presenting the main aspects of the proposed architecture and some of its key elements in terms of implementation, which serve to address more representative complex cases like case 2.

Figure 29: E2E slicing high-level architecture – satellite GEO as transport solution. MNO internal operation

To analyze the architecture, as a general reference case, we will consider typical infrastructure available in the ground network, with a parabolic reflector pointed to a GEO satellite in the remote side, with a point-to-point connection to a pre-defined gateway with a baseband platform matching the remote side able to work with the same satellite.

This way, in this case, resources in the satellite ground segment which can be configured to adapt to the slice high level parametrization (throughput, latency, availability...) would be, among other (as commented, possibilities are directly dependent on the baseband platform, RF and antenna type available in the remote side):

- Baseband mode of operation and subnet configuration (SCPC, TDM/MF-TDMA, TDM/dynamic SCPC...)
- Carrier (or carrier pool) configuration (frequency, ACM, FEC, power and power control, dynamic features, etc.)
- QoS, service (e.g. L2 VLAN, etc.) and networking protocol parameters.

It must be noted that the GEO satellite needs to support the configuration made in the ground network (matching frequency and bandwidth for the forward and return carriers, proper transponder operational settings and resource reallocation in the channelizer in case of multi-beam HTS, etc.) and that a variation in the ground segment parameters (e.g. for a slice reconfiguration action) might need a parallel reallocation of the satellite parameters and resources as well, which would require coordination with the SNO, as the satellite in the typical scenario is an element out of the MNO domain. This type of coordination is, to our knowledge, not typically supported via systems, with interfaces to support all this not normally available for the SNO clients, and requires, in most cases, a specific “manual” reconfiguration request and process, which is one of the gaps within the proposed architecture.

Considering all of the above, the proposed architecture for the integration of the satellite segment in the MNO transport orchestration architecture and thus in the overall network slice E2E, is depicted in **Figure 30**. The satellite transport segment will become integrated following the same architectural principles as the rest of the terrestrial transport domain, simplifying the integration with the terrestrial network and its potential for exploitation.

- At the highest level, in (1) the E2E orchestrator addresses the hierarchical transport controller hosting the NSC for the provisioning of network slices with RESTCONF/YANG interfaces using service models, like the IETF slicing service NBI *draft-ietf-teas-ietf-network-slice-nbi-yang-22* [8], already covered in section 2.3.1. Once the need for the creation of a new slice is triggered (internals, external customer) the parameters needed for the request (SDPs, connectivity constructs, attachment-circuits, SLO/SLEs, etc., as defined in the IETF framework) will be extracted from the slice request template (ultimately proceeding from a GSMA GST template) and the inventory of 3GPP objects according to the 3GPP NRM in the E2E orchestrator.
- At the same level, the NSC can also expose abstract topology information for the E2E controller, performance data related to the slice, or notifications linked to the requested slice SLOs. In this case, as all the network domains are within

the MNO administrative domain, other interfaces, such as those aiming at automatically provisioning inter-tenant attachment circuits, might not be needed.

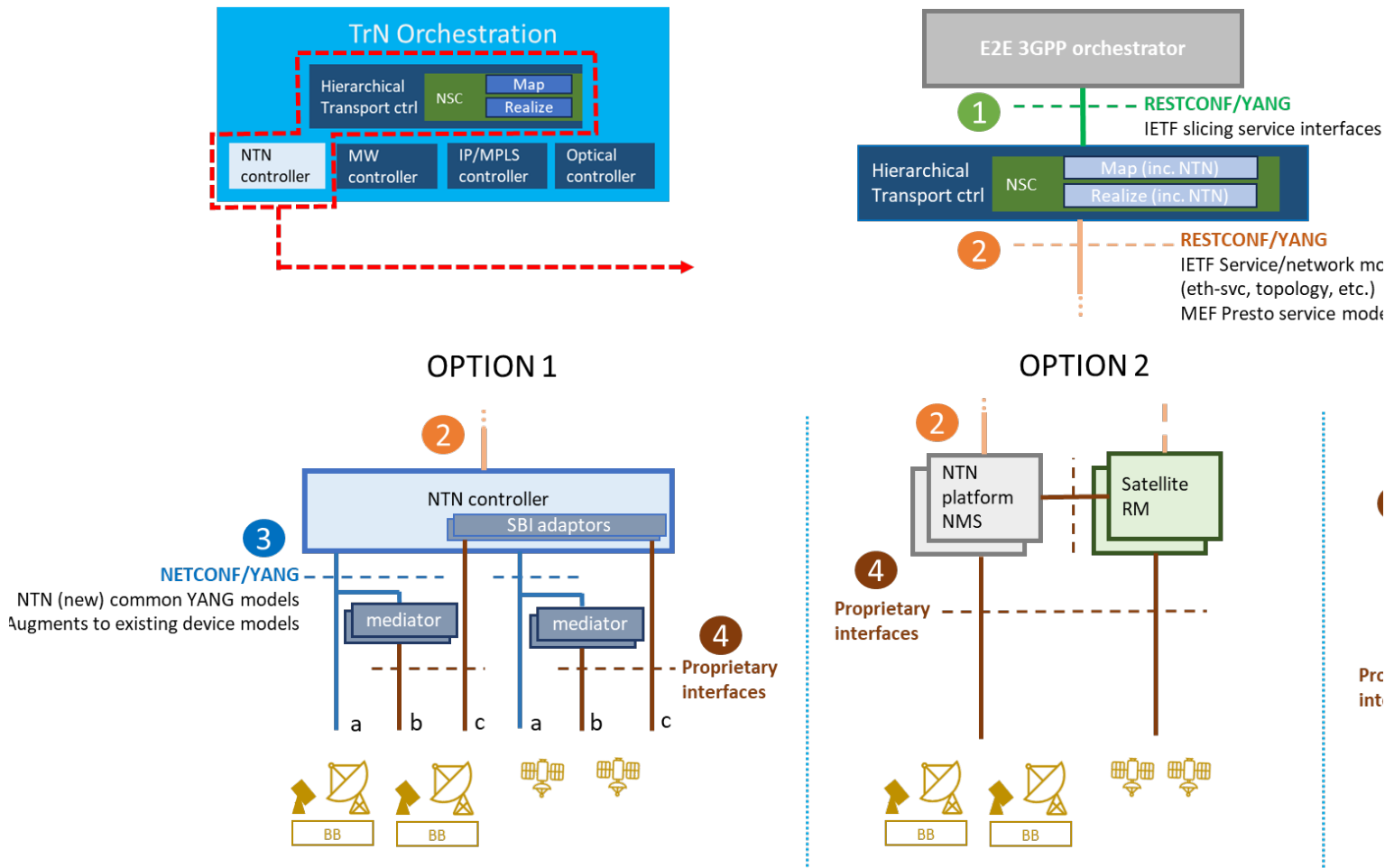


Figure 30: Transport domain service orchestration architecture for TN-NTN integration – case 1

- The NSC hosts the transport network slice mapping and realization functions as considered in IETF and presented in section 2.3.1. The selection of the proper network controllers to be addressed to fulfil the transport slice (which might require the horizontal composition of multiple per-domain slices across several transport domains depending on the RAN and CN NF endpoints) and the “translation” from the highly abstracted service request to a more domain-dependent service and network level models to address the underlying transport domain controllers will be done at this level. The NSC will also check the slice feasibility, checking the slice parameter request with its underlying network view (topology, resources, utilization, etc.).
- To support the NTN domain, the NSC mapping and realization functions need to be adapted to include the new domain. The adaptations depend on how much functionality is hosted in the NTN domain controller. Following the same principles applied in other transport domains, the hierarchical controller should be kept as technology-independent as possible. This way, RESTCONF/YANG interfaces in (2) to the NTN domain controller should consider service or network models with reasonable abstraction, leaving domain-specific complexity to the lower controller.
- A potential example for (2) in this case, with point-to-point connectivity between the remote device at the gNB site and the gateway, would be considering models like the IETF Ethernet service YANG in *draft-ietf-ccamp-client-signal-yang-14* [26] or, for example, equivalent MEF Presto models like MEF 60 L2 ethernet service models. It must be considered that, potentially, model augmentations for NTN might be needed (although it is preferable to work with technology abstraction at this level). The implementation option below the NSC might determine the choice between models.
- Below the NSC, the figure depicts three different implementation options. The preferred or ideal target option would be option 1, in which an agnostic NTN domain controller is deployed to manage control of both the ground technology configuration and (ideally) the satellites in parallel to the device configuration. However, this requires that below the controller harmonized NETCONF/YANG SBIs in (3) are available or defined for the open management of the satellite device technologies, which is not the case today, constituting a relevant gap which forces the consideration of alternative options (temporarily or permanently, depending on industry evolution).
- In **option 1**, a dedicated NTN SDN domain controller is considered, supporting RESCONF/YANG interfaces at its NBI (2) and NETCONF/YANG interfaces at its SBI (3). The controller would manage the satellite domain ground devices (baseband platforms, etc.) and satellite resources (addressing the satellites or a satellite specific resource manager) using standard YANG models (keeping vendor-proprietary augmentations at a minimum) as shown in (3-a), which would provide lots of benefits, as a much higher flexibility to integrate different devices from multiple vendors. In case of existing devices not supporting NETCONF/YANG interfaces, SW mediators can be developed to translate from NETCONF/YANG to vendor proprietary management (e.g. SNMP) as shown in (3-b), or specific interface adaptors can be developed within the NTN controller (3-c). The NTN domain controller is then responsible for configuring the devices and (ideally) the satellites, but also to build the network topology view, handle notifications coming from the devices, gather performance/fault

information, etc., which will be (after processing and adapting to the necessary abstraction level e.g., at service/slice level, not at granular device level) made available for upper elements. However, there are relevant gaps in this option:

- To our knowledge, harmonized YANG models for agnostic satellite ground device management are unavailable.
 - The same happens with satellite control. In this case, in most cases, interfaces to control satellite resources are not open to the SNO clients, and modifications need to be conducted through specific processes, which are not yet supported via OSS/BSS systems.
- Considering the previous gaps, **option 2** provides a quicker way of integration when harmonized SBIs are not commonly available (and would take a long time to develop), avoiding the development of multiple adaptors or mediators. In this option, ground platform-specific NMS systems are considered for managing the devices through their proprietary SBIs but exposing to the NSC common NBIs as chosen for (2). This would be a similar approach to the optical transport domain. Multiple vendor-specific NMS systems are needed (as much as different ground vendor technologies are deployed), but simplified integration with the NSC is done through the support in the NMS of harmonized NBIs. NMSs are considered here to include interfacing (which might be proprietary or open) to the satellite resource managers¹⁵ to adapt the satellite resources to the service (and underlying device and platform configuration) definition. The main aspects which can impact this option:
 - Unavailability of common NBIs as required in (2) in current NMS platforms, which in many cases support REST APIs for integration with higher layers, but are proprietary. Here, although an IETF reference was set, considering the IETF approach followed for transport slices and adoption in the NSC and other network domains like IP, if the industry moves towards other common approach (e.g. supporting common MEF APIs in the NMS API) this might motivate a different choice for the MNO in this level (2), impacting for example the NSC realization module.
 - The interfaces in the satellite resource managers need to be available and open to the MNO (interfacing the platform NMS) in order to fully coordinate reconfiguration linked to service/slice requests.
 - If harmonized APIs in (2) are not available or supported by lower layer elements, **option 3** would be needed. However, this is not a preference for an MNO, as it is not scalable (in cases where multiple technologies and platforms are operated), requiring in this case an API adaptation layer in the NMS NBI in (2). This component would translate between the RESTCONF/YANG service interfaces in the NSC and the proprietary NBI APIs in the ground system / platform NMSs, with new developments needed whenever a new technology is required, constraining the flexibility of the architecture. It can also be seen also as a potential module within the NSC, but the principles followed in the architecture try to respect that the NSC should be kept domain independent.

¹⁵ Evolution in this aspect is already identified in the concept of newer NMS systems of latest generation baseband platforms (e.g. Idirect Intuition, Gilat Elastix with RESTful or Kafka interfaces)

To complement the architectural description for the integration in the transport network segment, **Figure 31** shows graphically some of the key steps in the E2E slice provisioning scope:

- In (a), a slice request is received, following the GSMA template (GST/NEST) principles. This will be translated to 3GPP NRM slice objects in the E2E service orchestrator, as the higher-level *NetworkSlice* and *ServiceProfile*, and the related *NetworkSliceSubnets* and *SliceProfiles*.
- These include the Top, RAN and CN *SubnetProfiles* and relevant objects like the *EP_transport*, which, as introduced in sections 2.2.3 and 2.3.1 constitute the base for stitching 3GPP RAN and CN domains to the non-3GPP transport network. This will be used in (b) to address all the different domain service orchestrators to create the slice. In the transport domain, this means constructing the IETF slice request (with the NBI slicing service YANG) using the information from the 3GPP and profile objects. As indicated in sections 2.2.3 and 2.3.1 and reflected in the figure in (c), VLAN handoff is considered, with RAN and CN network elements presenting traffic to the transport network with slice-related VLAN and traffic with DSCP markings.
- In (d), the NSC will drive the NTN slice configuration process as described before, using any of the presented options for the lower-level domain device configuration
- Finally, it must be considered that in general scenarios, horizontal composition between the NTN transport slice and the terrestrial transport slice from the gateway location to the relevant CN NF location must also be realized. The NSC, relying on inter-domain information, will be responsible for that.

