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Technical Specification

O-RAN Working Group 1
Slicing Architecture

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Contents

Chapter 1. Introduction

1.1 Scope

This Technical Specification has been produced by O-RAN Alliance.

The contents of the present document are subject to continuing work within O-RAN WG1 Slicing Task Group and may change following formal O-RAN approval. In the event that O-RAN Alliance decides to modify the contents of the present document, it will be re-released by O-RAN Alliance with an identifying change of release date and an increase in version number as follows:

Release x.y.z

where:

x the first digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc. (the initial approved document will have x=01).

y the second digit is incremented when editorial only changes have been incorporated in the document.

z the third digit included only in working versions of the document indicating incremental changes during the editing process.

The current document describes the high level O-RAN slicing related use cases, requirements and architecture. While some of the requirements are derived from use cases, some of the relevant SDO requirements are captured as they have impact on O-RAN functions. Along with requirements and reference slicing architecture, slicing related impact to O-RAN functions and interfaces are captured as well.

1.2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document in Release 16.

[1] 3GPP TR 21.905: “Vocabulary for 3GPP Specifications”

[2] 3GPP TS 22.261: “Technical Specification Group Services and System Aspects; Service requirements for the 5G system; Stage 1”, Release 16, December 2019.

[3] 3GPP TS 23.501: “Technical Specification Group Services and System Aspects; System Architecture for the 5G System; Stage 2”, Release 16, December 2019.

[4] 3GPP TS 28.526: “Technical Specification Group Services and System Aspects; Telecommunication management; Life Cycle Management (LCM) for mobile networks that include virtualized network functions; Procedures”, Release 15, December 2018.

[5] 3GPP TS 28.531: “Management and orchestration; Provisioning”, Release 16, March 2020.

[6] 3GPP TS 28.541: "Management and orchestration; 5G Network Resource Model (NRM); Stage 2 and stage 3", Release 16, January 2020.

[7] 3GPP TS 28.552: "Technical Specification Group Services and System Aspects; Management and orchestration; 5G performance measurements", Release 16, January 2020.

[8] 3GPP TS 38.300: "NR and NG-RAN Overall Description", Release 16, January 2020.

[9] ETSI GS NFV 003: "Network Functions Virtualisation (NFV); Terminology for Main Concepts in NFV", 1.4.1, August 2018.

[10] O-RAN.WG1.O1-Interface.0-v04.00: "O-RAN Operations and Maintenance Interface Specification".

[11] O-RAN.WG1.OAM-Architecture-v04.00: "O-RAN WG1 Operations and Maintenance Architecture".

[12] ORAN.WG2.A1.GA&P-v01.00: "O-RAN Working Group 2; (A1 interface: General Aspects and Principles)".

[13] ORAN.WG3.E2GAP-v01.00: "O-RAN Working Group 3; Near-Real-time RAN Intelligent Controller Architecture & E2 General Aspects and Principles".

[14] O-RAN-WG6.CAD-V02.01: "Cloud Architecture and Deployment Scenarios for O-RAN Virtualized RAN".

[15] O-RAN.WG6.ORCH-USE-CASES-v02.00: "Orchestration Use Cases and Requirements for O-RAN Virtualized RAN".

[16] O-RAN.WG9.XPSAAS-v01.00: "O-RAN Open Transport Working Group 9 Xhaul Packet Switched Architectures and Solutions".

[17] O-RAN-WG9.XTRP-REQ-v01.00: "O-RAN Open Xhaul Transport Working Group 9 Xhaul Transport Network Requirements".

[18] O-RAN_Study_ORAN_Slicing_Technical_Report.v02.00: "Study on O-RAN Slicing", Technical Report.

1.3 Definitions and Abbreviations

1.3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

A1: Interface between non-RT RIC and Near-RT RIC to enable policy-driven guidance of Near-RT RIC applications/functions, and support AI/ML workflow.

A1 policy: Type of declarative policies expressed using formal statements that enable the non-RT RIC function in the SMO to guide the near-RT RIC function, and hence the RAN, towards better fulfilment of the RAN intent.

A1 Enrichment information: Information utilized by near-RT RIC that is collected or derived at SMO/non-RT RIC either from non-network data sources or from network functions themselves.

E2: Interface connecting the Near-RT RIC and one or more O-CU-CPs, one or more O-CU-UPs, and one or more O-DUs.

E2 Node: a logical node terminating E2 interface. In this version of the specification, O-RAN nodes terminating E2 interface are:

- for NR access: O-CU-CP, O-CU-UP, O-DU or any combination;
- for E-UTRA access: O-eNB.

FCAPS: Fault, Configuration, Accounting, Performance, Security.

near-RT RIC: O-RAN near-real-time RAN Intelligent Controller: a logical function that enables near-real-time control and optimization of RAN elements and resources via fine-grained data collection and actions over E2 interface.

non-RT RIC: O-RAN non-real-time RAN Intelligent Controller: a logical function that enables non-real-time control and optimization of RAN elements and resources, AI/ML workflow including model training and updates, and policy-based guidance of applications/features in near-RT RIC.

NMS: A Network Management System.

Network Service: Composition of Network Function(s) and/or Network Service(s), defined by its functional and behavioural specification [9]

O-CU: O-RAN Central Unit

O-CU-CP: O-RAN Central Unit – Control Plane: a logical node hosting the RRC and the control plane part of the PDCP protocol.

O-CU-UP: O-RAN Central Unit – User Plane: a logical node hosting the user plane part of the PDCP protocol and the SDAP protocol.

O-DU: O-RAN Distributed Unit: a logical node hosting RLC/MAC/High-PHY layers based on a lower layer functional split.

O-RU: O-RAN Radio Unit: a logical node hosting Low-PHY layer and RF processing based on a lower layer functional split. This is similar to 3GPP's "TRP" or "RRH" but more specific in including the Low-PHY layer (FFT/iFFT, PRACH extraction).

O1: Interface between the Service Management and Orchestration Framework and O-RAN managed elements

O2: Interface between the Service Management and Orchestration Framework and the O-Cloud

RAN: Generally referred as Radio Access Network. In terms of this document, any component below near-RT RIC per O-RAN architecture, including O-CU/O-DU/O-RU.

1.3.2 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

eNB	eNodeB (applies to LTE)
gNB	gNodeB (applies to NR)
KPI	Key Performance Indicator
KQI	Key Quality Indicator
Near-RT RIC	O-RAN Near-Real-Time RIC

NFMF	Network Function Management Function
Non-RT RIC	O-RAN Non-Real-Time RIC
NS	Network Service
NSMF	Network Slice Management Function
NSSMF	Network Slice Subnet Management Function
O-CU	O-RAN Central Unit
O-DU	O-RAN Distributed Unit
O-RU	O-RAN Radio Unit
PNF	Physical Network Function
PRB	Physical Resource Block
RIC	O-RAN RAN Intelligent Controller
RRM	Radio Resource Management
SDO	Standards Developing Organizations (For ex: 3GPP, ETSI, ONAP, O-RAN)
SMO	Service and Management Orchestration
VNF	Virtual Network Function

Chapter 2. Slicing Overview

Network Slicing is expected to play a critical role in 5G networks because of various use cases and services 5G will support. It allows a network operator to provide services tailored to customers' requirements. Network slice is defined as a logical network with a bundle of specified network services over a common network infrastructure. A single physical network is sliced into multiple virtual networks that can support different service types over a single RAN. 3GPP has standardized 4 different service types: eMBB, URLLC, MIoT and V2X [3].

3GPP defined 5G architecture and procedures containing network slicing and related concepts in Release 15. Furthermore, management and orchestration of 5G networks featuring slicing was defined in the 3GPP specifications. Other standard groups e.g. GSMA, ETSI NFV-MANO, ETSI ZSM and ONAP focus on the different aspects of network slicing. Further information regarding network slicing and other SDO's contributions was discussed in the Study on O-RAN Slicing Technical Report [18].

A sample RAN slicing deployment of O-RAN network functions based on the select initial deployment option, option B as described in [14], is shown in Figure 2-1, with some of the network functions shared between RAN slice subnets (such as O-CU-CP, O-DU, O-RU) and some network functions dedicated to a particular RAN slice subnet (such as O-CU-UP).

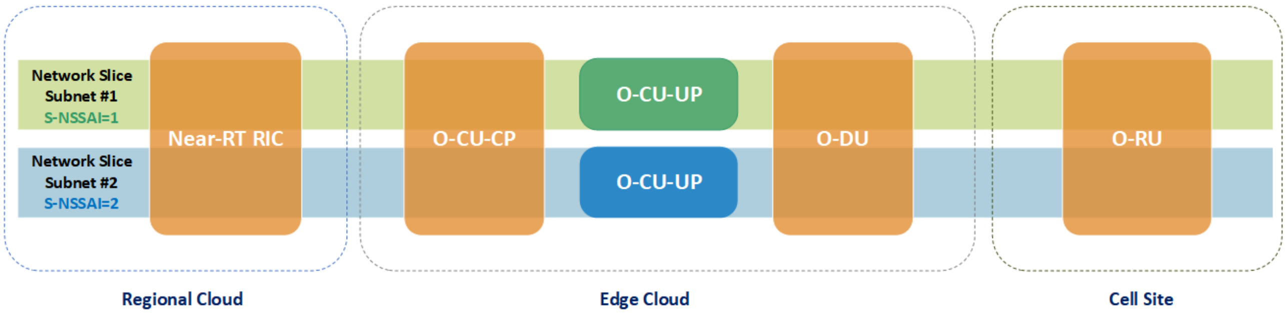


Figure 2-1: Example O-RAN Slicing Deployment

Chapter 3. High-Level O-RAN Slicing Use Cases

This section contains high-level O-RAN slicing use cases that O-RAN is expected to support. Slicing requirements will include the requirements derived from the specified use cases. Additional use cases will be added as prioritized by the O-RAN community in future versions of this document. It should be noted that not all of the use cases presented here are currently supported by O-RAN specifications and these use cases will be addressed in future O-RAN work.

3.1 O-RAN Slice Subnet Management and Provisioning Use Cases

Network slicing is conceived to be an end-to-end feature that includes the core network, the transport network and the RAN. Although 3GPP has started defining network slicing support with Release 15, slicing in O-RAN needs to be further addressed in line with 3GPP to achieve deployable network slicing in an open RAN environment.