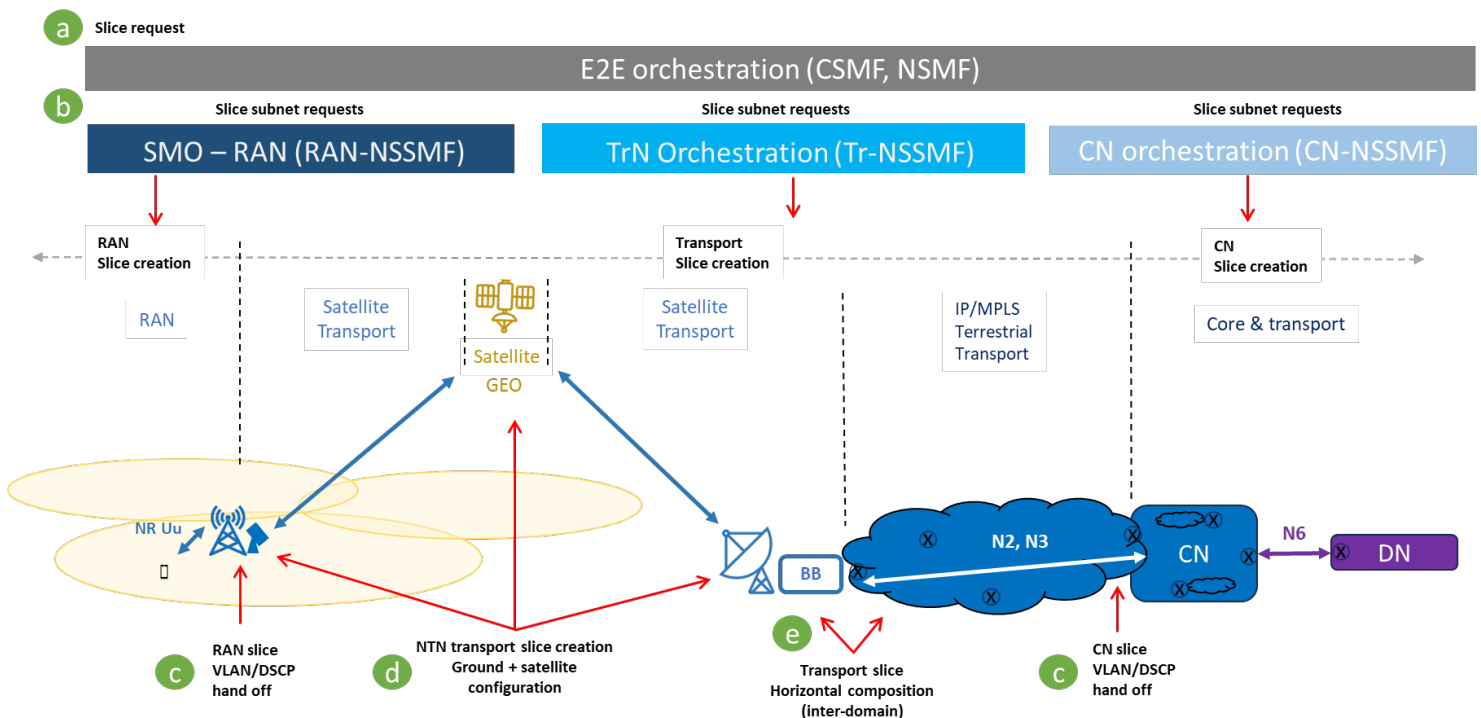


Figure 31: E2E slice creation – high level representation. case 1

4.1.1 Planned PoCs for concept validation

The PoCs will be focused on demonstrating some of the key concepts in the proposed architecture for the integration of the NTN and TN networks, principally:

- The translation from a high-level E2E slice request to the transport domain slice requirements.
- The adaptation of mapping and realization functions in the transport NSC to integrate the NTN transport domain, identifying the proper satellite transport endpoints and providing a realization function to configure the slice in the satellite transport segment (configuring radio-related or QoS/ networking parameters)
- Show the potential for an agnostic SDN controller working with standardized NBI and SBI interfaces (to support option 1, as introduced in the previous section)
- The potential to work alternatively in option 2 or option 3 using API adaptation layers
- Illustrating the need for additional interfaces from the transport orchestration architecture to satellites or satellite resource managers.
- Potentially, depending on the availability of components:
 - Composing an inter-domain transport slice with the terrestrial and non-terrestrial transport sections.
 - Extending to the full service E2E with RAN and CN elements, stitching all the domains.

A lab setup with different components will support the realization of these concept demonstrations. The next figure shows the planned scope. In light yellow, the optional elements that can be integrated depending on final availability.

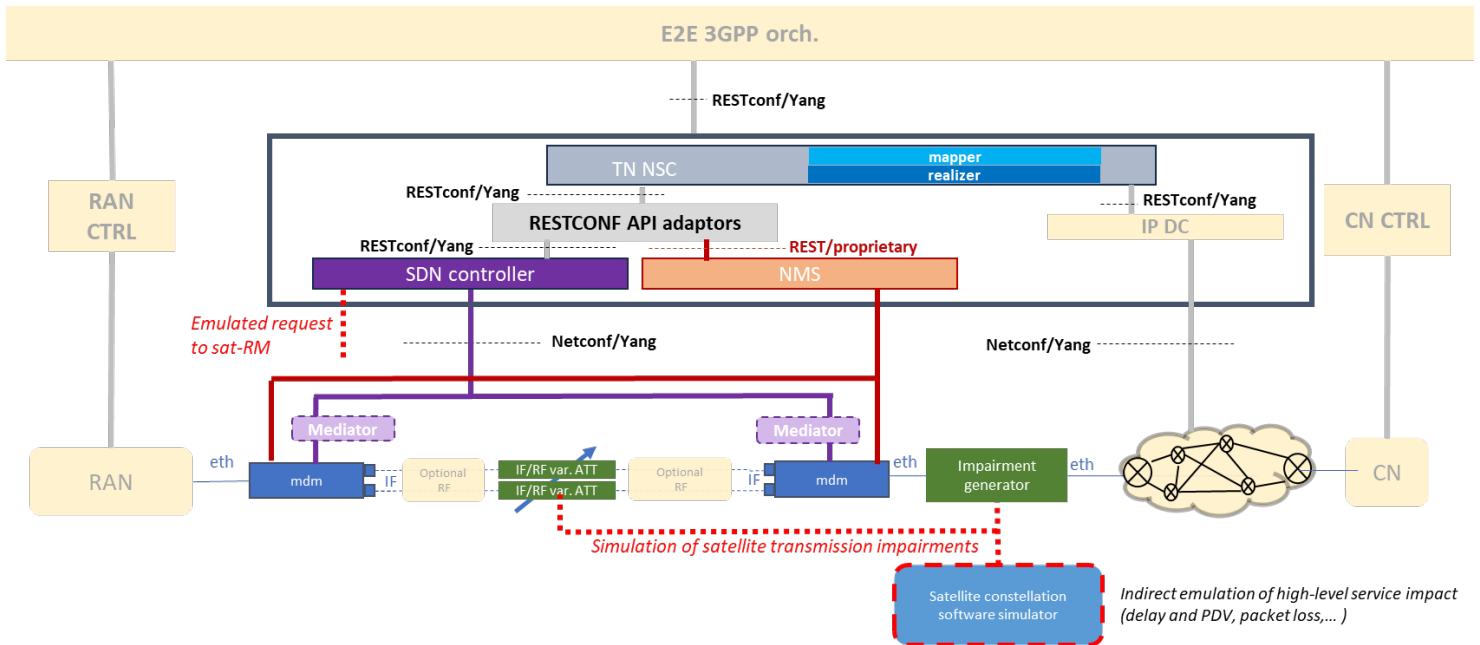


Figure 32: Lab setup for the support of case1 PoCs

As the main blocks:

- The transport network NSC is a simplified software component that includes the transport slicing functionality typically embedded in a more complex terrestrial SDN controlling element, including the mapping and realization functions for terrestrial networks, which needs to be extended for the NTN support.
- As NTN SDN controller for option 1 implementation, an ODL controller will be used, supporting RESTCONF and NETCONF NBI/SBIs. To avoid complex SW developments within ODL, the support of abstract NBIs as those planned for the NSC, RESTCONF API (YANG to YANG) adaptors will be used. Typically, this functionality will be developed within the NTN controller in real scenarios.
- Comtech Elevate 230 modems (which can work as SCPC or Hubless star topology with TDM/TDMA) will represent the devices/platform in the ground network. Modems support SNMP configuration or configuration via their own NMS platform through a REST based API (which would represent option 2/3 as described in the previous section). Legacy Comtech CDM570 SCPC modems are also available to demonstrate the concept of SW mediators with common NTN YANGs with flexible NETCONF to SNMP translation.
- RF components will not be used in principle as part of the overall setup, but can also be considered as an extension. Interconnection between modems will be done at IF (L-band frequency).
- Variable (and programmable) attenuators from Mini-circuits (RCDAT-40G-30) are placed between the modems to emulate, if needed, attenuation variation or fading between the satellite endpoints.
- Next to one of the modems, connected to an output Ethernet interface, an IP impairment generator (Ixia / Keysight Network Emulator II) will be used to emulate the effects of the satellite transmission on the IP flows (delay, delay variation, packet loss). This approach is simpler and cheaper than using an RF-based propagation emulation HW, which was not feasible within the project scope and budget (which, in any case, provides higher benefits when the focus

is put on the validation of the RF and modem performance and characteristics). With the focus on integration and controllability, indirect emulation of impairments has been considered a viable and interesting alternative.

- To generate impact profiles for the network emulator, a software GEO/LEO constellation/network emulator SW (SNS3) and MATLAB will be used to explore representative scenarios and compute the impairment profiles.
- Although the focus is put on the satellite segment, and then on the elements above, the setup can be extended, depending on the final availability of components with (depicted in light yellow in the figure):
 - IP virtual or physical routers to simulate an IP transport segment between the satellite segment and core network functions, for the composition of transport slices, and the IP/MPLS SDN controller to manage their configuration.
 - RAN and CN elements, to extend the slice creation to the full service E2E.
 - RAN/CN and E2E controllers and orchestrators, although at this point, due to complexity, this seems quite unlikely. If finally introduced, the potential extension to E2E with RAN and CN elements will most probably consider the direct configuration of slices in both domains.

4.1.2 Case 1 related extensions

Some variations around the base case 1 can be considered, but due to the additional complexity on top of the baseline case marked in the previous sections or the uncertainty regarding potential consolidation in the industry. A brief reference is provided here for completeness, although the focus will be kept on the scope presented before and the related concept demonstrations.

First, multi-connectivity combining terrestrial and non-terrestrial scenarios can allow for the realization of more flexible service or slice definitions. A section of the MNO remote sites might combine terrestrial (e.g., microwave radio link) and satellite HW on site to provide a backhaul connection (for back-up or terrestrial network traffic offloading purposes). The full E2E is not changing regarding administrative responsibilities; only a second path becomes available for the MNO, leveraging (internally managed) HW on site. Multi-connectivity within 3GPP constitutes a less mature case, also for backhauling. As some potential options for implementation (using the same architecture proposed before):

- With the correct exposure of topologies, inventories and service demarcation points, the NSC can, for a given slice request, select the best path to implement it (so, it would correspond to a mixture between soft and hard slicing, with a best path selection by the NSC which can then be shared with other already implemented slices using the soft mechanisms already presented (e.g., QoS-related). The main challenge in this case lies in the multi-domain nature of the transport domain. Besides the horizontal composition of satellite and terrestrial transport slices presented before, the NSC needs to consider more complex procedures to define the slices, existing parallel transport paths with differentiated resources and capabilities, and being managed by different SDN domain controllers (e.g. the MW link would be handled by the Microwave SDN controller).
- An SD-WAN solution can be added at the gNB site and at a given central terrestrial transport site, aggregating traffic from both paths. The mixed transport path can be operated as an overlay combining both transmission path

capabilities, optimizing services via traffic policies (e.g., assigning different traffic types statically or dynamically¹⁶ to the different paths). The main impact in this case would be fitting the SD-WAN management within the already existing domains within the transport layer and adapting the NSC mapping and realization functions to accommodate that.

- A routing-based solution (adding a router to the gNB site) using similar principles to those presented for IP/MPLS networks in sections can also be explored. As before, the main complexity comes from interleaving transport domains. In this case, in the remote site, an additional element, managed by the IP domain controller is added, requiring a more complex composition of the overall transport slice.

A second variation might come linked to the development and maturity growth of 3GPP NTN R18+ for broadband applications (to VSAT elements, as already presented in section 2.1). This is depicted in the next **Figure 33**, where a 3GPP 5G NTN broadband service to VSAT in FSS band, using MNO internally operated satellite hardware (e.g., ground RF in own teleports) is used. Here, the main impacts in terms of architecture and the full slice E2E are:

- The satellite segment becomes mapped to the RAN domain, and becomes responsibility of the RAN orchestrator (e.g., SMO in O-RAN). The slice subnet in the RAN domain includes the non-terrestrial segment, which comprises an NTN-compliant gNB, the ground elements (antennas, RF, VSAT) and the GEO satellite (which would be the only element external to the MNO).
- The RAN orchestrator -SMO in O-RAN- would need to be updated this way to support the orchestration of the NTN part. This, following O-RAN terminology would typically require the development of modified or new specific control functions and SMOs to handle the NTN configuration, specific Apps (r or xApps) for the optimization of the NTN operation. Additional interfaces to the satellite resource management systems, like in the base case, are also necessary. Although not as complex as it would be in a LEO constellation scenario, coordination between the gNB functions and the rest of the NTN systems, including their operation and management is required. Most of these topics are still not mature and already being the subject of specific studies in SDOs like O-RAN, as presented in section 2.2.2.

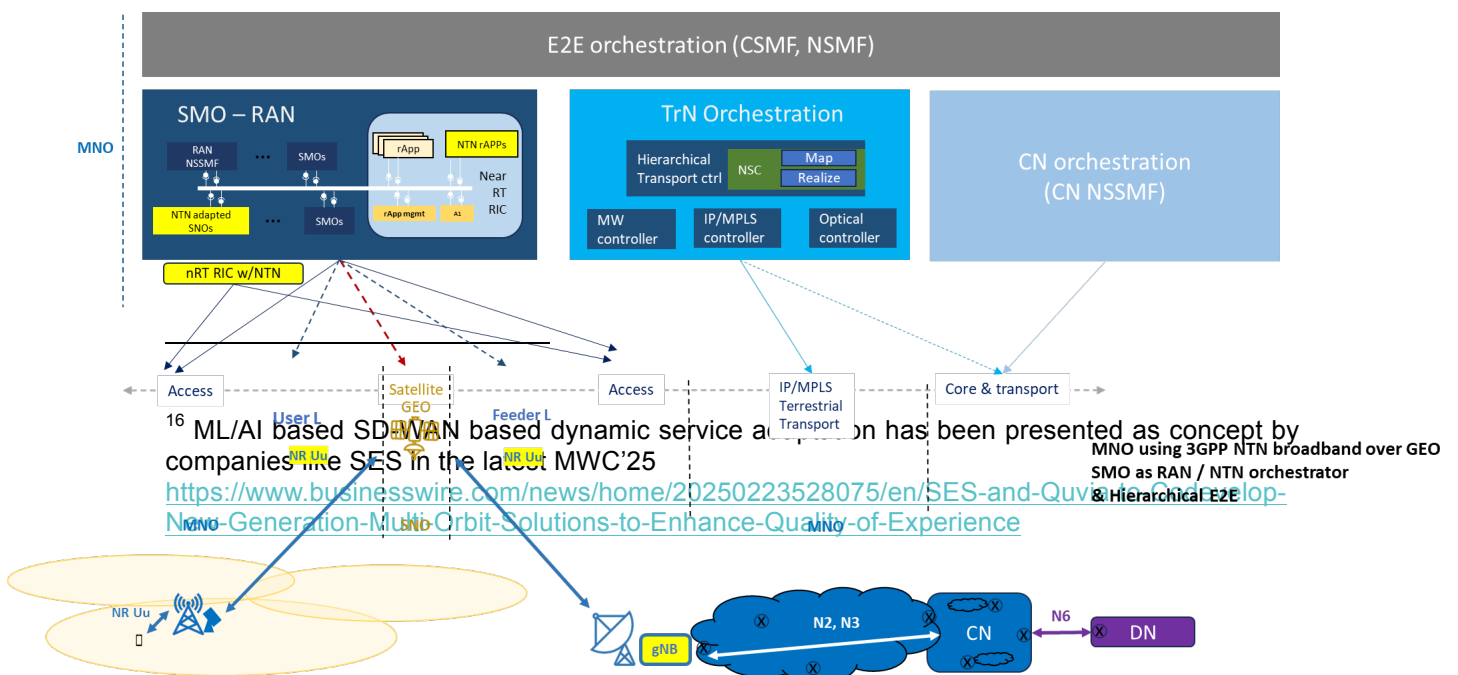


Figure 33: E2E slicing high-level architecture – 3GPP NTN broadband over GEO FSS, MNO internal operation

It is still uncertain whether cases like this would materialize, or if, on the other hand, as technology and standardization develop, similar options would be better integrated as a managed service (e.g., case 2) using gNBs and ground assets property and operated by the SNO, or through more complex scenarios like case 3, where a shared network approach might be followed, like in some integration architectures foreseen for D2D services.

4.2 Case 2: NTN as 5G transport – managed service

This case, as introduced in the first project deliverable, constitutes a more typical case nowadays for MNOs, especially in the case of VHTS or MEO/LEO constellations, which are not typically directly owned and operated by the MNO. Connectivity services in this case are made available to the MNO as a fully managed service by an SNO that owns and operates the NTN system (vertically integrated to provide connectivity services) or by a specialized satellite service system integrator and service provider which has its own agreements with one or several SNOs. Use cases are similar to those applicable to case 1, but with higher potential performance in terms of throughput or latency (in the case that MEO/LEO systems are used) or flexibility, linked to the additional capabilities of satellite very high throughput satellites and constellations. In this case:

- All the elements but the complete satellite segment (including the ground-supporting platforms and devices) lie within the MNO administrative domain. The MNO's E2E service orchestration architecture directly manages the RAN, CN, and a section of the transport network in this way.
- The SNO (or satellite service provider) has its own service orchestration platform, which manages the complete satellite segment, which might include sections of terrestrial transport (e.g. IP/optical terrestrial network) between the system gateway locations and the interconnection PoPs where traffic is delivered to the client (MNO).

The next figure shows a high-level diagram of the E2E slice orchestration architecture in this case, including the elements under the responsibility of each network domain

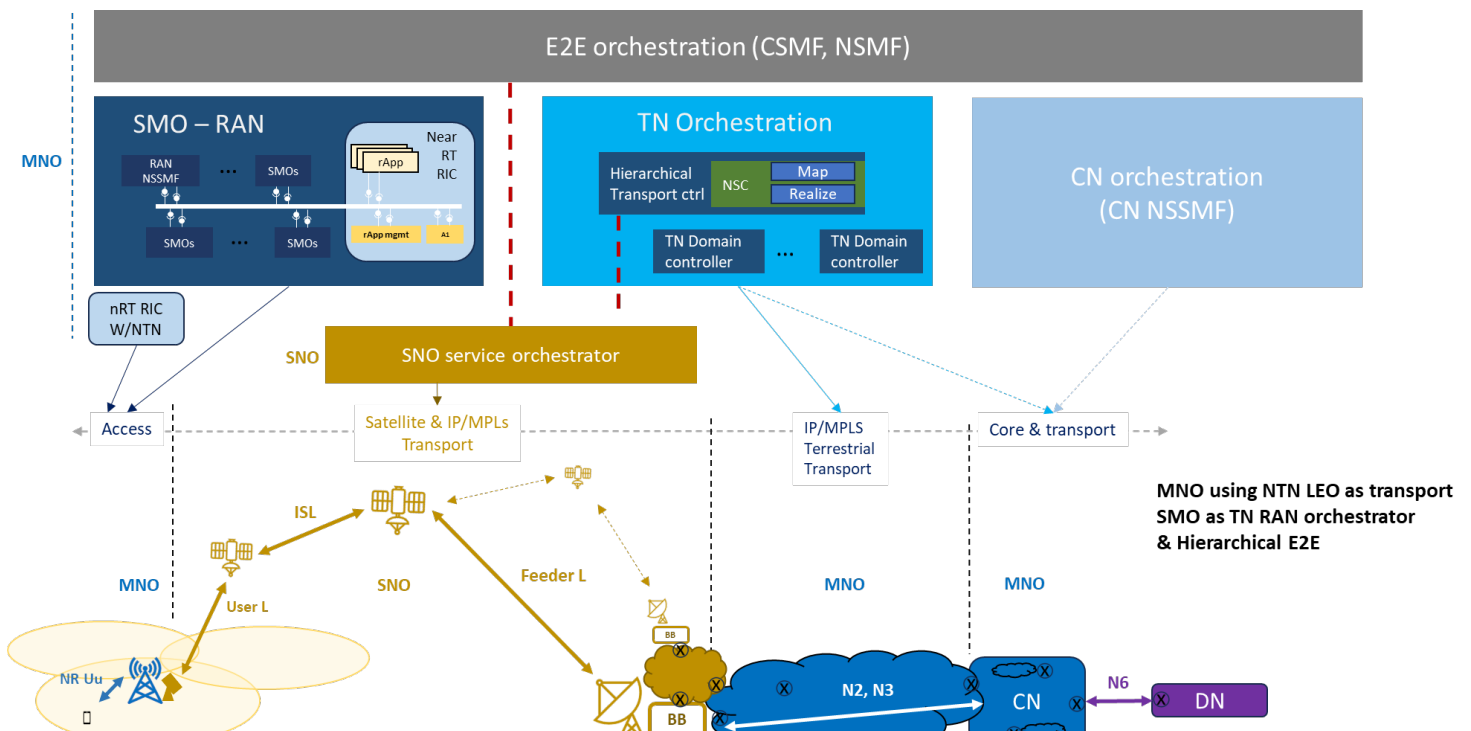


Figure 34: E2E slicing high-level architecture – satellite LEO as transport solution – SNO managed service

orchestrator below the E2E system.

The main differentiating aspect in this scenario with respect to case 1 is that the whole satellite segment is within the administrative domain of a third company (for simplicity, we will assume an SNO), which will use its own intra-domain service orchestration architecture and systems, as depicted in the figure.

As considered also in case 1, the capabilities of the underlying satellite network and the platforms employed for the services are those which will define the type of slices and parametrization ranges which can be supported in the integration scenario. These would not be the same in a GEO VHTS or in a LEO transparent or regenerative satellite network, and, even with similar satellite system types, there can be differences linked to how the SNO operates and manages the underlying resources, exposes APIs with constrained functionality to the MNO, etc.

Section 3.1.1 provided a brief update on LEO/MEO broadband constellation systems, highlighting some differences between the solutions that reinforce the presented point. For example, not all the systems provide similar commercial services with similar specifications. Some systems commercialize just pre-defined best effort plans with closed service profiles and performance characteristics, others mix best effort services with assured services (SLA) mixing guaranteed and non-guaranteed traffic, others offer the option, within a more or less constrained service offering, of making (with limitations in frequency) changes to the services via service request. The underlying networks rely on different technologies and are not operated similarly by the SNO (some present an underlay with 4 classes of service, others with 3, etc.).

In summary, transport slice capabilities will depend on the satellite solution and the service management and operational constraints dictated by the SNO. Of course, a roadmap towards higher flexibility can be considered as SNOs adopt more flexible service orchestration architectures. APIs exposed to the MNO for provisioning, assurance, and SLA monitoring are also non-homogeneous as of today.

In any case, as was presented for case 1, multiple resources in the satellite ground segment can be configured to support the configuration of a transport slice matching some high-level parametrization (throughput, latency, availability, etc.). These extend to the underlying baseband platforms and their radio and networking (and QoS) functionalities and capabilities, RF systems, etc., and, in more complex (e.g. LEO global) systems, to the devices in the necessary complementary terrestrial transport network (also within the SNO scope) between the gateways and the interconnection points (to which similar considerations to those applicable for the MNO terrestrial transport network apply). LEOs can also be seen as HTS/VHTS systems, with lots of flexibility in resource allocation (per beam spectrum, beam power, QoS functionality and even SW reconfiguration, which can be orchestrated via centralized SDN controllers.

In addition, in this case, LEO constellations offer an additional degree of flexibility, especially those including ISLs between satellites, which can be seen as routed networks where optimizations can be done to optimize latency or to provide SLA differentiation to different traffic types (or slices when adapting to the concept explored in INTEGRATION-2). Although, as introduced in 2.3.2, standardized NTN routing solutions are still a research topic, proprietary implementations can still provide the necessary tools to implement extra functionality in relation to NTN transport slices. A similar consideration in terms of an extra degree of capabilities and flexibility can be

applied to multi-orbit satellite systems, either seen as a single constellation combining orbits or separated constellations combined by the SNO and offered as an integrated service to the MNO (which supposes a much higher complexity for orchestration for the SNO).

However, in this case, all these functionalities and complexity lie “hidden” for the MNO, being within the management and operational domain of the SNO. The key aspect for the integration with the MNO service orchestration architecture will be the interfacing between the orchestration systems of each company and the exposed/enabled functionality via APIs (linked, of course, to the mentioned system capabilities, which are SNO solution-dependent). Of course, the potential for implementation of transport slices keeps aligned with the capabilities and features of the SNO satellite solution.

In case two, as depicted in **Figure 34**, two main interfacing options¹⁷ are identified (which might not be exclusive) for the integration of the satellite transport domain in the overall E2E slice orchestration architecture. One would be a direct interface to the MNO E2E service orchestrator at the OSS layer, and the other to the NSC within the transport network service orchestration domain of the MNO. **Figure 35** provides a higher level of detail in relation to the proposed integration solution.

The satellite transport segment will be integrated using the same architectural principles as in case 1, using the satellite network as a broadband transport solution to provide backhaul to remote 5G nodes. The overall E2E and transport network domain orchestration architecture will then be used as the base for the integration.

- As a first option for the integration, in (1), the MNO E2E can directly address the SNO service orchestrator if the SNO uses a higher-level service orchestrator supporting RESTCONF/YANG service interfaces as defined by IETF and considered for use in the MNO terrestrial transport segment, as presented in section 2.3.1. This would be the simplest and most straightforward case for the MNO, which would be able to address at a high abstraction level the top element in the SNO service orchestration domain with similar interfaces to those used for its own terrestrial domain. If these types of interfaces were commonly adopted and supported by SNOs, integrating multiple satellite solutions would simplify.
- The E2E orchestrator would need to process the slice and break it down to the individual requests for all domains. In the specific case of the transport segment, the transport slice spans in this case two administrative domains, so to effectively process and distribute the proper requests, the orchestrator will need to rely on information provided by the NSC (own element) and the SNO service orchestrator to compose the request.
- Like in case 1, at (1), the same IETF service models will be considered, like the IETF transport slice service in *draft-ietf-teas-ietf-network-slice-nbi-yang-22* [8] to provision the satellite transport slices, following similar considerations to

¹⁷ *The focus is kept here on the technical integration aspects. However, for purposes like billing, etc, it is possible that additional interfacing is also needed at the BSS layer, and that agreements and contracts are also in place between companies prior to the services becoming operational.*

generate the request. However, in this case, there is additional complexity in the overall service E2E, and there will be slice endpoints belonging to different administrative domains (SNO and MNO), and the proper attachment connection between them needs to be managed as well.