Management aspects of network slicing such as Network Slice Instances (NSI) and Network Slice Subnet Instances (NSSI) are defined by 3GPP. While NSI refers to an end-to-end network slice, NSSI refers to a part of it such as a RAN slice subnet. The provisioning of network slicing includes the four phases which are preparation, commissioning, operation and decommissioning. The NSI/NSSI provisioning operations include:

- Create an NSI/NSSI;
- Activate an NSI/NSSI;
- De-active an NSI/NSSI;
- Modify an NSI/NSSI;
- Terminate an NSI/NSSI.

Further details of NSI and NSSI lifecycle management and provisioning can be found 3GPP TS28.531 [5], Section 4.1.

This chapter provides the use cases and procedures necessary for O-RAN Slice Subnet Management that is in-line with 3GPP Slice Management framework. For this purpose, use cases such as slice subnet creation, activation, modification, deactivation, termination, configuration and feasibility check are considered for O-RAN architecture.

3.1.1 O-RAN Slice Subnet Instance Creation

Table 3.1.1-1: O-RAN Slice Subnet Instance Creation Use Case

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Creation of a new O-RAN network slice subnet instance (O-NSSI) or use an existing O-NSSI to satisfy the RAN slice subnet related requirements (see clause 5.1.2 in TS 28.531 [5]).	
Actors and Roles	NSSMS_C such as NSMF, who acts as an example network slice subnet management service consumer. NSSMS_P such as NSSMF, who acts as an example of network slice subnet management service provider. NFMS_P such as SMO OAM Functions or NFMF who acts as an example of network function management service provider. O-Cloud M&O, who acts as O-Cloud management and orchestration provider within SMO. Non-RT RIC O-RAN Network Functions: NFs such as Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU.	
Assumptions	NSSMS_P is aware of O-Cloud M&O to manage the lifecycle of VNFs and interconnection between the VNFs and PNFs.	
Pre conditions	VNF packages for virtualized O-RAN network functions to be included in the O-RAN slice subnet instance have been already on-boarded.	
Begins when	NSSMS_P receives request for a network slice subnet instance. The request contains network slice subnet related requirements.	
Step 1 (M)	NSSMS_P checks the feasibility of the request, based on the received network slice subnet related requirements.	O-RAN Slice Subnet Feasibility Check
Step 2 (M)	NSSMS_P decides to create a new O-NSSI or use an existing O-NSSI.	
Step 3 (M)	If an existing O-NSSI is decided to be used, NSSMS_P may trigger modification of the existing O-NSSI to satisfy the network slice subnet related requirements. Go to "Step 11". Otherwise, NSSMS_P triggers creation of a new O-NSSI, continue with Step 4	O-RAN Slice Subnet Instance Modification Use Case
Step 4 (M)	NSSMS_P derives the requirements for the constituent NSSI(s).	
Step 5 (O)	If the required O-NSSI contains constituent NSSI(s) managed by other NSSMS_P(s), NSSMS_P may trigger creation of respective constituent NSSI(s) through other NSSMS_P(s) which manages the constituent NSSI(s). In that case, NSSMS_P receives the constituent NSSI information from the other NSSMS_P(s) and associates the constituent NSSI(s) with the required O-NSSI.	(O-RAN) Slice Subnet Instance Creation Use Case (to create constituent (O-)NSSI(s) managed by other NSSMS_P(s))
Step 6 (M)	NSSMS_P determines the service related requirements and triggers a service request to O-Cloud M&O for instantiation of virtual O-RAN network functions and virtual links within the determined O-Cloud(s). Based on the service request, O-Cloud M&O performs corresponding NF instantiation procedures and virtual link establishment.	FFS in WG6
Step 7 (M)	NSSMS_P associates the service response received from O-Cloud M&O with the corresponding O-NSSI.	FFS in WG6
Step 8 (M)	NSSMS_P uses (O-RAN) NF provisioning service exposed by NFMS_P to configure (O-)NSSI constituents.	FFS in WG1
Step 9 (M)	NSSMS_P configures the O-NSSI MOI with each constituent (O-)NSSI MOI identifier.	FFS in WG1
Step 10 (M)	NSSMS_P triggers O-RAN TN Manager coordination procedure to establish necessary links such as for A1, E2, and midhaul and fronthaul connectivity.	FFS in WG9
Step 11 (M)	NSSMS_P notifies Non-RT RIC with network slice subnet requirements and respective O-NSSI information.	FFS in WG2
Step 12 (M)	NSSMS_P notifies NSSMS_C with the resulting status of this process and relevant O-NSSI information.	
Ends when	O-RAN O-NSSI and relevant O-RAN NFs are created, and Non-RT RIC is configured with slice requirements and O-NSSI information.	
Exceptions	One of the steps identified above fails.	
Post Conditions	O-NSSI is ready to satisfy the network slice subnet related requirements.	
Traceability	REQ-SL-FUN14, REQ-SL-FUN20 - REQ-SL-FUN27	

3.1.2 O-RAN Slice Subnet Instance Activation

Table 3.1.2-1: O-RAN Slice Subnet Instance Activation Use Case

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Activation of an O-RAN network slice subnet instance (O-NSSI) (see clause 5.1.10 in TS 28.531 [5]).	
Actors and Roles	NSSMS_C such as NSMF, who acts as an example network slice subnet management service consumer. NSSMS_P such as NSSMF, who acts as an example of network slice subnet management service provider. NFMS_P such as SMO OAM Functions or NFMF who acts as an example of network function management service provider. O-RAN Network Functions: NFs such as Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU.	
Assumptions	NSSMS_P is providing services to authorized consumers.	
Pre conditions	An O-NSSI has already been created and it is inactive. As an example, the O-NSSI may contain inactive O-RAN NFs:- Near-RT RIC is installed and active - O-CU-CP installed (i.e. `operationalState` = *enabled*), but not yet activated (i.e. `administrativeState` = *locked*). - O-CU-UP installed (i.e. `operationalState` = *enabled*), but not yet activated (i.e. `administrativeState` = *locked*). - O-DU installed (i.e. `operationalState` = *enabled*), but not yet activated (i.e. `administrativeState` = *locked*) (see figure B.2.2 in TS 28.541 [6]). - O-RU physically installed (i.e. `operationalState` = *enabled*), but not yet activated (i.e. `administrativeState` = *locked*). NOTE: The O-CU-CP, O-CU-UP, O-DU and O-RU are not shared by other O-NSSI, since they are not yet activated. Near-RT RIC has already been activated for other services.	
Begins when	NSSMS_P decides to activate the O-NSSI based on the received network slice subnet related request from its authorized consumer NSSMS_C.	
Step 1 (M)	NSSMS_P receives a request from NSSMS_C to activate the O-NSSI (via NSSI Provisioning service with operation *modifyMOIAttributes* (see table 6.2-1 in TS 28.531 [14]) to change `administrativeState` of the O-NSSI to *unlocked*.)	
Step 2 (M)	NSSMS_P identifies the inactive constituents within the O-NSSI and decides to activate those constituents which can be NFs or NSSI. As an example, NSSMS_P activates the following inactive O-RAN NF constituents: - the O-CU-CP NF constituent, and invokes NF Provisioning service with operation *modifyMOIAttributes* (see table 6.3-1 in TS 28.531 [5]) to request NFMS_P to activate the O-CU-CP by changing the `administrativeState` of the O-CU-CP to *unlocked*. NOTE: O-CU-CP starts to establish the E2 interface connection with Near-RT RIC. - the O-CU-UP NF constituent, and invokes NF Provisioning service with operation *modifyMOIAttributes* (see table 6.3-1 in TS 28.531 [5]) to request NFMS_P to activate the O-CU-UP by changing the `administrativeState` of the O-CU-UP to *unlocked*. NOTE 1: O-CU-UP starts to establish the E2 interface connection with Near-RT RIC. NOTE 2: E1 interface connection will be established between O-CU-CP and O-CU-UP. - the O-DU NF constituent, and invokes NF Provisioning service with operation *modifyMOIAttributes* (see table 6.3-1 in TS 28.531 [5]) to request NFMS_P to activate the O-DU by changing the `administrativeState` of the O-DU to *unlocked*. NOTE 1: O-DU starts to establish the F1 interface connection with O-CU, (see Annex A.1 in TS 28.541 [6]).	

	NOTE 2: O-DU starts to establish the E2 interface connection with Near-RT RIC. - the O-RU NF constituent, and invokes NF Provisioning service with operation *modifyMOIAttributes* (see table 6.3-1 in TS 28.531 [5]) to request NFMS_P to activate the O-RU by changing the `administrativeState` of the O-RU to *unlocked*. NOTE: O-RU starts to establish the M plane interface connection with O-DU [9].	
Step 3 (M)	NSSMS_P receives notifications indicating that all inactive NSSI constituents are activated. (NSSMS_P is notified by respective NFMS_P(s) which invokes NF Provisioning data report service with notification *notifyMOIAttributeValueChanges* (see table 6.3-1 in TS 28.531 [5]) that the O-CU-CP, O-CU-UP, O-DU and O-RU have been activated.)	
Step 4 (M)	NSSMS_P changes `administrativeState` of the O-NSSI to *unlocked, and* invokes NSSI Provisioning data report service with notification *notifyMOIAttributeValueChanges* (see table 6.2-1 in TS 28.531 [5]) to notify NSSMS_C that the O-NSSI has been activated.	
Ends when	O-RAN O-NSSI is activated.	
Exceptions	One of the steps identified above fails.	
Post Conditions	O-NSSI is in operation.	
Traceability	REQ-SL-FUN25, REQ-SL-FUN28	