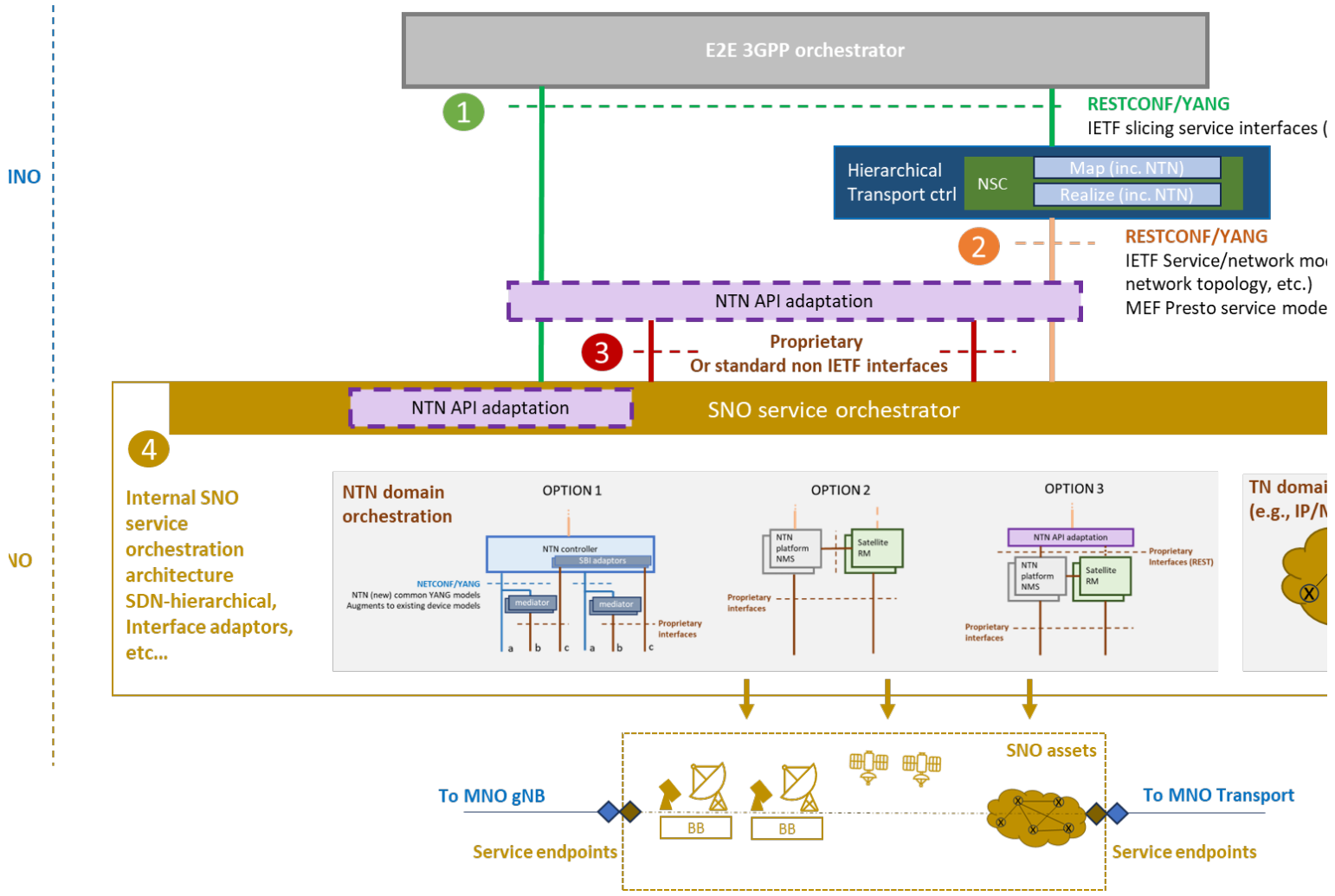


Figure 35: Transport domain service orchestration architecture for TN-NTN integration – case 2

- To increase automation, additional models like *draft-ietf-opsawg-teas-attachment-circuit-20* [9] to provision the necessary attachment services or others, for example, *draft-ietf-teas-network-slice-topology-yang-00* [18] to allow requesting topology intents in the MNO request. Additional ones within the IETF transport slicing general framework can also be relevant to enable the SNO to expose service attachment points and resource and topology views to the E2E MNO service orchestration layer
- A second option for integration would be for the hierarchical transport controller within the transport domain of the MNO, which hosts the NSC function, to become the element interfacing with the SNO service orchestrator. The MNO transport network controller builds the complete transport network resource and topology view of the MNO and can work at a lower level, with additions (especially in the mapping and realization functions) that can provide the requests to the SNO service orchestrator with a lower abstraction. Being also the element keeping the MNO transport domain topology and resource view, it might be simpler to coordinate the overall transport slice (satellite and terrestrial) processes at this level, and to stitch the MNO and SNO domains horizontally composing the slice. Going one way or another might depend on

the functionality and level of abstraction in which the SNO service orchestrator works and its supported APIs. It must be noted that IETF service model definitions at the NSC level still try to be technology independent (L2/L3 service and network models, as those already mentioned) and that no specific NTN transport slice realization work is available in IETF definitions.

- To avoid interfacing the NSC via NBI through the E2E controller, the options presented before might not be exclusive and can be implemented in parallel. Additional BSS interfacing (and prior existing contracts between parties) would complement these interconnections as OSS layer.
- In either of the two options, there is likely no interface alignment between the MNO orchestration architecture and the SNO service orchestrator. In these cases, adaptation functions would be needed to allow for quicker integration while standard adoption develops, as shown in the figure, at (3). This is not desirable, being a non-scalable procedure, unless there is at least a common adoption in the satellite industry of open APIs (even if different to the ones proposed for the MNO domain, common APIs would at least minimize the impacts, reducing the number of adaptation functions). API adaptors would be needed in this case within the SNO service orchestrator, as intermediate elements or in the NSC or E2E orchestrator of the MNO (which is not typically desirable, especially if interfaces are not technology agnostic).
- At (4), the SNO will implement its own service orchestration architecture, which will be transparent to the MNO. However, the technologies used and the architecture for the management and orchestration might impact the service performance, SLAs, slice provisioning and lifecycle management procedures. The adoption of similar architectures and procedures (layered architectures, SDN and intent-based control relying on open interfaces, etc.) is probably a need, although it is not to be set or defined by the MNO.
- Once the SNO service orchestrator receives the request for provisioning a slice, after checking and notifying feasibility, it will manage the provision and configuration of the necessary resources in the ground elements and the satellites to ensure that connectivity as requested by the slice service request is created between the necessary endpoints and that it can meet the required SLA. In this respect, it will be a similar problem to solve to that already presented in case 1, although the way to solve it might be the same, adopting similar orchestration procedures and architecture (SDN agnostic control, vendor NMS with common APIs, adaptors, ...) or be SNO solution-specific. If the connectivity (it would be the typical case) spans a terrestrial and non-terrestrial segment in the SNO domain, a transport slice in the terrestrial segment of the SNO will also be needed to provide continuity, and the horizontal composition of both transport slices will be needed as well.
- Besides supporting provisioning procedures, the SNO orchestrator must expose abstract topology information for the E2E controller or the NSC and performance data related to the slice or notifications linked to the requested slice SLOS.
- If the SNO orchestrator is not interfacing directly the MNO NSC, the E2E MNO orchestrator, as part of the overall E2E slice creation, supported by its

underlying transport network NSC and the SNO service orchestrator, will be the entity responsible of ensuring that the MNO and SNO are composed together (SNO-MNO horizontal slice composition). If there is a direct interface between the SNO orchestrator and the MNO NSC, the process can also be managed by the MNO NSC.

To complement the architectural description for the integration in the transport network segment, **Figure 36** shows some of the key aspects in the E2E slice provisioning

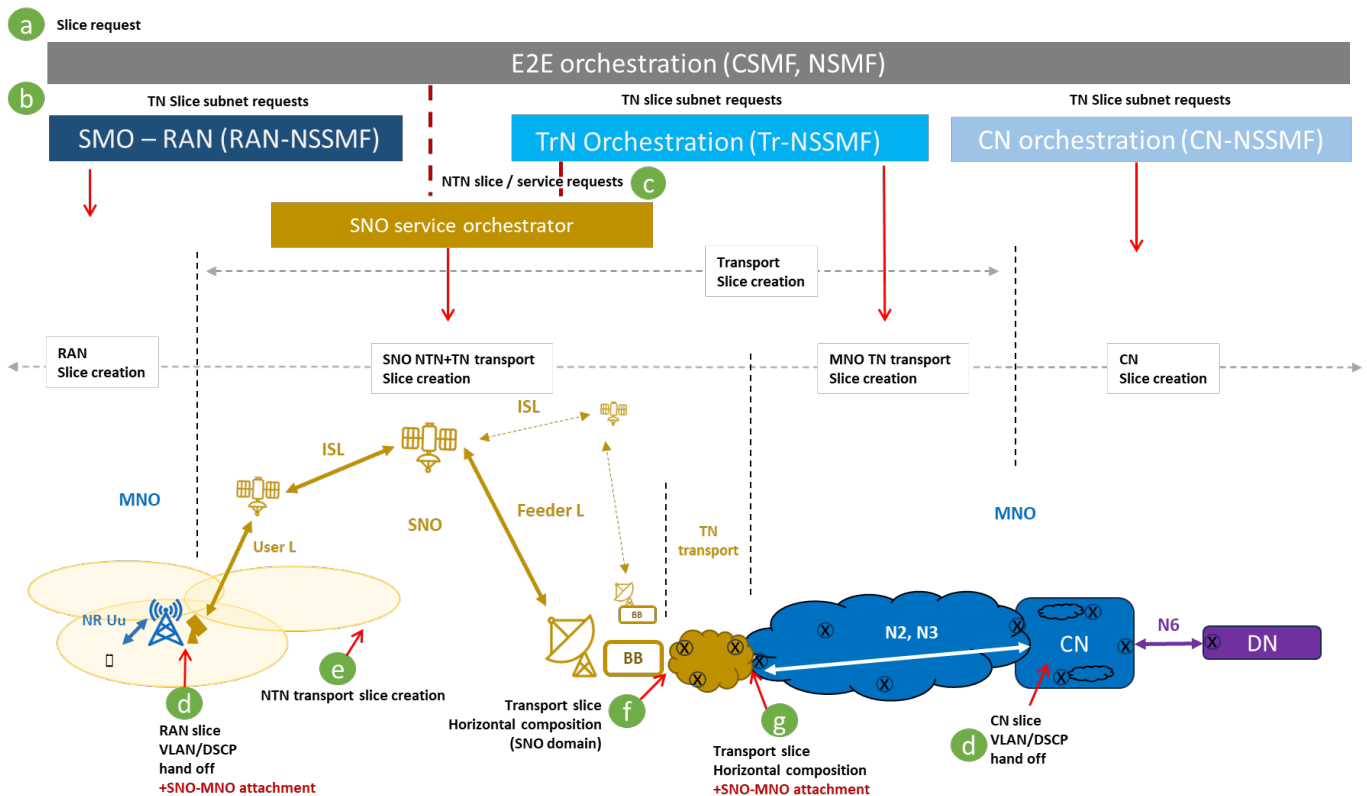


Figure 36: E2E slice creation – high level representation, case 2

scope:

- In (a), slice requests are received, following GSMA template (GST/NEST) principles. These are translated to 3GPP NRM slice objects in the E2E service orchestrator, as the higher-level *NetworkSlice* and *ServiceProfile*, and the related *NetworkSliceSubnets* and *SliceProfiles*. These include the Top, RAN and CN *SubnetProfiles* and relevant objects like the *EP_transport*, which, as introduced in sections 2.2.3 and 2.3.1 constitute the base for stitching 3GPP RAN and CN domains to the non-3GPP transport network. The E2E orchestrator relies on the underlying domain orchestrators to build all the necessary inventory and topology information. In this case, the information for the NTN domain might come directly from the SNO orchestrator or the TN NSC depending on interfacing.
- These objects and information will be used in (b) and (c) to address all the different domain service orchestrators to create the slice. In the transport domain, in this case, this means constructing the proper IETF NBI slice service requests for the terrestrial (MNO domain) and non-terrestrial (SNO domain)

segments using the necessary attachment circuits and endpoints in (d), which shall be provisioned either automatically or already prepared and configured before the slice service requests.

- As indicated in sections 2.2.3 and 2.3.1 and reflected in the figure in (d), VLAN handoff is considered, with RAN and CN network elements presenting traffic to the transport network with slice-related VLAN and traffic with DSCP markings.
- In (e) the SNO service orchestrator will drive the NTN slice configuration process using its resources, without MNO intervention. If the connectivity extends from a (several) satellite gateway(s) to other terrestrial PoP(s) for interconnection with the MNO, the NTN transport slice will need to be composed (f) with a TN SNO transport slice that also needs to be provisioned.
- The MNO NSC will provision the transport slice in its terrestrial network according to the procedures already introduced in 2.2.3 and 2.3.1, and the SNO transport slice and the MNO transport slice need to be horizontally composed as well (g). This can be managed by the E2E orchestrator or the MNO NSC, depending on the interface with the SNO orchestrator.

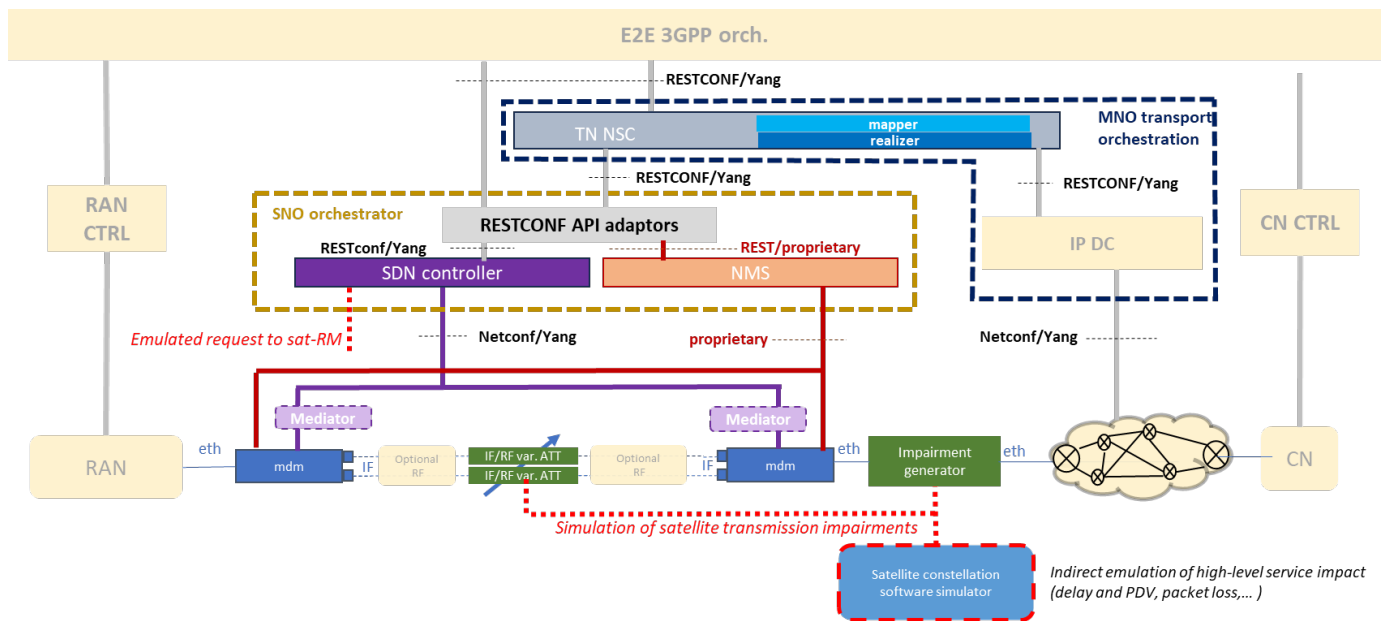
4.2.1 Planned PoCs for concept validation

The PoCs in this case are incremental to those presented for case 1. In case 2, all the concepts presented in case 1 are of applicability as well, but in a practical application would be within the responsibility of the SNO, hidden from the MNO. E2E architectures are similar in both cases, with the differences set by the different tenancy in the satellite segment and the proposed solution for integration and slicing support bases also on the same principles (IETF transport slices and integration considering the TN service orchestration architecture, taking as a reference the transport domain).

Taking this into consideration, on top of the aspects already targeted in case 1, the main aspects of case 2 PoCs are:

- Exploring the options/gaps for interfacing at the SNO orchestrator NBI (to the E2E MNO orchestrator or the MNO transport domain NSC), with different levels of abstraction depending on the interfaced system.
- Exploring the complexity of stitching domains under different administrative responsibility (e.g., automated provisioning of attachment circuits, etc.) and horizontal composition of transport slices from different tenants.
- Identifying potential constraints in the NTN domain functionalities and APIs exposed by commercial SNOs in terms of slicing provisioning and impacts to the proposed architecture.

The lab setup from case 1 can be fully reused to support part of these targets. The next figure shows it, identifying the administrative responsibilities in this case. The components are similar to those already presented, but interfaces, API adaptors, and network impact generation can differ (in the latter case, simulating LEO constellations with different architecture and functionality).



To complement this and explore the main constraints and impacts coming from the multi-tenancy model, the development of an additional setup is currently being explored with a satellite provider (Intelsat), which would open the possibility to explore the previous targets using a multi-orbit GEO+LEO (OneWeb) managed service. Extending the previous lab setup is seen as desirable to complement the internal tests with integration aspects with commercial platforms and APIs, but it is still dependent on the final availability of resources and support by the satellite operator. The following **Figure 38** shows the planned setup, which would include:

- The transport network NSC, playing a similar role to that presented in the rest of the setups, with the proper internal developments to integrate the NTN segment.
- API adaptors, which will be needed to adapt from the proposed interfaces to those supported by the commercial SNO service orchestration and management layer, which most likely will not match those set as a reference in

Figure 37: Lab setup for the support of case 2 PoCs

the terrestrial transport network.

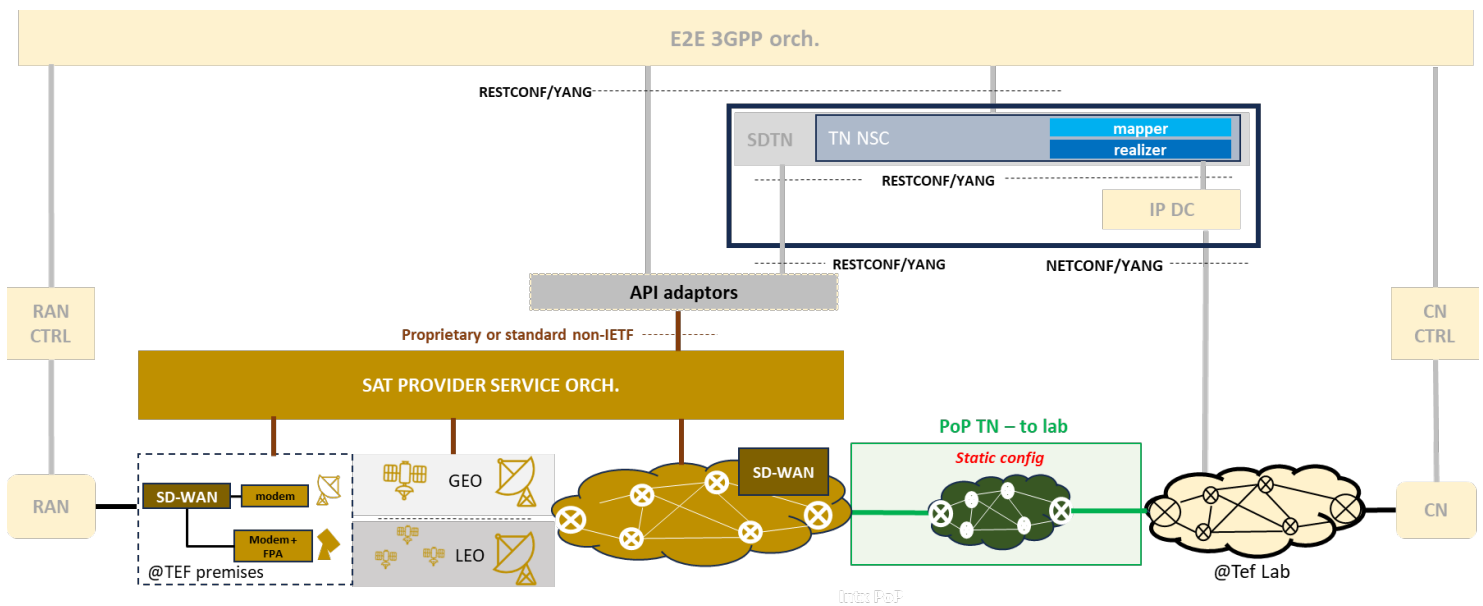


Figure 38: Multi-orbit commercial managed service setup for the support of case 2 PoCs

- GEO and LEO and SD-WAN devices placed in Telefonica premises (site survey pending). In principle, a setup composed of a Gilat Capricorn modem, with RF and a parabolic antenna for the GEO transmission and a flat panel integrated device from Hughes for the LEO transmission, with Xiplink SD-WAN.
- The SNO service orchestration platform, deployed remotely, which will expose APIs which can be used for monitoring and management.
- A statically configured transport section from the SNO PoPs to the Telefonica premises
- Optionally, as in case 1, depicted in light yellow, an IP/MPLS routing section with an IP SDN domain controller and RAN / CN elements to extend to the full slice E2E if finally possible, depending on the availability of the components.

Other potential extensions for the lab setup in case 2 are being explored at the time of writing, also targeting the analysis of interfacing options and complexity towards systems under development by the satellite industry. An option under assessment being replacing the internal SDN control of the lab modems with an SDN multi-orbit orchestration system. A collaboration with Aalyria is being explored to assess the potential extension in this direction, which would result in a potentially alternative setup as depicted in the following figure.

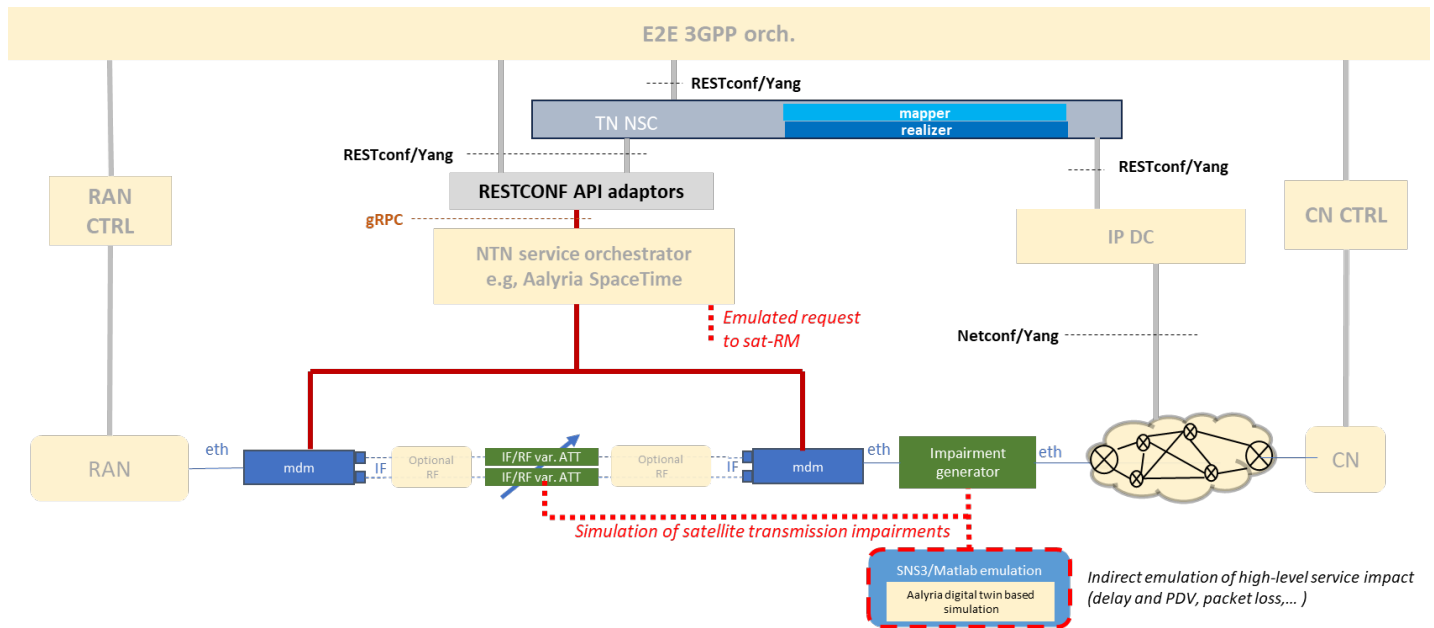


Figure 39: Alternative lab setup for case 2, integrating a third-party NTN orchestrator with open APIs

4.2.2 Case 2 related extensions

Case 2 includes inherently the extension to satellite multi-orbit configurations, which are transparent to the MNO and are not impacting the overall architecture but for the specific constraints that a given multi-orbit configuration and underlying devices and satellite infrastructure can have on the available resources, service performance and acceptable slice parametrizations, as well as limitations which might apply to the exposed orchestration APIs.

Similar variations to those presented in case 1 can be considered, but they are left equally for further study. Combining a non-terrestrial transport connection with a terrestrial network in a multi-connectivity scenario would mean a similar case here, with identical considerations, with the extra complexity of managing a dual connectivity section in which one of the options corresponds to a different tenant.

In this case, it is also possible to consider the longer-term evolution towards 3GPP 5G NTN broadband services for the transport link. A potential way of integrating these services can be, among the options typically considered for D2D applications as presented in case 3, as a fully managed connectivity service, leveraging the complete 5G mobile network from the SNO. It can be seen as a similar case to that of Onweb LEO as of today, which relies on an LTE physical layer with LTE-adapted RAN network functions (RAN and CN) but still provides a fully managed transport service between service demarcation points agreed with the client (e.g., MNO).

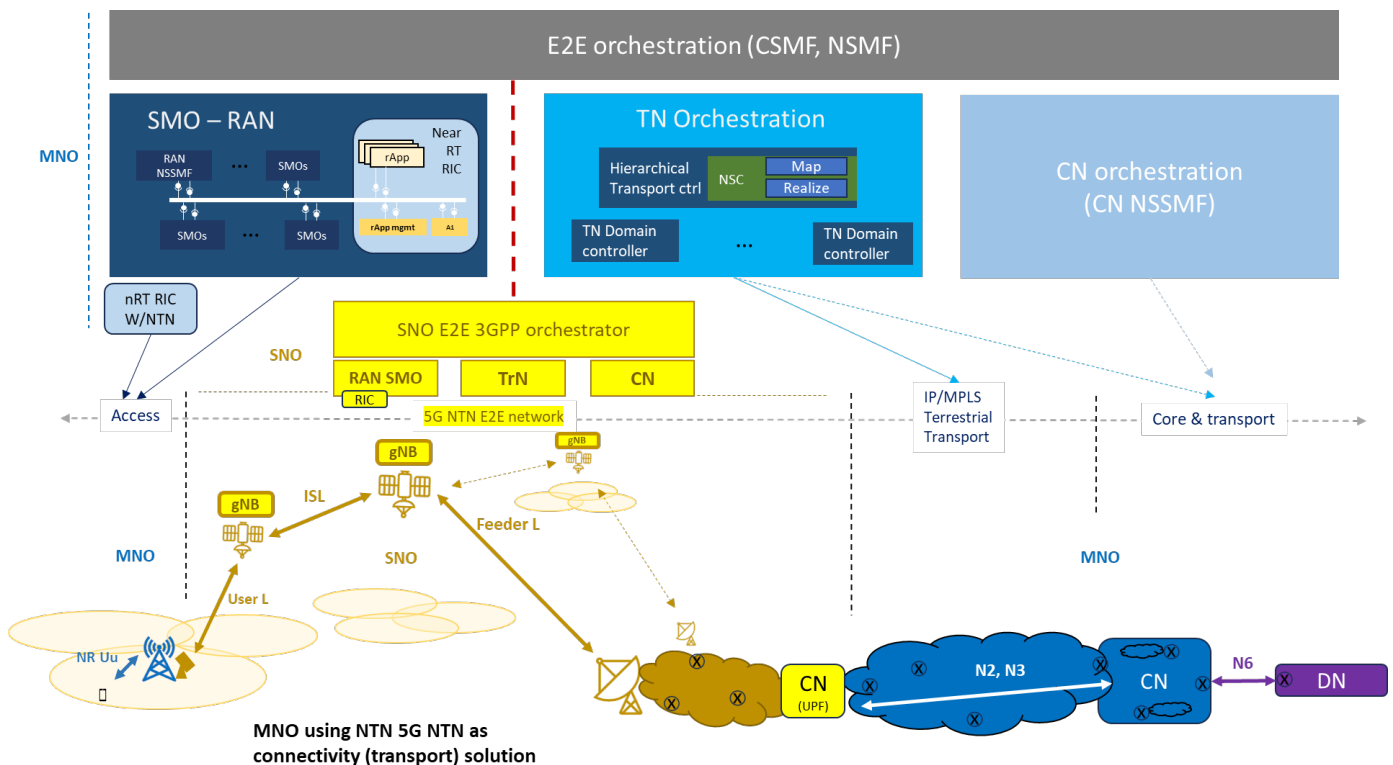


Figure 40: E2E slicing high-level architecture – 3GPP NTN broadband with LEO regenerative, as managed connectivity service

Figure 40 shows a high-level diagram of the case, particularized for a LEO regenerative architecture (others like transparent and not only in LEO but MEO or GEO can also be similarly considered). Here, the SNO has its own 3GPP 5G NTN mobile network, including RAN, transport and CN NFs, and manages it via a similar 3GPP layered service orchestration architecture as presented for the terrestrial network. Integration in this case would be most probably done at the E2E orchestration level in the OSS layer (and in parallel in the BSS systems on top) with 3GPP and TMF interfaces, but it would mean a quite similar case to that studied in the base case 2.