3.1.3 O-RAN Slice Subnet Instance Modification

Table 3.1.3-1: O-RAN Slice Subnet Instance Modification Use Case

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Modification of an existing O-NSSI to satisfy O-RAN slice subnet related requirements (see clause 5.1.9 in TS 28.531 [5]).	
Actors and Roles	NSSMS_C such as NSMF, who acts as an example network slice subnet management service consumer. NSSMS_P such as NSSMF, who acts as an example of network slice subnet management service provider. NFMS_P such as SMO OAM Functions or NFMF who acts as an example of network function management service provider. O-Cloud M&O, who acts as O-Cloud management and orchestration provider within SMO. Non-RT RIC O-RAN Network Functions: NFs such as Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU.	
Assumptions	NSSMS_P is aware of O-Cloud M&O to manage the lifecycle of VNFs and interconnection between the VNFs and PNFs.	
Pre conditions	VNF Packages for virtualized O-RAN network functions to be included in the O-RAN slice subnet instance have been already on-boarded.	
Begins when	NSSMS_P receives request for a modification of an existing O-NSSI. The request contains new network slice subnet related requirements.	
Step 1 (M)	NSSMS_P checks the feasibility of the request, based on the received network slice subnet related modification requirements. If the modification requirements can be satisfied, go to step 2, else go to step 8.	O-RAN Slice Subnet Feasibility Check
Step 2 (M)	NSSMS_P decomposes the O-NSSI modification request into modification requests for each (O-)NSSI constituent.	
Step 3 (O)	If the required O-NSSI contains constituent (O-)NSSI(s) managed by other NSSMS_P(s), NSSMS_P may trigger modification of respective constituent (O-)NSSI(s) through other NSSMS_P(s) which manages the constituent (O-)NSSI(s). In that case, NSSMS_P receives the constituent (O-)NSSI information from the other NSSMS_P(s) and associates the constituent (O-)NSSI(s) with the required O-NSSI.	(O-RAN) Slice Subnet Instance Modification Use Case (to modify constituent (O-)NSSI(s) managed by other NSSMS_P(s))

Step 4 (O)	If the O-NSSI contains virtualized part(s), NSSMS_P triggers a service modification request to O-Cloud M&O for scaling, updating, instantiation etc. of virtual O-RAN network functions and virtual links within the determined O-Cloud(s).	FFS in WG6
Step 5 (O)	If the O-NSSI consists of NF instances, NSSMS_P uses NF provisioning service exposed by NFMS_P to (re-)configure (O-)NSSI constituents.	FFS in WG1
Step 6 (O)	If the NSSI contains TN part, NSSMS_P triggers O-RAN TN Manager coordination procedure to establish/modify necessary links such as for A1, E2, midhaul and fronthaul connectivity.	FFS in WG9
Step 7 (M)	NSSMS_P notifies Non-RT RIC with the updated network slice subnet requirements and respective O-NSSI information.	FFS in WG2
Step 8 (M)	NSSMS_P notifies NSSMS_C with the resulting status of this process and relevant O-NSSI information.	
Ends when	O-RAN O-NSSI and relevant O-RAN NFs are modified, and Non-RT RIC is configured with modified slice requirements and O-NSSI information.	
Exceptions	One of the steps identified above fails.	
Post Conditions	O-NSSI is ready to satisfy the updated network slice subnet related requirements.	
Traceability	REQ-SL-FUN24 - REQ-SL-FUN27, REQ-SL-FUN29, REQ-SL-FUN30	

3.1.4 O-RAN Slice Subnet Instance Deactivation

Table 3.1.4-1: O-RAN Slice Subnet Instance Deactivation Use Case

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Deactivation of an O-RAN network slice subnet instance (O-NSSI) (see clause 5.1.11 in TS 28.531 [5]).	
Actors and Roles	NSSMS_C such as NSMF, who acts as an example network slice subnet management service consumer. NSSMS_P such as NSSMF, who acts as an example of network slice subnet management service provider. NFMS_P such as SMO OAM Functions or NFMF who acts as an example of network function management service provider. O-RAN Network Functions: NFs such as Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU.	
Assumptions	NSSMS_P is providing services to authorized consumers.	
Pre conditions	An O-NSSI has already and it is in active state. As an example, the existing O-NSSI includes active O-CU-CP, O-CU-UP, O-DU and O-RU O-RAN NFs, where the `administrativeState` is *unlocked* (see figure B.2.2 in TS 28.541 [6]). NOTE: The O-CU-CP, O-CU-UP, O-DU and O-RU are not shared by other O-NSSI.	
Begins when	NSSMS_C decides to deactivate the O-NSSI based on the received network slice subnet related request from its authorized consumer NSSMS_C.	
Step 1 (M)	NSSMS_P receives a request from NSSMS_C to deactivate the O-NSSI (via NSSI Provisioning service with operation *modifyMOIAttributes* (see table 6.2-1 in TS 28.531 [5]) to request NSSMS_P to deactivate the O-NSSI that is to change `administrativeState` of the O-NSSI to *locked)*.	
Step 2 (M)	NSSMS_P identifies active constituents (e.g. NSSI, NF) of the NSSI and decides to deactivate those constituents. As an example, NSSMS_P finds that the O-NSSI contains active non-shared O-RAN NFs: - the O-CU-CP NF constituent, and invokes NF Provisioning service with operation *modifyMOIAttributes* (see table 6.3-1 in TS 28.531 [5]) to request NFMS_P to deactivate the O-CU-CP by changing the `administrativeState` of the O-CU-CP to *locked*. NOTE 1: O-CU-CP starts to terminate the E2 interface connection with Near-RT RIC. NOTE 2: E1 interface connection will be released between O-CU-CP and O-CU-UP.	

	- the O-CU-UP NF constituent, and invokes NF Provisioning service with operation *modifyMOIAttributes* (see table 6.3-1 in TS 28.531 [5]) to request NFMS_P to deactivate the O-CU-UP by changing the `administrativeState` of the O-CU-UP to *locked*. NOTE: O-CU-UP starts to terminate the E2 interface connection with Near-RT RIC. - the O-DU NF constituent, and invokes NF Provisioning service with operation *modifyMOIAttributes* (see table 6.3-1 in TS 28.531 [5]) to request NFMS_P to deactivate the O-DU by changing the `administrativeState` of the O-DU to *locked*. NOTE 1: O-DU starts to terminate the F1 interface connection with O-CU, (see Annex A.1 in TS 28.541 [6]). NOTE 2: O-DU starts to terminate the E2 interface connection with Near-RT RIC. - the O-RU constituent, and invokes NF Provisioning service with operation *modifyMOIAttributes* (see table 6.3-1 in TS 28.531 [5]) to request NFMS_P to deactivate the O-RU by changing the `administrativeState` of the O-RU to *locked*. NOTE: O-RU starts to terminate the M plane interface connection with O-DU [9].	
Step 3 (M)	NSSMS_P receives notifications indicating that all active non-shared NSSI constituents are deactivated. (NSSMS_P is notified by respective NFMS_P(s) which invoke NF Provisioning data report service with notification *notifyMOIAttributeValueChanges* (see table 6.3-1 in TS 28.531 [5]) to notify that the O-CU-CP, O-CU-UP, O-DU and O-RU have been deactivated.)	
Step 4 (M)	NSSMS_P changes `administrativeState` of the O-NSSI to *locked, and* invokes NSSI Provisioning data report service with notification *notifyMOIAttributeValueChanges* (see table 6.2-1 in TS 28.531 [5]) to notify NSSMS_C that the O-NSSI has been deactivated.	
Ends when	O-RAN O-NSSI is deactivated.	
Exceptions	One of the steps identified above fails.	
Post Conditions	O-NSSI is inactive.	
Traceability	REQ-SL-FUN25, REQ-SL-FUN31	

3.1.5 O-RAN Slice Subnet Instance Termination

Table 3.1.5-1: O-RAN Slice Subnet Instance Termination Use Case

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Termination or disassociation of an existing O-RAN network slice subnet instance (O-NSSI) (see clause 5.1.4 in TS 28.531 [5]).	
Actors and Roles	NSSMS_C such as NSMF, who acts as an example network slice subnet management service consumer. NSSMS_P such as NSSMF, who acts as an example of network slice subnet management service provider. O-Cloud M&O, who acts as O-Cloud management and orchestration provider within SMO. Non-RT RIC O-RAN Network Functions: NFs such as Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU.	
Assumptions	NSSMS_P is aware of O-Cloud M&O to manage the lifecycle of VNFs and interconnection between the VNFs and PNFs.	
Pre conditions	O-NSSI exists and it is in inactive state.	
Begins when	NSSMS_P receives a request for an O-RAN network slice subnet instance indicating that the O-NSSI is no longer needed. The request contains network slice subnet identifier.	
Step 1 (M)	NSSMS_P checks whether the O-NSSI is a shared network slice subnet instance.	O-RAN Slice Subnet Instance

	If the O-NSSI is shared, O-NSSI will be disassociated via O-NSSI slice subnet instance modification use case. Go to step 5 If the O-NSSI is not shared, O-NSSI will be terminated. Go to step 2	Modification Use Case
Step 2 (M)	If the O-NSSI consists of constituent NSSIs that are not managed directly by the NSSMS_P, it sends a request to other NSSMS_P(s) indicating that the constituent NSSIs are no longer needed for the O-NSSI.	O-RAN Slice Subnet Instance Termination Use Case
Step 3 (O)	NSSMS_P triggers a service termination request to O-Cloud M&O for removal of non-shared virtual O-RAN network functions.	FFS in WG6
Step 4 (O)	If the O-NSSI includes constituent transport links, NSSMS_P triggers O-RAN TN Manager coordination procedure.	FFS in WG9
Step 5 (M)	NSSMS_P notifies Non-RT RIC that the O-NSSI has been terminated.	FFS in WG2
Step 6 (M)	NSSMS_P notifies NSSMS_C with the resulting status of this process and relevant O-NSSI information.	
Ends when	All the steps identified above are successfully completed.	
Exceptions	One of the steps identified above fails.	
Post Conditions	O-NSSI has been terminated or disassociated and Non-RT RIC is notified.	
Traceability	REQ-SL-FUN21, REQ-SL-FUN23, REQ-SL-FUN27, REQ-SL-FUN32 - REQ-SL-FUN34	

3.1.6 O-RAN Slice Subnet Instance Configuration

Table 3.1.6-1: O-RAN Slice Subnet Instance Configuration Use Case

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Configuration of an O-NSSI (see clause 5.1.13 in TS 28.531 [5]).	
Actors and Roles	NSSMS_C such as NSMF, who acts as an example network slice subnet management service consumer. NSSMS_P such as NSSMF, who acts as an example network slice subnet management service provider. NFMS_P such as SMO OAM Functions or NFMF, who acts as an example network function management service provider. O-RAN Network Functions: NFs such as Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU.	
Assumptions	NSSMS_P is providing services to authorized consumers. NSSMS_P is aware of the respective NSSMS_P(s) and NFMS_P(s) which manages the constituent NSSI(s) and NF(s).	
Pre conditions	The O-NSSI exists.	
Begins when	NSSMS_C triggers the (re-)configuration of an O-NSSI and its constituents.	
Step 1 (M)	NSSMS_P receives a request from NSSMS_C with slice subnet (re-)configuration information for (re-)configuration of an O-NSSI.	
Step 2 (M)	NSSMS_P decomposes the received slice subnet configuration information and prepares CM requests for each constituent if necessary and applicable.	
Step 3 (O)	NSSMS_P configures the constituent O-NSSI(s) if it is managed directly by the NSSMS_P.	
Step 4 (O)	If the O-NSSI contains constituent NSSI(s) managed by other NSSMS_P(s), NSSMS_P triggers configuration of respective constituent NSSI(s) through NSSMS_P(s) which manages the constituent NSSI(s).	(O-RAN) Slice Subnet Configuration Use Case
Step 5 (O)	If the required O-NSSI contains constituent O-RAN NF(s) managed by NFMS_P(s), NSSMS_P triggers configuration requests with corresponding slice subnet configuration information through NFMS_P(s) which manages the constituent O-RAN NF(s).	FFS in WG1
Step 6 (M)	NSSMS_P sends the configuration result to the NSSMS_C which might be based on results received from other CM service providers.	
Ends when	All the steps identified above are successfully completed.	
Exceptions	One of the steps identified above fails.	
Post Conditions	The required (re-)configuration is accomplished at the corresponding constituent(s).	

Traceability	REQ-SL-FUN24, REQ-SL-FUN25	

3.1.7 O-RAN Slice Subnet Feasibility Check

Table 3.1.7-1: O-RAN Slice Subnet Feasibility Check

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	To check the feasibility of provisioning an O-RAN network slice subnet instance (O-NSSI) to determine whether the O-NSSI requirements can be satisfied (e.g., in terms of resources) (see clause 5.1.21 in TS 28.531 [5]).	
Actors and Roles	NSSMS_C such as NSMF, who acts as an example network slice subnet management service consumer. NSSMS_P such as NSSMF, who acts as an example of network slice subnet management service provider. NFMS_P such as SMO OAM Functions or NFMF who acts as an example of network function management service provider. O-Cloud M&O, who acts as O-Cloud management and orchestration provider within SMO. Non-RT RIC O-RAN Network Functions: NFs such as Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU.	
Assumptions	NSSMS_C has decided to check the feasibility of provisioning an O-NSSI based on, for example, internal decision or an external service request.	
Pre conditions	Network slice subnet requirements have been derived or received by network slice subnet management service consumer NSSMS_C.	
Begins when	NSSMS_P receives the request to evaluate the feasibility of an O-NSSI according to the network slice subnet requirements.	O-RAN Slice Subnet Instance Creation, O-RAN Slice Subnet Instance Modification
Step 1 (M)	NSSMS_P identifies the network slice subnet constituents according to the requirements, e.g., network services to be requested from O-Cloud M&O.	
Step 2 (O)	For the purpose of checking the feasibility of provisioning an O-NSSI, NSSMS_P may obtain information from the SMO and Non-RT RIC (e.g., load level information, resource usage information from management data analytics services).	FFS in WG2
Step 3 (M)	NSSMS_P sends enquiries with reservation requests to O-Cloud M&O to determine availability of network constituents, e.g., network services, network functions.	FFS in WG6
Step 4 (O)	For the purpose of checking the feasibility of transport network links, NSSMS_P may obtain information from TN Manager.	FFS in WG9
Ends when	NSSMS_P provides feasibility check results to NSSMS_C. If provisioning of O-NSSI is feasible, the information about reserved resources may also be provided.	
Exceptions	One of the mandatory steps fails.	
Post Conditions	N/A	
Traceability	REQ-SL-FUN35 - REQ-SL-FUN37	

3.2 O-RAN Slicing Use Cases

3.2.1 Use Case 1: RAN Slice SLA Assurance

In the 5G era, network slicing is a prominent feature which provides end-to-end connectivity and data processing tailored to specific business requirements. These requirements include customizable network capabilities such as the support of very high data rates, traffic densities, service availability and very low latency. According to 5G standardization efforts, the 5G system should support the needs of the business through the specification of several service needs such as data rate, traffic capacity, user density, latency, reliability, and availability. These capabilities are always provided based on a Service Level Agreement (SLA) between the mobile operator and the business customer, which brought up interest for mechanisms to ensure slice SLAs and prevent its possible violations. O-RAN’s open interfaces and AI/ML based architecture will enable such challenging mechanisms to be implemented and help pave the way for operators to realize the opportunities of network slicing in an efficient manner.

RAN slice SLA assurance scenario involves Non-RT RIC, Near-RT RIC, E2 Nodes and SMO interaction. The scenario starts with the retrieval of RAN specific slice SLA/requirements (possibly within SMO or from NSSMF depending on Operator deployment options). Based on slice specific performance measurements from E2 Nodes, Non-RT RIC and Near-RT RIC can fine-tune RAN behavior aligned with O-RAN architectural roles to assure RAN slice SLAs. Non-RT RIC monitors long-term trends and patterns for RAN slice subnets’ performance, and employs AI/ML methods to perform corrective actions through SMO (e.g. reconfiguration via O1) or via creation of A1 policies. Non-RT RIC can also construct/train relevant AI/ML models that will be deployed at Near-RT RIC. A1 policies possibly include scope identifiers (e.g. S-NSSAI) and statements such as KPI targets. On the other hand, Near-RT RIC enables optimized RAN actions through execution of deployed AI/ML models in near-real-time by considering both O1 configuration (e.g. static RRM policies) and received A1 policies, as well as received slice specific E2 measurements.

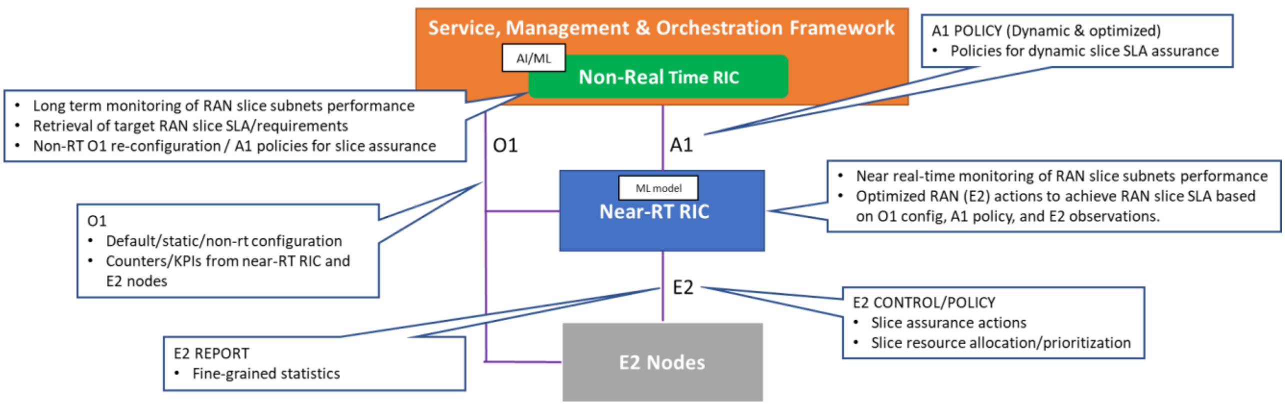


Figure 3.2.2-1: RAN Slice SLA Assurance use case overview

The more detailed functions provided by the entities for RAN slice SLA assurance are listed as below:

1) Non-RT RIC:
    a) Retrieve RAN slice SLA target from respective entities such as SMO, NSSMF
    b) Long term monitoring of RAN slice subnet performance measurements
    c) Training of potential ML models that will be deployed in Near-RT RIC for optimized slice assurance
    d) Support deployment and update of AI/ML models into Near-RT RIC
    e) Send A1 policies and enrichment information to Near-RT RIC to drive slice assurance

    f) Send O1 reconfiguration requests to SMO for slow-loop slice assurance

2) Near-RT RIC:
    a) Near real-time monitoring of slice specific RAN performance measurements
    b) Support deployment and execution of the AI/ML models from Non-RT RIC
    c) Support interpretation and execution of policies from Non-RT RIC
    d) Perform optimized RAN (E2) actions to achieve RAN slice subnet requirements based on O1 configuration, A1 policy, and E2 reports
3) RAN:
    a) Support slice assurance actions such as slice-aware resource allocation, prioritization, etc.
    b) Support slice specific performance measurements through O1
    c) Support slice specific performance reports through E2

3.2.2 Use Case 2: Multi-vendor Slices

This use case enables multiple slices with functions provided by multi-vendors, such as slice #1, composed of DU(s) and CU(s), provided by vendor B and slice #2, composed of DU(s) and CU(s), provided by vendor C.

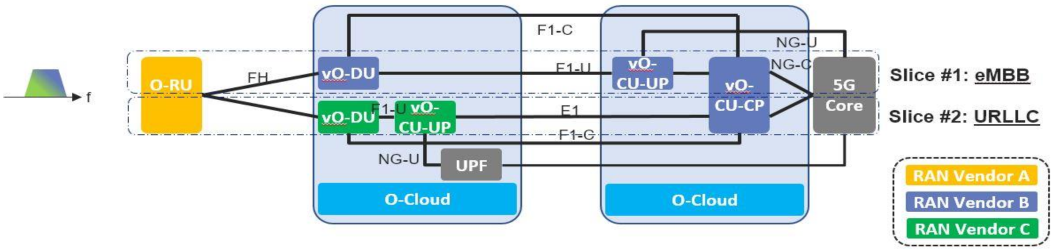


Figure 3.2.2-1: Multi-vendor Slices

When providing multiple slices, it is assumed that suitable vO-DU/scheduler and vO-CU treat each slice respectively. A vendor who provides vO-DU and vO-CU function may have a strength of a customized scheduler for a certain service. With accomplishment of multi-vendor circumstances, following benefits can be expected:

1) More flexible and time to market deployment

    Operators can maximize options to choose suitable vO-DU/scheduler and vO-CU to offer various slices. For example, some vendors may have a strength of a scheduler for eMBB service and the other may have a strength of scheduler for URLLC service. Or, vendor A can provide vO-DU/scheduler and vO-CU suitable for URLLC earlier than vendor B, therefore operators can choose vO-DU and vO-CU functions from vendor A to meet their service requirements.