As commented for case 1 extensions, it is also still uncertain whether a case like this will become feasible or attractive for commercialization by SNOs and materialize or, if, on the other hand, other alternative scenarios like case 3 would be preferred.

4.3 Case 3: L1-service and sharing based NTN integration for D2D

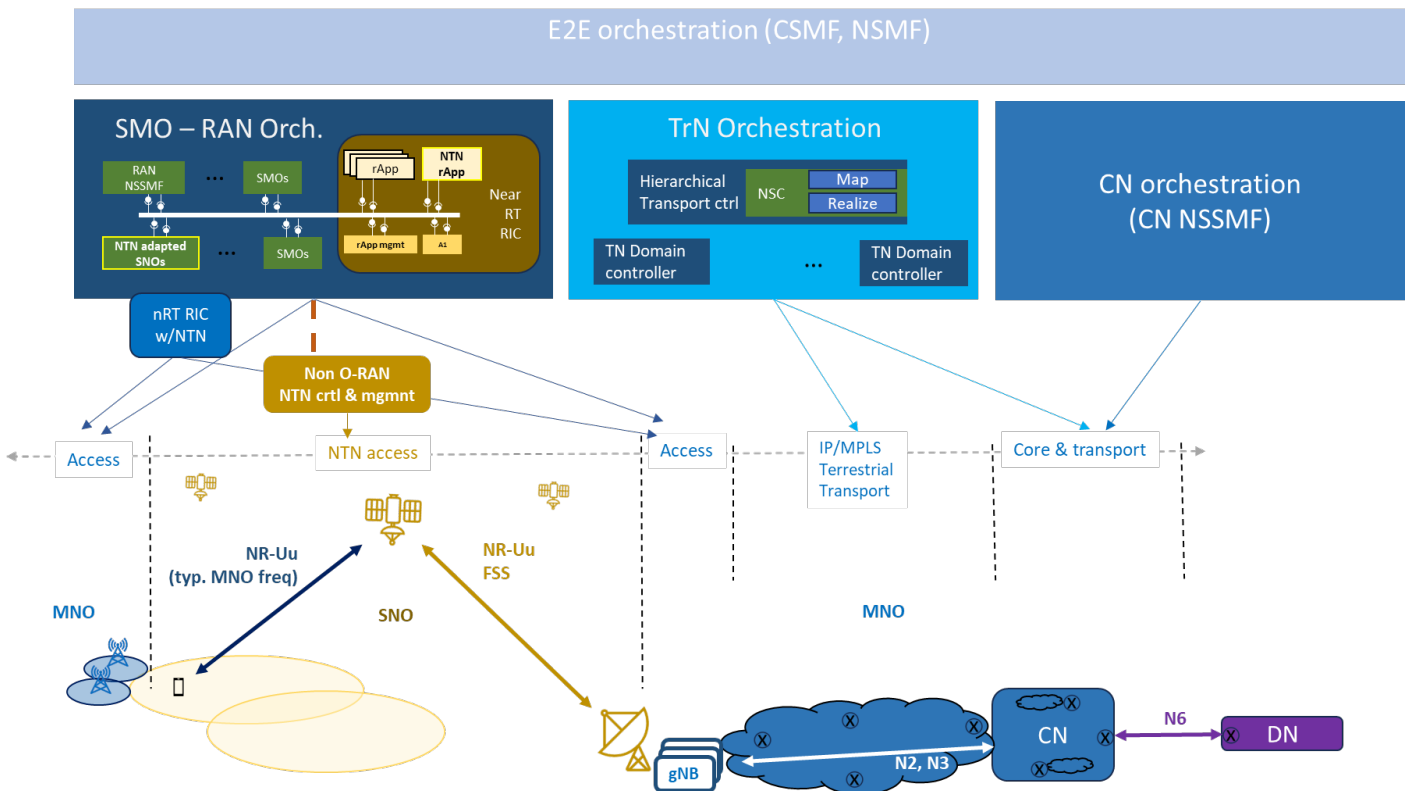
In the first project deliverable, case 3 was particularized for NTNs providing D2D service with a transparent architecture, taking as a reference projects in development targeting this type of architecture. Here, we will focus first on a particular transparent case, followed by a more generic approach. The evolution in NTN standardization (as updated in section 2.1) opens options for the implementation of different TN-NTN integration architectures not directly linked to the specific satellite architecture, so it is this way possible to find TN-NTN network sharing based integrations for regenerative or transparent satellite architectures, with the same applying to roaming based integrations (where for example, transparent GEO satellites are already being used in a roaming based integration for R17 NTN IoT services).

Considering this, the following provides a general update around the expected architectures for integration keeping a high-level definition, considering the larger immaturity of this category (where the main systems aiming at generic services start with a 4G service approach and limited services for some time, as IoT or non-continuous messaging and light broadband), building on top of the rest of considerations already included in the first deliverable released during the project.

4.3.1 L1 satellite connectivity for D2D service

This case will be kept as a more particular one, applicable for transparent satellite architectures, corresponding to the implementation architecture planned in one of the running projects for D2D presented in section 3.1.2. This would be that of AST SpaceMobile, at least in its initial project stage (as reflected already in **Figure 24**), together with the potential evolution to the more general architectures consolidated also depicted in that figure. The case is also quite similar to that presented in **Figure 33**, with the main difference being that a D2D service is targeted instead of a BB service to a VSAT-like terminal and the ground infrastructure tenancy and management responsibility, which correspond to the SNO.

In this particular architecture, gNBs are to be deployed in the gateway locations of the SNO, but the RAN nodes are owned and under the management responsibility of the MNO. The architecture here has been intentionally simplified, considering the MNO will deploy its own transport to its CN, which would be a typical case. So, the E2E service scope is within the MNO domain, but for the satellite gateway and satellite configuration (beamformer, etc.), which needs to be coordinated with the gNB



configuration to provide the services.

Figure 41: E2E slicing high-level architecture – transparent satellite LEOs as L1 connectivity service

Figure 41 shows the E2E slice orchestration high-level architecture, considering that the MNO has adopted O-RAN and its SMO orchestration in the RAN domain (which is not mandatory), to link with the progress ongoing in the O-RAN standardization presented in 2.2.2.

This case, considering the current approach, does not totally adjust to 3GPP NTN standards, as the frequencies used in the user side are those of the MNO and not MSS bands, which are the ones considered by now for D2D in 3GPP from R17. In terms of end-to-end slicing, it is an almost full E2E for the MNO which needs to be solved relying on the referenced terrestrial slice service orchestration architecture, relying on mechanisms and resource management within each of the network domains. The specific considerations for the NTN elements integration are still open and part of standardization work:

- Proprietary adaptations or extensions in the ground NTN RAN nodes are needed. This typically restricts the vendor map that can be used as part of the SNO solution, even if the tenancy, management, and operation rely on the MNO. This way, specific NTN-related configuration actions might be needed in the RAN NFs.
- This way, the RAN orchestrator needs to integrate the necessary functionality and interfaces to address the NTN-enabled RAN NFs. As depicted in the figure, for a case with O-RAN NFs, taking as a reference the concept already presented in sections 2.2.1 and 2.2.2, the SMO will need O&M SMOS adaptations to allow for the specific management needs. Updates to interfaces and underlying models like O1 are also required. As already presented, these adaptations are part of open standardization work.
- The NTN control and management function will typically be a dedicated element under the SNO domain to control the satellites and the ground NTN infrastructure (including radio resources), as well as the radio resources of the NTN infrastructure (NTN payload(s) & NTN Gateway(s)). However, there needs to exist coordination between the gateway and satellite and the RAN NF configuration to deliver the services with a required SLA, and interfacing between the NTN control function and the RAN NF is needed to interchange relevant information from the NTN segment as beam reference locations, information about feeder and user link handovers and availability periods, identification of satellites and gateways, cell identifiers, etc. These interfaces are outside the scope of 3GPP and under discussion in the open studies in O-RAN. In the figure, an interface between the SMO and the NTN control function has been depicted, which can serve the two purposes (the SMO would be able to enable indirect connectivity from the NTN control element to the RAN NFs via the E2, O1 and A1 interfaces, and would include additional elements as rAPPs and xAPPs in the RIC controllers to optimize the NTN-TN operation, for use cases like TN-NTN handovers, interference optimization, etc.).

For slicing support, most of the resource configuration will lie on the RAN NF, through general RAN mechanisms as scheduling, resource partitioning configuration, etc. Slice continuity and consistency between TN and NTN is simpler than in other cases, as both the TN RAN and NTN RAN NFs are within the same administrative domain and orchestration architecture. There might be some configuration and monitoring aspects which extend to the NTN part (supported by the previously cited aspects and underlying architecture), as, for example, power configuration per beam or others, which might be factors enabling the achievement of better service performance or SLA target. How many of these are to be configured dynamically as part of the network slice

provisioning is still to be defined (can be defined statically as part of the MNO – SNO agreement with no option for modification, just defining the maximum performance targets which can be reached on a per-beam basis).

4.3.2 Network-sharing-based integration for D2D

Network sharing can be seen as a potential evolution of the previous case, for example, where the SNO uses its own RAN NFs and its frequencies to support services for MNOs out of their coverage areas or in situations like disaster recovery. The applicability for this integration is not restricted to LEO transparent architectures (as particularized in the previous deliverable version), but can be generally considered for regenerative ones as well, these being the latest focus of 3GPP NTN standardization efforts¹⁸. Additionally, the SNO is not restricted to the RAN domain, it can have its own complete mobile network, including transport and core domains for its own services, depending on its strategy. In that case, the SNO needs to orchestrate a full E2E network (and as a minimum a complete RAN NTN domain plus probably some transport), so it needs to adopt similar principles to those applicable and presented for the terrestrial networks. Depending on the type of satellite system architecture and scale, and the type of RAN deployment (e.g. O-RAN) and the overall SNO scope (RAN to complete mobile network) two options would be:

- The SNO has its own 3GPP management system and a similar E2E service and slicing orchestration architecture to that taken as a reference for the TN, including per-domain orchestration in the lower layers and implementing similar mechanisms. This might be the case of SNOs with a complete network scope and a large-scale 3GPP NTN access network.
- The SNO adopts O-RAN and implements SMO as RAN domain orchestrator with the option of extending it to the transport and to the CN (including the C-NSSMF) playing also the role of E2E service orchestrator (CSMF, NSMF) depending on scale.

The next figure shows the E2E service high-level architecture for network sharing integration. It depicts a particular case with an SMO-based orchestration for the SNO and an NTN regenerative architecture with distributed gNBs in the satellites, including also a section of SNO-operated transport to peering points with the MNO transport (which might not be needed if the MNO transport reaches the SNO gateway locations, simplifying the architecture).

¹⁸ Besides D2D in low and mid-band IMT or MSS frequencies, it would be also possible to consider extending the architecture for FSS broadband applications, left for further study. Although still not reflected in RAN R19 version specifications like TS 38.300 and TS 38.401, 3GPP 5G R19 TS 23.501 [28], seems to indicate viability for NTN link in MWAB nodes (not for IAB or MBSR).

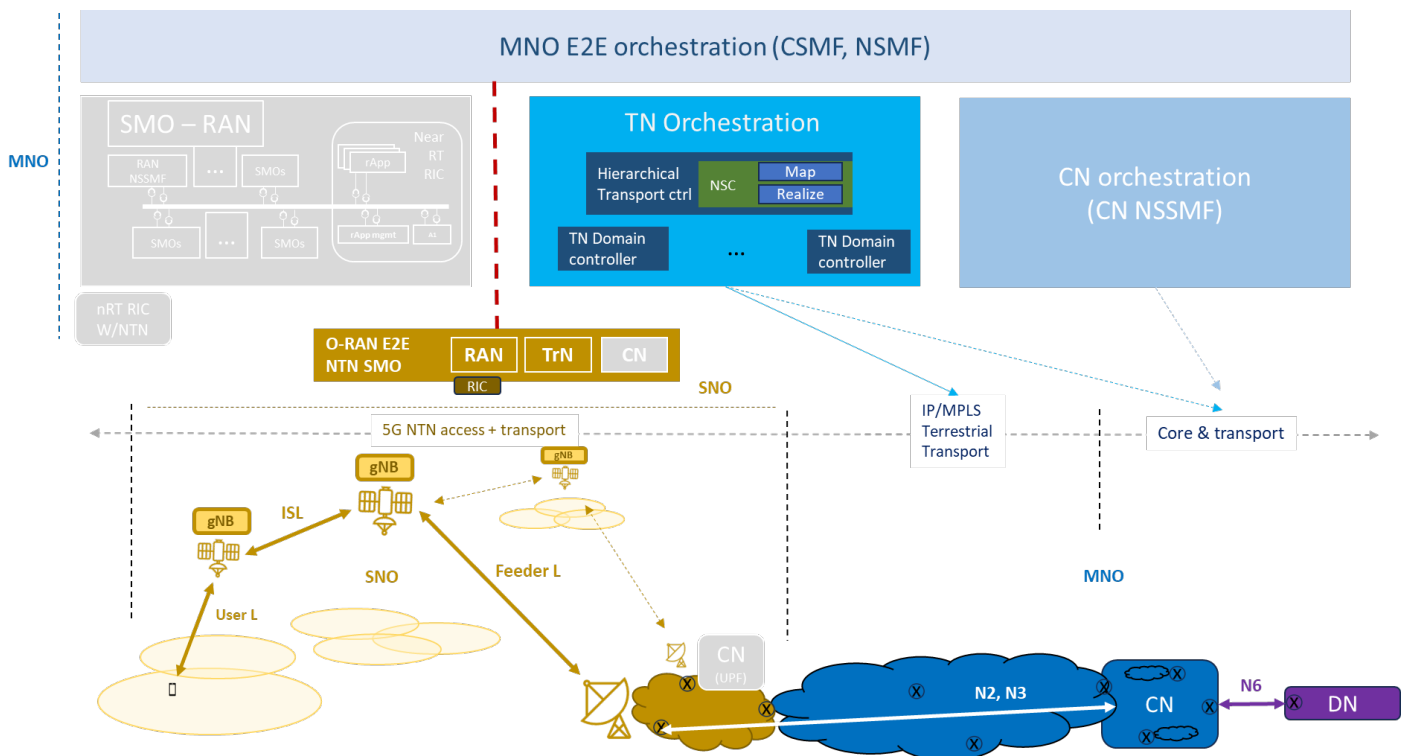


Figure 42: E2E slicing high-level architecture – RAN sharing scenario (MOCN)

The E2E service splits between an NTN RAN section (and potentially a transport section) under the SNO administrative domain, orchestrated by the E2E extended SMO and a Transport network section and the core network of the MNO, orchestrated by the MNO E2E 3GPP system and underlying architecture. In the areas where the MNO has no network, the SNO will act as master operator in the RAN sharing.