    Also, when an operator wants to add a new service/slice, new functions from a new vendor can be introduced with less consideration for existing vendors if multi-vendor circumstance was realized. This may help expand vendor's business opportunities rapidly.

2) Flexible deployment when sharing RAN equipment among operators

When operators want to share RAN equipment and resources, RAN vendors and their placement of each RAN functions may be different. If multi-vendor circumstance was introduced, then it can relax restrictions among operators to share RAN equipment and resources. This may help expanded opportunities for reaching agreements of RAN sharing among operators. With expansion of RAN sharing, operators CAPEX and OPEX can be optimized, helping with additional investment opportunities.

3) Reducing supply chain risk

If an existing vendor providing a certain pair of vO-DU and vO-CU functions withdraws of the market due to business reasons, operators can deploy new vO-DU and vO-CU functions alternatively from other vendors under this multi-vendor circumstance. This can reduce a risk for operators' business continuity.

To realise multi-vendor slices, some coordination between vO-DU/vO-CUs will be required since radio resource shall be assigned properly and without any conflicts. Depending on different service goals and the potential impact on O-RAN architecture, a required coordination scheme needs to be determined. The possible cases are:

1) Loose coordination through O1/E2/A1 interface (Case 1 in Figure 3.2.2-2)
2) Moderate coordination through X2/F1 interface (Case 2 in Figure 3.2.2-2)
3) Tight coordination through a new interface between vO-DUs (Case 3 in Figure 3.2.2-2)

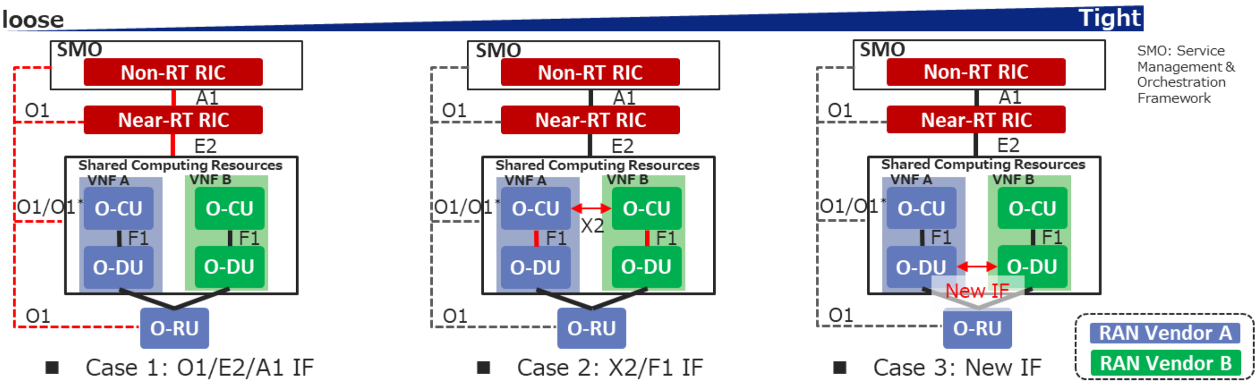


Figure 3.2.2-2: Multi-vendor Slices Coordination Scheme Options

In case 1, a resource allocation between slices or vO-DU/vO-CUs is provisioned through O1/A1/E2 interface and each pair of vO-DU and vO-CU will allocate radio resources to each customer within radio resources allocated by Near-RT RIC and/or Non-RT RIC.

In case 2, a resource allocation can be negotiated between slices or vO-DU/vO-CUs through X2 and F1 after provisioned through O1/E2/A1 interface. Negotiation period will be several seconds due to periodicity of X2 and F1 message exchange between vO-CU(s).

If a more adaptive radio resource allocation is needed (case 3), a more frequent negotiation would be required. This can potentially be achieved via an interface or API extension between vO-DU(s), which would be for FFS in WG1 and WG4.

3.2.3 Use Case 3: NSSI Resource Allocation Optimization

5G networks are becoming increasingly complex with the densification of millimeter wave small cells, and various new services, such as eMBB (enhanced Mobile Broadband), URLLC (Ultra Reliable Low Latency Communications), and mMTC (massive Machine Type Communications) that are characterized by high speed high data volume, low speed ultra-low latency, and infrequent transmitting low data volume from huge number of emerging smart devices, respectively. It is a challenging task for 5G networks to allocate resources dynamically and efficiently among multiple network nodes to support various services. However, eMBB, URLLC, and mMTC services in 5G are typically realized as NSI(s) (Network Slice instance(s)). Therefore, the resources allocated to NSSI (Network Slice Subnet Instance) to support the O-RAN nodes can be optimized according to the service requirements.

As the new 5G services have different characteristics, the network traffic tends to be sporadic, where there may be different usage pattern in terms of time, location, UE distribution, and types of applications. For example, most IoT sensor applications may run during off-peak hours or weekends. Special events, such as sport games, concerts, can cause traffic demand to shoot up at certain times and locations. Therefore, NSSI resource allocation optimization function trains the AI/ML model, based on the huge volume of performance data collected over days, weeks, months from O-RAN nodes. It then uses the AI/ML model to predict the traffic demand patterns of 5G networks in different times and locations for each network slice subnet, and automatically re-allocates the network resources ahead of the network issues surfaced.

Figure 3.2.3-1 shows the NSSI resource allocation optimization on the Non-RT RIC, and may consist of the following steps:

1. Monitoring: monitor the radio network(s) by collecting data via the O1 interface, including the following performance measurements that are measured per NSSI (TS 28.552 [7]):

    - DL PRB used for data traffic
    - UL PRB used for data traffic
    - Average DL UE throughput in gNB
    - Average UL UE throughput in gNB
    - Number of PDU Sessions requested to setup
    - Number of PDU Sessions successfully setup
    - Number of PDU Sessions failed to setup

2. Analysis & Decision: analyse the data to train the AI/ML model, and then determine the actions needed to add or reduce the resources (e.g. capacity, VNF resources, slice subnet attributes (TS 28.541 [6]), etc.) for the NSSI at the given time, and location.

3. Execution: execute the following actions to reallocate the NSSI resources:

    3a. Re-configure the NSSI attributes via the O1 interface
    3b. Update the cloud resources via the O2 interface

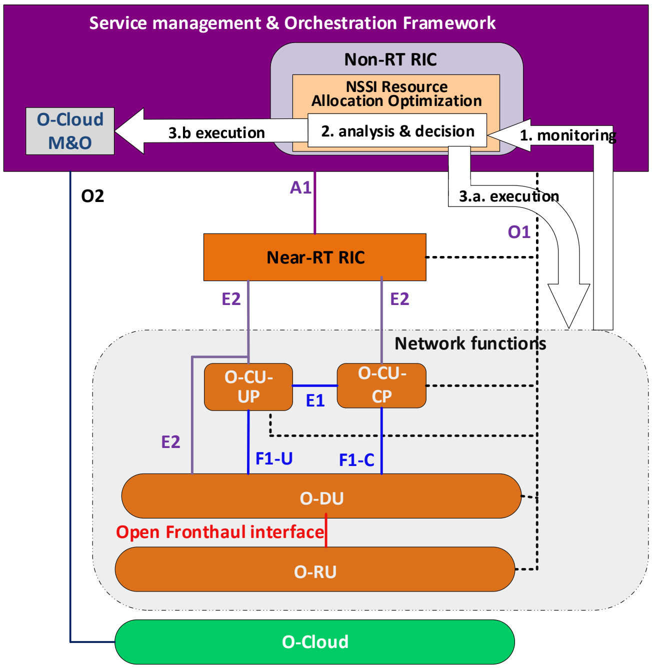


Figure 3.2.3-1: The realization of NSSI resource allocation optimization over Non-Real Time RIC

The more detailed functions provided by the entities for NSSI resource optimization are listed as follows:

1) Non-RT RIC:
   a) Collect the performance measurements related to NSSI resource usage from the O-RAN nodes via the O1 interface.
   b) Train the AI/ML model based on the analysis of historical performance measurements, to predict of the traffic demand patterns of NSSI at different times and locations.
   c) Determine the time/date and locations (i.e. which O-RAN nodes) to add or reduce the resources (e.g. capacity, VNF resources, slice subnet attributes (TS 28.541 [6]), etc.) for a given NSSI based on inference.
   d) Perform the following action(s) to optimize the NSSI resource allocation, at the time determined by the model
      i. Re-configure the NSSI attributes via the O1 interface
      ii. Update the cloud resources via the O2 interface

2) E2 Nodes (O-CU-CP, O-CU-UP, O-DU, and O-RU):
   a) Support the performance measurement collection with required granularity over O1 interface.
   b) Support the configuration related to the NSSI resource allocation update over O1 interface.

Chapter 4. O-RAN Slicing Principles and Requirements

4.1 General Principles

This section contains the general O-RAN slicing architecture principles as described below:

- O-RAN slicing architecture and interface specifications shall be consistent with 3GPP architecture and interface specifications to the extent possible
- O-RAN slicing architecture shall provide standardized management service interfaces for RAN slicing management services
- O-RAN slicing architecture shall enable multi-vendor interoperability
- O-RAN slicing architecture shall support various Network Operator deployment options
- O-RAN slicing architecture shall support management of RAN slice subnets in multi-operator scenarios

4.2 Slicing Requirements

4.2.1 Functional Requirements

Initial set of O-RAN slicing functional requirements based on the use cases defined in this version of the specification are captured in Table 4.2.1-1

Table 4.2.1-1: O-RAN Slicing Functional Requirements

REQ	Description	Note
[REQ-SL-FUN1]	O-RAN slicing architecture and interfaces must support network slicing, where an instance of O-RAN network function may be associated with one or more slices.	ORAN OAM Specification v02.00
[REQ-SL-FUN2]	O-RAN slicing architecture shall support differentiated handling of traffic for different RAN slice subnets	3GPP TS 38.300
[REQ-SL-FUN3]	O-RAN slicing architecture shall support resource isolation between slices	3GPP TS 38.300
[REQ-SL-FUN4]	O-RAN slicing architecture shall enable traffic and services in one RAN slice subnet having no impact on traffic and services in other RAN slice subnets in the same network	3GPP TS 22.261
[REQ-SL-FUN5]	O-RAN slicing architecture shall enable mechanisms to avoid shortage of shared resources in one slice breaking the service level agreement for another slice	3GPP TS 38.300
[REQ-SL-FUN6]	O-RAN slicing architecture shall enable defining a priority order between different RAN slice subnets in case multiple slices compete for resources on the same RAN	3GPP TS 22.261

[REQ-SL-FUN7]	O-RAN slicing architecture shall apply policies at S-NSSAI level according to the SLA required by the network slice	-
[REQ-SL-FUN8]	O-RAN slicing architecture shall support means by which the operator can differentiate policy control, functionality and performance provided in different RAN slice subnets	3GPP TS 22.261
[REQ-SL-FUN9]	O-RAN slicing architecture shall support QoS differentiation within a slice	3GPP TS 38.300
[REQ-SL-FUN10]	O-RAN slicing architecture shall enable slice aware radio resource management strategies (such as admission control, congestion control, handover preparation)	3GPP TS 38.300
[REQ-SL-FUN11]	O-RAN slicing architecture shall allow creation, modification, and deletion of a RAN slice subnet	3GPP TS 28.531
[REQ-SL-FUN12]	O-RAN slicing architecture shall support interaction between the SMO Framework and Non-RT RIC to consume provisioning management services exposed by each O-RAN managed element to configure RAN slice subnets through the O1 interface	RAN Slice SLA Assurance use case, NSSI Resource Allocation Optimization use case
[REQ-SL-FUN13]	O-RAN slicing architecture shall support the interaction between the SMO Framework and Non-RT RIC to consume management of slice specific PM jobs, PM data collection/storage/query/statistical reports from O-RAN network functions through the O1 interface	RAN Slice SLA Assurance use case, NSSI Resource Allocation Optimization use case
[REQ-SL-FUN14]	O-RAN slicing architecture shall support interaction between the SMO Framework and Non-RT RIC to retrieve/notify RAN slice subnet requirements (SLA) along with O-NSSI information	RAN Slice SLA Assurance use case, O-RAN Slice Subnet Instance Creation use case
[REQ-SL-FUN15]	O-RAN slicing architecture shall support provisioning, generation and monitoring of slice specific RAN performance metrics through O1 interface	RAN Slice SLA Assurance use case, NSSI Resource Allocation Optimization use case
[REQ-SL-FUN16]	O-RAN slicing architecture shall support training, deployment and execution of AI/ML models for slice SLA assurance and NSSI resource allocation optimization	RAN Slice SLA Assurance use case, NSSI Resource Allocation Optimization use case
[REQ-SL-FUN17]	O-RAN slicing architecture shall support slice specific policy guidance, enrichment information and policy feedback	RAN Slice SLA Assurance use case
[REQ-SL-FUN18]	O-RAN slicing architecture shall support provisioning, generation and monitoring of slice specific RAN performance data through E2 interface	RAN Slice SLA Assurance use case
[REQ-SL-FUN19]	O-RAN slicing architecture shall support reconfiguration of slice specific RAN parameters and resources for slice SLA assurance	RAN Slice SLA Assurance use case
[REQ-SL-FUN20]	O-RAN slicing architecture shall enable creation of O-RAN network slice subnet instances as O-RAN network service (NS) instance(s) within O-Cloud(s)	O-RAN Slice Subnet Instance Creation use case
[REQ-SL-FUN21]	O-RAN slicing architecture shall enable association and disassociation of O-Cloud NS instances with corresponding O-NSSIs	O-RAN Slice Subnet Instance Creation use case, O-RAN Slice Subnet Instance Termination use case
[REQ-SL-FUN22]	O-RAN slicing architecture shall enable creation of O-RAN network slice subnet instances as O-RAN network function (NF) instance(s) within O-Cloud(s)	O-RAN Slice Subnet Instance Creation use case

[REQ-SL-FUN23]	O-RAN slicing architecture shall enable association and disassociation of O-Cloud NF instances with corresponding O-NSSIs	O-RAN Slice Subnet Instance Creation use case, O-RAN Slice Subnet Instance Termination use case
[REQ-SL-FUN24]	O-RAN slicing architecture shall support (re-)configuration of an O-NSSI's constituent network functions through the O1 interface	O-RAN Slice Subnet Instance Creation use case, O-RAN Slice Subnet Modification use case, O-RAN Slice Subnet Configuration use case
[REQ-SL-FUN25]	O-RAN slicing architecture shall support (re-)configuration of an O-RAN network slice subnet instance (O-NSSI) attributes	O-RAN Slice Subnet Instance Creation / Activation / Modification / Deactivation / Configuration use case
[REQ-SL-FUN26]	O-RAN slicing architecture shall have the capability for the establishment of required transport network connectivity between O-RAN NFs during provisioning of O-RAN network slice subnet instances	O-RAN Slice Subnet Instance Creation use case, O-RAN Slice Subnet Instance Modification use case
[REQ-SL-FUN27]	O-RAN slicing architecture shall enable Non-RT RIC to be notified when an O-NSSI has been created, activated, modified, deactivated and terminated	O-RAN Slice Subnet Instance Creation use case, O-RAN Slice Subnet Instance Modification use case, O-RAN Slice Subnet Instance Termination use case
[REQ-SL-FUN28]	O-RAN slicing architecture shall support the capability to activate the constituent physical network functions such as O-DU and O-RU within an O-NSSI	O-RAN Slice Subnet Instance Activation use case
[REQ-SL-FUN29]	O-RAN slicing architecture shall enable modification of O-RAN network slice subnet instances through modification (such as scaling, updating, instantiation, etc.) of O-RAN network service (NS) instance(s) within O-Cloud(s)	O-RAN Slice Subnet Instance Modification use case
[REQ-SL-FUN30]	O-RAN slicing architecture shall enable modification of O-RAN network slice subnet instances through modification (such as scaling, updating, instantiation, etc.) of O-RAN network function (NF) instance(s) within O-Cloud(s)	O-RAN Slice Subnet Instance Modification use case
[REQ-SL-FUN31]	O-RAN slicing architecture shall support the capability to deactivate the constituent physical network functions such as O-DU and O-RU within an O-NSSI	O-RAN Slice Subnet Instance Deactivation use case
[REQ-SL-FUN32]	O-RAN slicing architecture shall enable removal of constituent O-RAN network service (NS) instance(s) that were functioning within O-Cloud(s) and were associated to O-RAN network slice subnet instance(s)	O-RAN Slice Subnet Instance Termination use case
[REQ-SL-FUN33]	O-RAN slicing architecture shall enable removal of constituent O-RAN network function (NF) instance(s) that were functioning within O-Cloud(s) and were associated to O-RAN network slice subnet instance(s)	O-RAN Slice Subnet Instance Termination use case
[REQ-SL-FUN34]	O-RAN slicing architecture shall have the capability for the removal of non-shared transport network connectivity between O-RAN NFs during termination of O-RAN network slice subnet instances	O-RAN Slice Subnet Instance Termination use case

[REQ-SL-FUN35]	O-RAN slicing architecture shall enable reservation of O-RAN network service (NS) instance(s) within O-Cloud(s)	O-RAN Slice Subnet Feasibility Check
[REQ-SL-FUN36]	O-RAN slicing architecture shall enable reservation of O-RAN network service (NF) instance(s) within O-Cloud(s)	O-RAN Slice Subnet Feasibility Check
[REQ-SL-FUN37]	O-RAN slicing architecture shall enable retrieval of network utilization information from the SMO and Non-RT RIC (e.g., load level information, resource usage information from management data analytics services)	O-RAN Slice Subnet Feasibility Check
[REQ-SL-FUN38]	O-RAN slicing architecture shall support interaction between the SMO Framework and Non-RT RIC to consume O-Cloud management and orchestration services through the O2 interface	RAN Slice SLA Assurance use case, NSSI Resource Allocation Optimization use case
[REQ-SL-FUN39]	O-RAN slicing architecture shall enable provisioning and management of multiple slices on O-RU	Multi-vendor Slices use case
[REQ-SL-FUN40]	O-RAN slicing architecture shall enable O-RU to route per slice user plane traffic to one or more O-DUs	Multi-vendor Slices use case

4.2.2 Non-Functional Requirements

Initial set of O-RAN slicing non-functional requirements based on the use cases defined in this version of the specification are captured in Table 4.2.2-1

Table 4.2.2-1: O-RAN Slicing Non-Functional Requirements

REQ	Description	Note
[REQ-SL-NFUN1]	O-RAN slicing architecture shall support use of AI/ML to support RAN slicing use cases	

Chapter 5. O-RAN Reference Slicing Architecture

This section provides O-RAN reference slicing architecture along with the high level roles and responsibilities of O-RAN network functions.