Generally, in network sharing scenarios the hosting (master) operator, the SNO in this case, will be responsible for the allocation of resources to the participant operator(s), the MNO in our case, with the possibility to differentiate traffic of the participant operators, apply QoS policies to manage resource occupation, conduct admission control and provide visibility about the allocated resources to the participant MNO. O&M (selected) capabilities need also to be provided by the host (SNO) to the participant (MNO), including also resource monitoring and support for dynamic capacity requests as reflected in [27].

The slicing support in the referenced architecture relies on slice-as-a-service functionality with inter-orchestrator interfacing at OSS layer (and BSS layer on top), via standardized interfaces as those in TMF (e.g. TMF 622 or TMF 641), being unclear if options where the MNO orchestrator can address directly the RAN of the SNO via 3GPP models for slice creation will also be viable. As introduced in section 3.2, slicing implementation in sharing or roaming scenarios is less mature in terms of both standardization and implementation in terrestrial networks, especially in relation to achieving higher automation.

With this approach, the MNO can order or modify (and monitor, if allowed by the SNO) a service via BSS request, and the SNO can implement it, supported by its OSS layer (requests are outside scope of 3GPP, but TMF has been considered here as a proposal). Capability exposure functionality is required to support the case.

Associations between profiles and object instances from the MNO and SNO are needed, with different ways originally explored in 3GPP TR 28.811 [28]., linked to the complexity and issues related to terminology, modelling (for example, one problem being that the slice service request for the RAN host is just referred to a section of the network, but not the E2E), APIs, abstraction level and security. Solutions based on NSSaaS were those seen with more potential and reduced impact, but still not clearly reflected in final specifications as 3GPP TS 28.530 [29, 30].

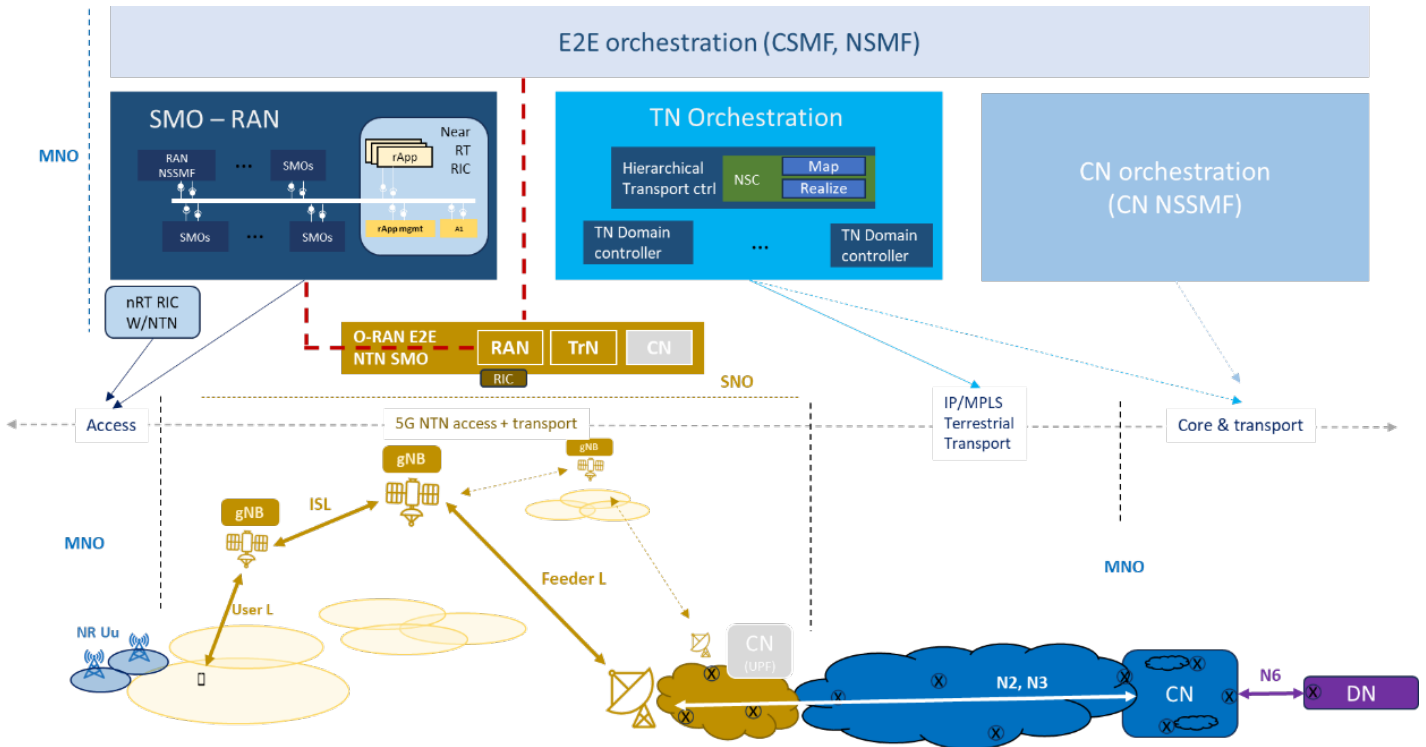
As in the rest of the cases, the type of slices and the range of acceptable service parametrizations will directly and highly depend on the type of NTN and its resources and architecture. Here, with respect to the original reference architecture considered in the first project deliverable, which was particularized for transparent satellite architecture, it must be considered that multiple variations do exist, linked to all the alternatives considered and part of the 3GPP (and now O-RAN) standardization studies and normative work. Besides a transparent architecture with the gNBs on the ground, this way, regenerative ones with different types of functional splits and distribution of RAN NFs between the ground gateways and satellites would be possible, and even with CN NFs distributed as well for store and forward architectures, as presented in section 2.1.3 and 2.2.4. It must be noted though, that aspects related to the management of NTNs are still evolving, with open studies in 3GPP R19 as 3GPP TR 28.874 [31], dealing with issues or complexity associated with the new regenerative architectures (with continuous mobility of the RAN NFs or architectures like store and forward) which will lead to future normative updates.

Besides the impact on service capabilities and potential performance, and requirements for the terrestrial network (which need to consider using elements compatible in terms of 3GPP release with the NTN system and its architecture and functionality) the main impacts in terms of service orchestration architecture lie principally in the SNO side, as already reflected in section 2.2.4.

- Different NTN systems, architectures, and the NTN system scale might motivate adopting a hierarchical E2E architecture over a flattened, more straightforward SMO-like approach.
- Separating RAN NFs as RU, DU, CU impacts directly the orchestration of the NTN part, as between the RAN NFs, transport links need to be managed as well, which might impact the RAN and transport network orchestration functionality and its interfaces

Figure 13, **Figure 14** and **Figure 15** showed already some alternative cases, which can be directly mapped to the SNO domain within **Figure 42** as case 3 potential variations (among others depending on the NTN solution), assuming distribution of RAN NFs and impacts and options for the SNO orchestration. In all these, in principle, the general integration architecture with the MNO would remain unchanged.

However, an aspect that remains open, being, for example, a subject under current study in O-RAN as introduced in section 2.2.2, is the potential implementation of east-west interfaces between RAN orchestrators (aside from the indirect option via orchestrator NBI). Procedures such as interference management between TN and NTN, handover between TN-NTN, and others might benefit from the direct interaction between RAN domains. The following figure shows schematically the same case, including the potentially adjacent TN cells under the management of the MNO RAN domain orchestrator and the additional interface.



Finally, in relation to network sharing, 3GPP R19 introduces the concept of indirect RAN sharing after dedicated studies as 3GPP TR 22.851 [32], which might also be an alternative or variation of the previously presented case. Indirect RAN sharing is based on home-routed roaming architecture principles and enables the potential to avoid the direct interconnection of the host operator to the participant operator's core network functions, allowing for the indirect interconnection via the host operator's core network functions. This way, the complexity linked to the interconnection (e.g., number of network interfaces) between the shared RAN and several other core networks (especially for many shared base stations) can be avoided. 5G system architecture definitions around indirect sharing are reflected in 3GPP TS 23.501 [33]. The next figure shows schematically the concept.

Figure 43: E2E slicing high-level architecture – RAN sharing scenario (MOCN) and potential inter-SMO interfacing

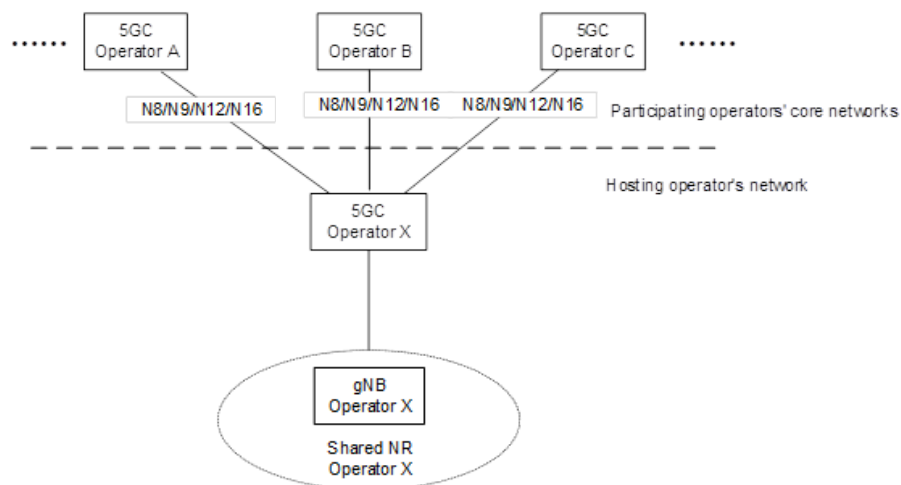


Figure 44: Indirect Network Sharing in which multiple participating operators, as in 3GPP TS 23.501 [33]

Indirect sharing also has implications concerning the implementation of network slices. In the case of 5G MOCN, each PLMN sharing the RAN supports its PLMN-specific set of slices, which the common RAN supports. In indirect sharing, there are some differences depending on the broadcasted PLMN ID and its correspondence to the HPLMN ID or EHPMLMN ID of the user equipment (being this dependent on the RAN sharing agreement between parties), motivating a implementation of the slices dictated either by general procedures for non-roaming scenarios or by those applicable for roaming scenarios [33].

Figure 45 represents a high-level architectural overview of the main impacts that a scenario like this would have versus the previous case. It basically means a larger

scope for the SNO, with its own CN NFs interfacing the MNO NFs to enable the indirect share, which extends as well to the orchestration domain, with a full E2E required.

It must be noted that the management of indirect network sharing is also an open topic within 3GPP standardization, with recent studies as 3GPP TR 28.878 [34] addressing the specifics, and new phase 3 working ID launched afterwards which will be translated to further R19 and later specification updates. Additionally, studies in R20 have also been launched, particularized for the use of indirect sharing in non-terrestrial networks, to investigate new requirements applicable to the use of a shared satellite access network.

MNOs, if architectures like the ones presented are implemented via adoption of standardized interfaces for the OSS/BSS layer, can develop agreements and integrate flexibly multiple solutions from different SNOs adapting to the service needs and areas where the service is needed. An extension to flexible multi-orbit by the SNO in any of the cases shall be transparent to the MNO, with additional complexity for the SNO especially in cases where the multi-orbit is not inherently achieved through orbital design of a single satellite system, but through the combination of multiple independent satellite systems (with potentially different tenants). These cases, as introduced in section 2.1.2, are beginning to be targeted by the latest studies open in 3GPP R20 work and are left for further study.

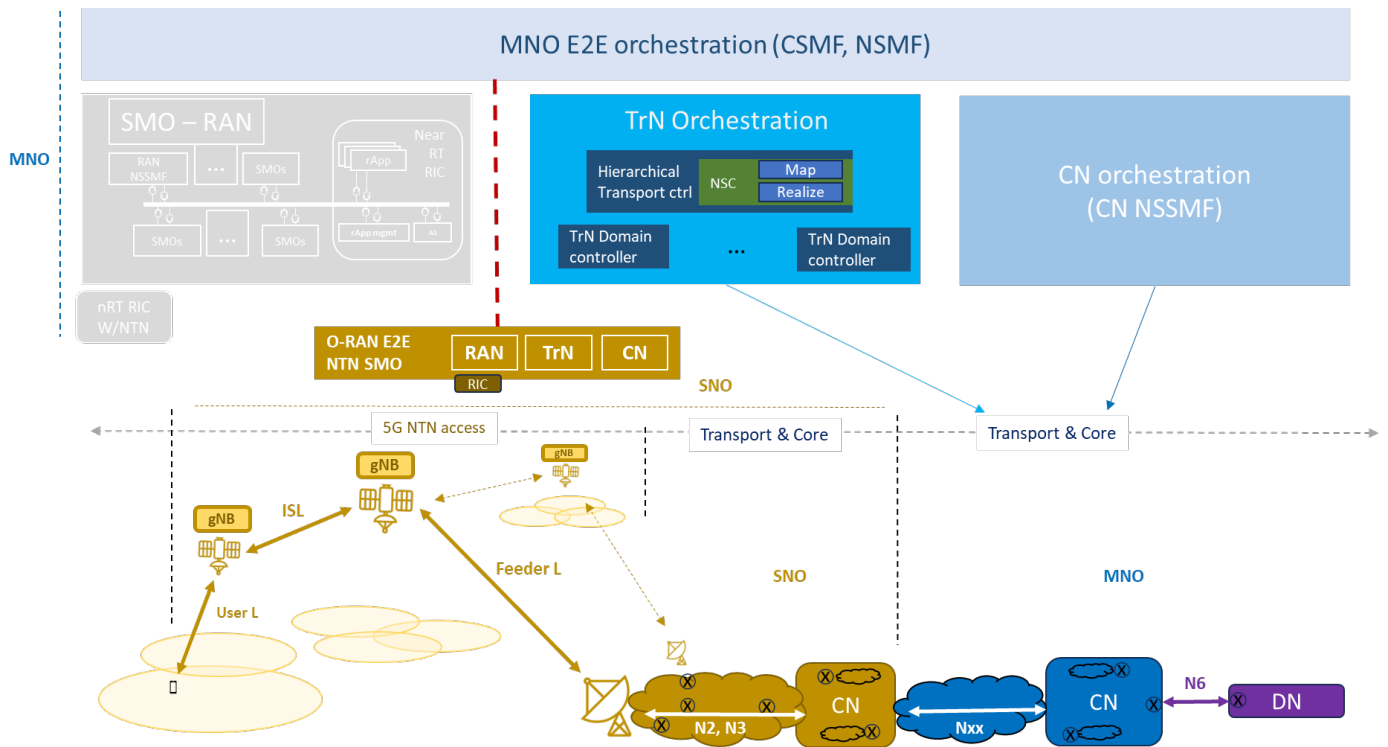


Figure 45: E2E slicing high-level architecture – RAN indirect sharing scenario

4.4 Case 4: roaming based NTN integration for D2D

Like in the previous case, **6G-INTEGRATION-02-E5** proposed a high-level architecture for the orchestration of network slices for a roaming-based scenario, taking as a reference a developing LEO constellation project adopting it (Starlink D2D, although corresponding for now to a solution focused short term in 4G services). The integration via roaming is not restricted to LEO regenerative systems like this. Still, it can also be adopted (and is already being adopted) openly by other types of systems with different satellite system architectures. An example would be Skylo or Viasat, which, as presented in section 3.1.3, follow a similar architecture for their GEO-based R17 NTN IoT commercial services, with transparent architecture on regular bent-pipe wide footprint satellites, which can extend to basic messaging or SOS.

The evolution towards higher flexibility in regenerative systems, including store and forward (relevant for low-scale systems with discontinuous coverage like IoT), or a flexible distribution of RAN NFs between the satellites, might lead to many variations within the same base approach for the integration and support of network slices. Although there are differences in implementation, management, CN NFs and their interfacing, etc., the previous **Figure 45** shows, also for this case at a high level, the E2E slice and service orchestration view (indirect sharing bases on home roaming architectural principles). It has been particularized for a LEO regenerative satellite system in which the SNO adopts an O-RAN E2E SMO orchestration, but, like in case 3, a hierarchical E2E orchestration with per-domain system orchestrators below can also be considered. Network architectural principles for slicing support and roaming scenarios, applicable for the MNO and SNO, are defined in [33].

Like in the indirect roaming case, the SNO has a full network E2E including RAN, transport and CN, and will need to adopt a 3GPP compliant E2E orchestration approach (or SMO extended service orchestration in the case of adoption O-RAN, which will align with 3GPP specifications). Core networks will be interconnected via transport from the MNO to complete the full service E2E. Similar considerations to case 3 do apply as well here in terms of complexity for service orchestration within the SNO domain, considering the range of options for implementation of the NTN network, and, in terms of slice performance and range of supported parametrizations, directly dependent on the NTN system architecture and capabilities.

For slice orchestration, as already covered in the first project deliverable and introduced in case 3, these scenarios will need to rely on NSaaS principles, capability exposure, and existing agreements between companies. Interfacing will occur at the BSS/OSS layer, considering TMF standardized interfaces (e.g., service and product ordering TMF 622 or TMF 641, etc.).

In this case, the MNO must inform the SNO about the S-NSSAI(s) used by the inbound roamers and the capabilities required for the services. The SNO needs to check on the *NetworkSlice* instances to be used by the inbound roamers and map the MNO S-NSSAIs to its own S-NSSAIs, relying on its OSS E2E slice orchestration system. This way, when receiving requests for inbound roaming for a network slice, the SNO will issue an *AllocateNsi* request as defined in 3GPP TS 28.531 [30] to allocate a *NetworkSlice* instance to fulfil its network slice-related requirements, with the allocation request potentially including the S-NSSAIs from the home operator (MNO) for the visited one (SNO) to configure the mapping of S-NSSAIs. The latter assumes that the agreement between them includes the possibility of supporting non-standard S-NSSAI values in the SNO network, which is an option reflected in 3GPP specifications.

As it also happened for case 3, there is the uncertainty in this integration option about the need (and specification) of inter RAN orchestration interfaces to support advanced cases like interference cancellation, handover optimization, performance, energy efficiency, etc. The following figure depicts the wider architecture, considering also the RAN of the MNO and the potentially required interface. Just for differentiation from the previous depicted cases, in this case, we will assume that the SNO adopts a multi-layered orchestration system.

Similarly, the case is not limited for D2D to UE devices, and evolution in standardization and integration into the 5G system architecture of elements like MWABs, with enabled NTN support in latest and future 3GPP releases, can allow the extension to broadband cases in FSS bands (as specified from R18 in Ka and Ku band). In any case, details, specific issues, or implementation constraints (generally, roaming and slicing features are already considered for MWABs, and the proposed high-level architecture would be applicable) are left for further study.

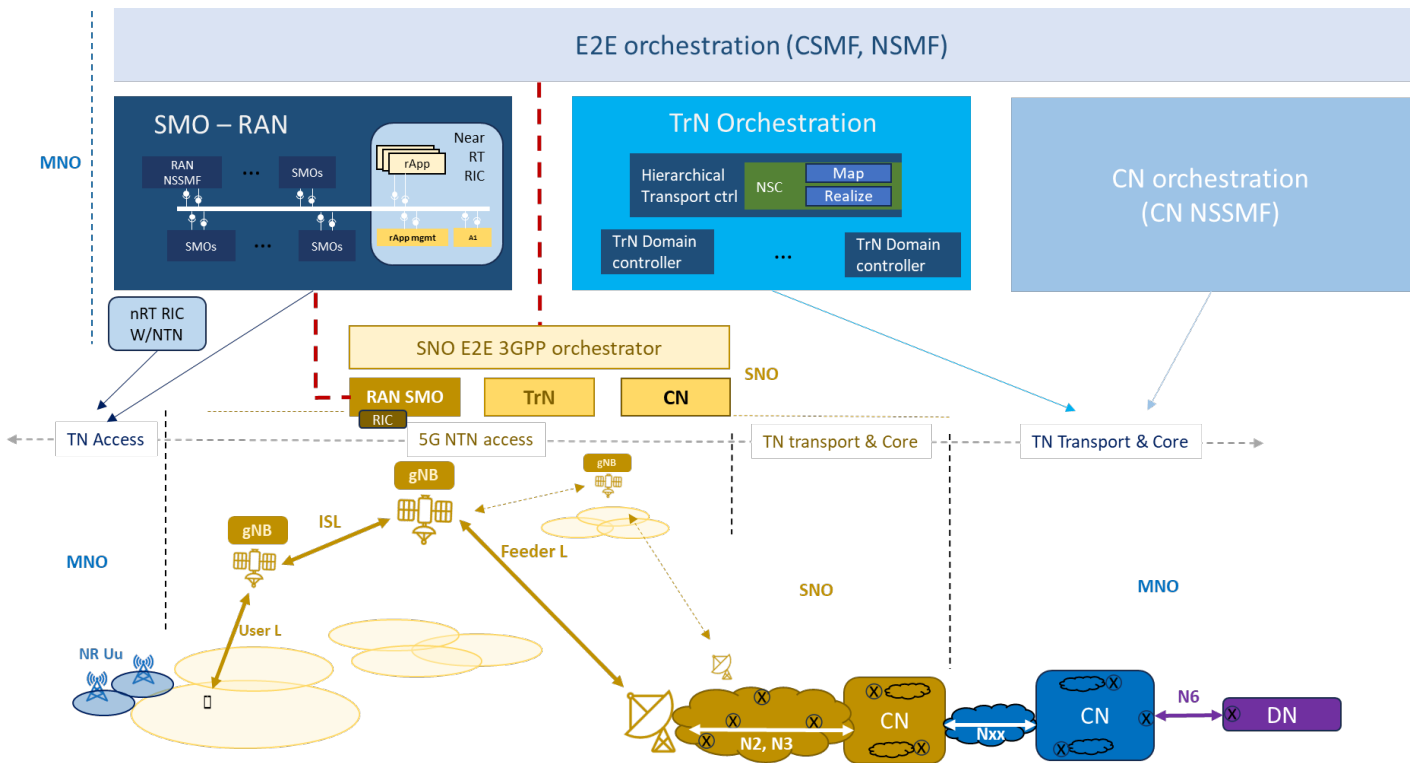


Figure 46: E2E slicing high-level architecture – roaming scenario, with potential inter-SMO interfacing

5. Conclusions

This deliverable extends the content in **6G-INTEGRATION-02-E5**, providing an update around the advances in standardization and technology related to the integration of non-terrestrial networks and terrestrial ones concerning the implementation of network slicing, a relevant feature in the framework of 5G networks and their evolution. Updates are reflected in the reference architectures analyzed in the previous deliverable, and a lower-level proposal is made for cases 1 and 2, focused on the use of non-terrestrial networks for advanced backhauling as part of E2E network slicing scenarios, which will be the base for subsequent PoCs.

3GPP constitutes the forum with the largest focus so far in NTNs. Standardization work has kept progressing up to R19 broadening the field of solutions, frequency bands, end devices and integration options within the specifications, with the latest focus put on regenerative payloads, which bring flexibility to accommodate new use cases and bring flexibility to the NTN design including the possibility to distribute radio access functions across satellites. R20 early work has also been reviewed, which will add extra flexibility and possibilities, bringing multi-orbit and multi-tenancy aspects into focus.

O-RAN, in parallel, has recently started work related to NTNs, which is still not mature. An initial focus on transparent architectures (like initial NTN R17 3GPP specifications) is being extended and merged, including regenerative ones, and the use cases and extensions required at general architecture, RIC control and management/interface level are being studied. Additional work in the groups related to transport in O-RAN is also expected about NTNs, linked to the typical O-RAN architectural network function split flexibility.

However, industry and 3GPP/O-RAN standard-compliant NTN constellations are still far from reaching the market, especially if we consider large constellations aiming at high-performance broadband services and D2D, with so far initial IoT GEO and LEO small-scale R17 systems paving the way. The market has developed faster for proprietary large-scale broadband systems, with some already available and others already being launched or manufactured and projected for the following years, and for D2D ones, where, although being a more immature field (and in some cases just capable for 4G), several systems are also operative and available for the provision of limited services or developing.

Although network slicing is a functionality defined and standardized for mobile networks by 3GPP, with implementations also developing, and new functionality and enhancements to standards developing, it has an E2E reach where the transport network, one of the domains within it, is outside the normative scope of 3GPP. Other organizations, such as IETF and O-RAN have developed specific work aligned with 3GPP definitions, targeting the implementation of network slices in the transport domain, including references for technology realizations and functionality to ensure continuity with the RAN and CN domains using 3GPP objects. Latest work has progressed enhancing relevant aspects that target these topics to provide the necessary convergence across the SDOs.

The implementation of network slicing is also progressing in MNO networks. Network slices are already a reality, with commercialization mainly kicking off in B2B segments, but still with road ahead, especially in relation to achieving a larger automation in the slice management and orchestration for NSaaS, and a broader implementation for

B2C. Scenarios like roaming and sharing, although included already in 3GPP standards, are more complex scenarios, also dependent on NSaaS functionality, additional aspects linked to the necessary inter-inter-operator agreements, and slice definition and matching between operators, and are advancing slower in terms of implementation in terrestrial networks. These are some of the scenarios expected for the integration with NTNs, especially for D2D applications, but also potentially for broadband in 3GPP NTN R18/19 compliant systems, which will need to mature.

The E2E service orchestration architectures becoming deployed to support network slicing in MNO networks have been taken as a reference for the integration with NTNs. Considering the larger maturity of broadband (and proprietary) NTN solutions and the already existing penetration in MNO networks, and that, within them, backhauling applications lie within the transport network domain, a solution for their integration in the MNO service orchestration architecture has been proposed in this document, examining two cases with different responsibility domains for the MNO and SNO which help showing the key aspects and complexities identified for implementation.

The solution leverages the latest progress and definitions done by IETF and O-RAN concerning transport slicing, extrapolating concepts of applicability for NTN solutions (VLAN handoff, attachment circuit provisioning, QoS-based policies for slice support, standard service-level models for transport slice definitions, etc.), and identifying areas and blocks in the architecture which will require adaptations for the specifics of satellite systems. The conceived solutions include several options for implementation, identifying ideal targets (e.g., fully standard-based management and orchestration) and alternatives to achieve a quicker (but "less ideal") integration in cases where relevant gaps (missing device or service models, missing interfaces, non-standard or harmonized API adoption, etc.) are found.

For the less mature cases, basically for D2D and also 3GPP future broadband constellations, the proposed architectures in the first deliverable have been refined, reflecting especially not only the impacts and variations coming from all the diversity of satellite solutions coming from the industry evolution and new standard definitions, but also new options for the integration, as new sharing architectures recently defined by 3GPP. For these cases, a high-level vision has been provided, considering the adoption of 3GPP/O-RAN orchestration solutions by the SNOs (which need to operate a partial or full 3GPP mobile network) and NSaaS concepts. The integration between the MNO and SNO architectures relies on inter-orchestrator interfaces (e.g., TMF or 3GPP) with the potential option to complement with inter-RAN-domain (e.g., SNO) orchestrator interaction. The complexity coming from regenerative (R19) or future flexible multi-orbit (R20) is in principle supported in the proposed architecture and does not impact the MNO service architecture directly, although it brings additional complexity to the SNO service/slice orchestration.

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