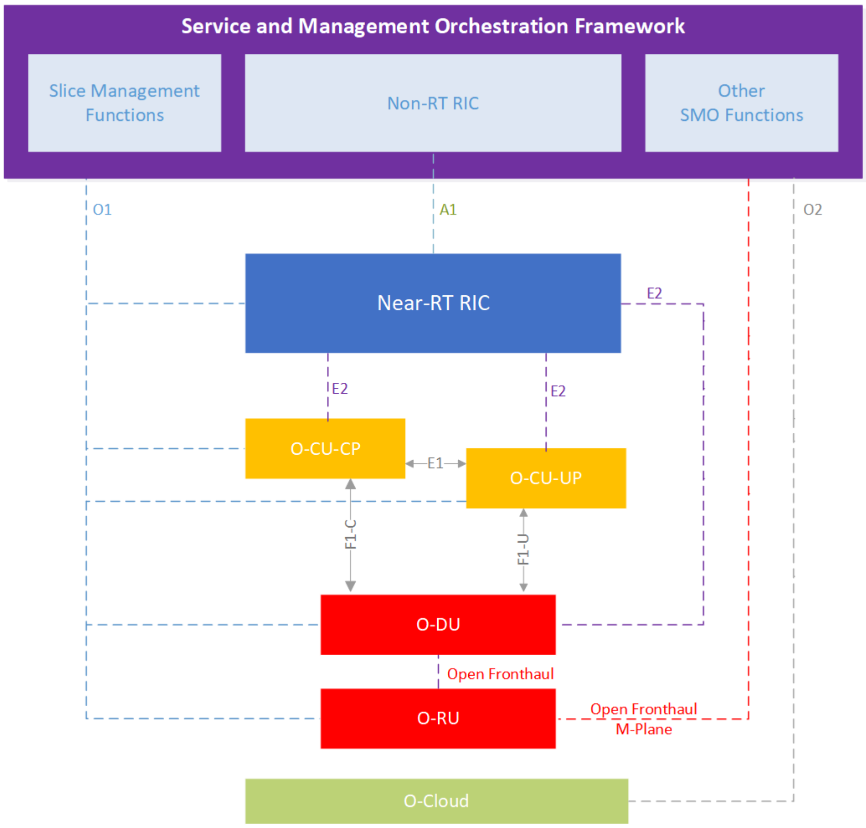


Figure 5-1: O-RAN Reference Slicing Architecture

O-RAN reference slicing architecture includes slice management functions along with O-RAN architectural components. As O-RAN's general principle is to be as compliant as possible with 3GPP architecture, these slice management functions are 3GPP defined NSMF and NSSMF with extensions for O-RAN network functions. Various deployment options of the location of NSMF and NSSMF have been presented in [18] and more detailed architectural implementation options for SMOs including NFV-MANO and ONAP are being presented in Appendix A.

5.1 Non-RT RIC

The fundamental role of the Non-RT RIC in O-RAN slicing architecture is to gather long term slice related data through interaction with the SMO framework and apply AI/ML based approaches interworking with the Near-RT RIC to provide innovative RAN slicing use cases. For this purpose, Non-RT RIC should be aware of RAN slice subnets and their respective SLAs through SMO. In addition, Non-RT RIC may retrieve enrichment information from 3rd party applications enabling advanced RAN slicing technology to be applied in O-RAN framework.

In order to construct AI/ML models to be deployed in the Near-RT RIC, Non-RT RIC retrieves slice specific performance metrics, configuration parameters and required attributes of the RAN slice subnets from the SMO framework. Complex problems for Near-RT RIC e.g. applying RRM policies can be tackled by learning capabilities of AI/ML. The output of these algorithms can lead non-real-time optimization of the slice specific parameters of Near-RT RIC, O-CU and O-DU over O1 interface through SMO interaction. Moreover, these performance, configuration and other slice related data are used to generate policy guidance and assist Near-RT RIC over A1 to provide closed loop slice optimization. Applying such slice optimizations in the Near-RT RIC can be used for SLA assurance and prevent SLA violations between the slices as well.

5.2 Near-RT RIC

Near-RT RIC is the component which enables near-real-time RAN slice subnet optimization through execution of slicing related xApps and communicating necessary parameters to O-CU and O-DU through E2 interface. Deployed xApps may utilize either AI/ML based models or other control schemes which can further be guided by A1 policies that are generated by Non-RT RIC.

In order to drive sliced RAN resources properly, Near-RT RIC should have the knowledge of existing RAN slice subnets as well as their requirements. This information will be received through O1 interface during provisioning of RAN slice subnets. Therefore similar to Non-RT RIC, Near-RT RIC will be aware of RAN slice subnets through O-RAN specific information models and provisioning procedures.

In O-RAN slicing architecture, configuration of slice resources on E2 nodes can be achieved through slow loop with O1 configuration and through fast loop with E2 configuration. This architecture enables advanced slicing use cases such as RAN slice SLA assurance and further enhances 3GPP slicing capability without misalignment. While Near-RT RIC is capable for fast-loop configuration, slicing related O1 configuration, such as RRM policy information sent to O-CU, configured by the SMO framework will be taken into account. Moreover, slice specific near-RT performance data will be monitored through E2 interface which needs proper PM mechanisms between E2 nodes and Near-RT RIC as well.

5.3 O-RAN Central Unit (O-CU)

O-CU, which includes a single O-CU-CP and possibly multiple O-CU-UP(s), which are communicating through E1 interface, needs to support slicing features as defined by 3GPP. Depending on slice requirements, O-CU-UP can be shared across slices or a specific instance of O-CU-UP can be instantiated per slice. On top of 3GPP slicing features, O-RAN further enhances slicing through the utilization of E2 interface and the assistance of Near-RT RIC dynamic slice optimizations along with the enhanced O1 interface to support additional slice configuration parameters.

O-CU stacks, which are the upper layer protocols of the RAN stack, should be slice aware and execute slice specific resource allocation and isolation strategies. These stacks are initially configured through O1 interface based on the slice specific requirements and then dynamically updated through E2 interface via Near-RT RIC for various slicing use cases.

Based on the PM requests from SMO and Near-RT RIC, O-CU may need to generate and send specific PMs through O1 and E2 interfaces respectively, where the PMs can be used for slice performance monitoring and slice SLA assurance purposes.

5.4 O-RAN Distributed Unit (O-DU)

O-DU, which runs the lower layer protocols of RAN stack, should support slice specific resource allocation strategies as well. Based on the initial O1 configuration of PRB allocation levels along with O-CU directives over F1 interface and the dynamic guidance received from Near-RT RIC over E2 interface, MAC layer needs to allocate and isolate relevant PRBs to specific slices.

Based on the PM requests from SMO and Near-RT RIC, O-DU may need to generate and send specific PMs through O1 and E2 interfaces respectively, where the PMs can be used for slice performance monitoring and slice SLA assurance purposes.

5.5 A1 Interface

A1, which is the interface between the Non-RT RIC and the Near-RT RIC, supports policy management, ML model management and enrichment information services [12]. These three services will be utilized for various slicing use cases, such as slice SLA assurance. Policy management will be used by Non-RT RIC to send slice specific (e.g. S-NSSAI based) policies to guide Near-RT RIC with slice resource allocations and slice specific control activities, as well as to receive slice specific policy feedback for the policies deployed on the Near-RT RIC.

For the use cases that make use of external enrichment data or where Non-RT RIC produces enrichment information, A1 enrichment interface will be used to send slice specific enrichment data to Near-RT RIC.

It should be noted that slice specific A1 policies are not persistent (do not survive the restart of Near-RT RIC) and while they may take precedence over O1 slice specific configurations, they should be aligned and not deviate significantly from O1 configurations.

Note: It is intended to add examples for the usage of A1 services for slicing use cases in the next version of this document.

5.6 E2 Interface

E2, which is the interface between the Near-RT RIC and the E2 nodes, supports E2 primitives (Report, Insert, Control and Policy) to control the services exposed by E2 nodes [13]. These primitives will be used by slice specific applications (xApps) to drive E2 nodes' slice configurations and slice specific behaviour, such as slice based radio resource management, radio resource allocations, MAC scheduling policies and other configuration parameters used by various RAN protocol stacks.

E2 will be used to configure and receive slice specific reports and performance data from E2 nodes. These reports may include 3GPP defined slice specific PMs (such as PRB utilization, average delay, etc. [7]) and new PMs that can be defined by O-RAN to support various slicing use cases.

Note: It is intended to add examples for the usage of E2 primitives for slicing use cases in the next version of this document.

5.7 O1 Interface

O1, which is the interface between O-RAN managed elements and the management entity as defined in [9], will be used to configure slice specific parameters of O-RAN nodes based on the service requirements of the slice. 3GPP have defined some of the slice specific information models in TS 28.541 [6], including the RRM policy attributes to provide the ratio of PRBs and the split of these PRBs among slices. To support O-RAN slicing use cases and their requirements, 3GPP information models may be extended and additional information models may be defined to capture slice profiles and slice specific configuration parameters, which will be carried over O1 interface as well.

O1 will also be used to configure and gather slice specific performance metrics and slice specific faults from O-RAN nodes.

Note: It is intended to add examples for the usage of O1 for the configuration, performance and fault management of slicing use cases in the next version of this document.

5.8 O2 Interface

O2, which is the interface between the SMO and O-Cloud as introduced in [14], will be used for life cycle management of virtual O-RAN network functions. As part of RAN NSSI creation and provisioning, RAN NSSMF, in interaction with SMO, triggers the instantiation of necessary O-RAN functions (such as Near-RT RIC, O-CU-CP, O-CU-UP and O-DU) based on slice requirements. After the creation of RAN NSSI, NSSMF in interaction with SMO can execute NSSI modification and NSSI deletion procedures.

Since Non-RT RIC is part of SMO and would be instantiated along with other SMO functions, O2 is not expected to be used for lifecycle management of Non-RT RIC.

Note: It is intended to add examples for the usage of O2 for slice lifecycle management of O-RAN network functions in the next version of this document.

5.9 Transport Network Slicing

As RAN Slice Subnet is composed of not only the O-RAN NFs but also the transport network components; Fronthaul interface (FH) between O-RU and O-DU and the Midhaul interface (MH) between the O-DU and O-CU, transport slicing aspects needs to be considered and incorporated into the overall O-RAN Slicing Architecture.

There are different emerging approaches for defining transport network slicing that can meet 5G requirements, which mobile interfaces (Fronthaul and Midhaul in RAN slice subnet, Backhaul between RAN slice subnet and Core slice subnet, and between Core slice subnet and the PDN) can and need to be sliced, what form they will take and the number of slices required at the transport layer [16].

This section aims to capture the transport network slicing aspects for Fronthaul and Midhaul links and provide references to relevant WG4 (Fronthaul), WG6 (intra-DC virtual links) and WG9 (inter-DC links) specifications as these specs become available. Given the current state and progress in these WGs, this version of the O-RAN Slicing Architecture Specification will focus only on WG9 aspects, with Figure 1 illustrating the scope of the network segments covered by WG9. The area inside the dotted green line characterizes the transport networks composed of a number of Transport Network Elements (TNE) deployed among different components defined in other O-RAN WGs. WG9 does not define the interfaces along the dotted green line. As an example, the Fronthaul interface of an O-RU or O-DU are defined by WG4.

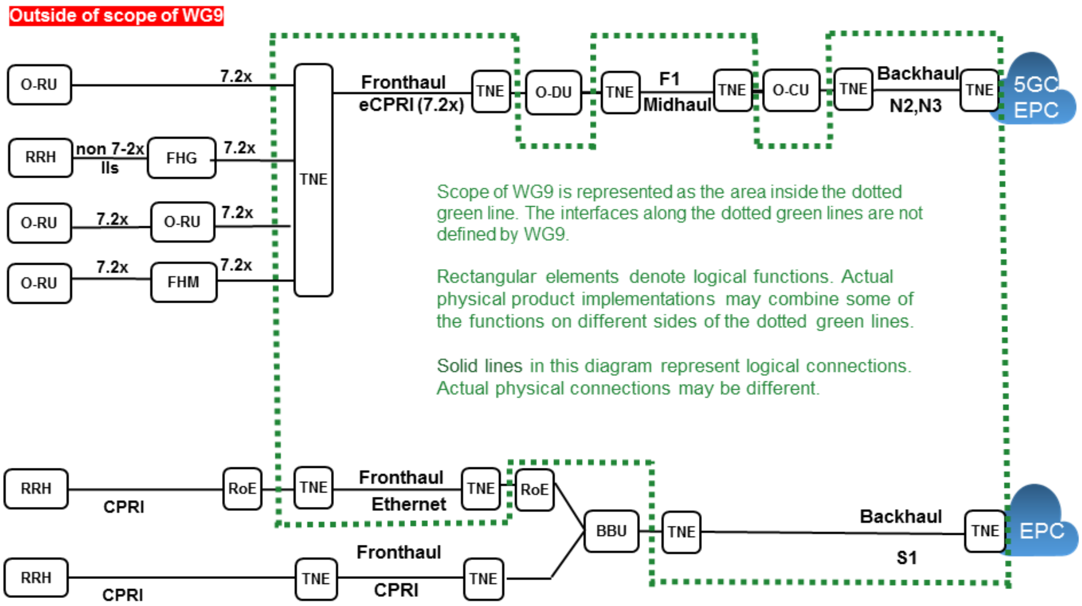


Figure 5.9-1: Xhaul Transport Network Overview (ref: Figure 5-1 [16])

Packet Switched Transport Network Slicing:

O-RAN WG9 has defined the architecture and the best practices for an Open Xhaul transport network based on an end-to-end packet switching architecture in "Xhaul Packet Switched Architectures and Solutions specification" [16] that can support the requirements outlined in the O-RAN WG9 Transport Requirements document [17]. While the "Xhaul Packet Switched Architectures and Solutions specification" [16] describes the best practices for O-RAN transport based on end-to-end packet switching technology, it is recognized that other solutions, not based on packet switching, could be utilized, or mixed with a packet switching solution as well (which are FFS).

As indicated in section 17 [16] the terms hard and soft slicing has emerged for transport networks, referring to the level of isolation between different slices:

- Hard slicing: Transport resources are dedicated to a specific "Network Slice Instance" (NSI) and cannot be shared with other slices.
- Soft slicing: Transport resources are shared and can be re-used by other slices.

A packet switched infrastructure, as described in [16], has an extensive toolset, consisting of underlay forwarding solutions, Quality of Service (QoS) and VPNs that allows an operator to scalable partition the transport network to cater for both hard and soft slices. See Figure 5.9-2 for transport slice requirements and associated toolset.

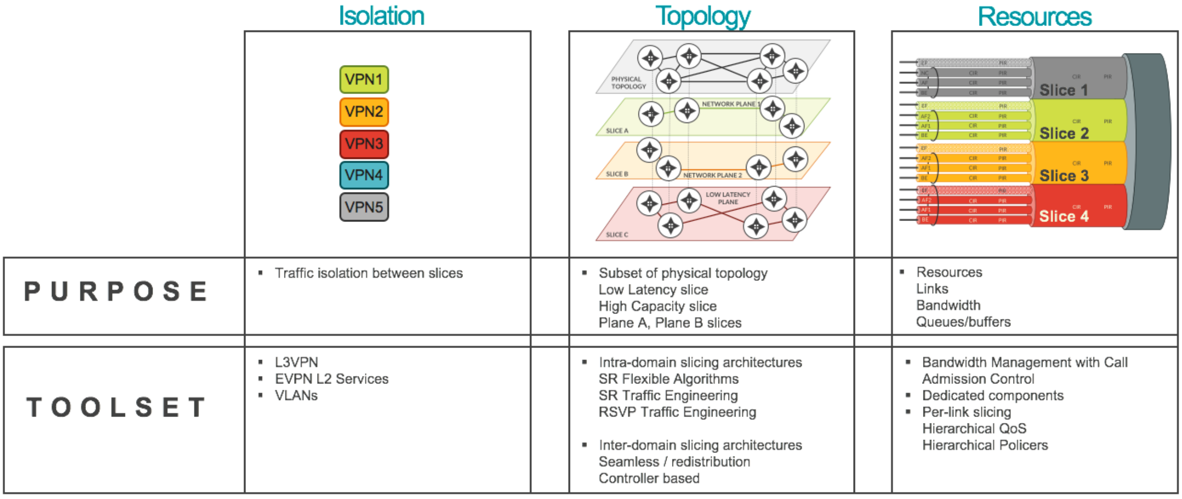


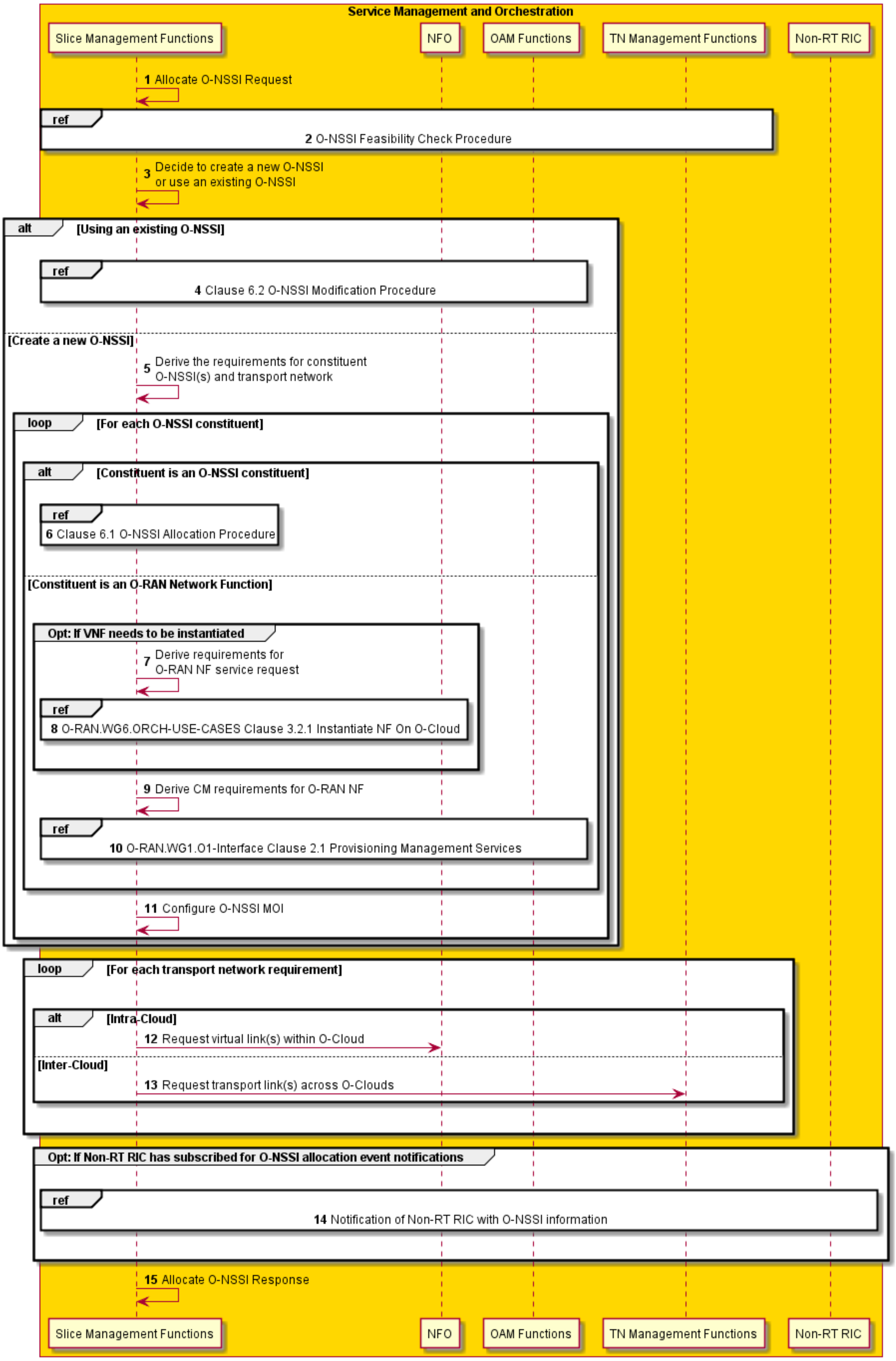
Figure 5.9-2: Packet switched toolset for transport level slicing (ref: Figure 17-2 [16])

Further details of transport network slicing based on packet switching technology is captured in section 17 and section 18.10 of [16], including packet-switched underlay networks, transport network Quality of Service, 5G service and slices and a transport slicing scenario on a packet switched Xhaul network.

Chapter 6. O-RAN Slice Subnet Provisioning Procedures

6.1 O-RAN Slice Subnet Instance (O-NSSI) Allocation Procedure

Figure 6.1-1 captures the procedure for allocation of an O-RAN slice subnet instance to satisfy the O-NSSI requirements.



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2 **Figure 6.1-1: O-NSSI Allocation Procedure**

1) Slice subnet management function receives an allocate O-NSSI request (see AllocateNssi operation defined in clause 6.5.2 in 3GPP TS 28.531 [5]) with network slice subnet related requirements (network slice subnet related requirements defined in SliceProfile see clause 6.3.4 in TS 28.541 [6]).
2) Slice subnet management function checks the feasibility of O-RAN slice subnet related requirements utilizing O-NSSI Feasibility Check Procedure (FFS). If the network slice subnet related requirements can be satisfied, the following steps are needed, else go to step 15.
3) Based on the O-RAN slice subnet related requirements slice subnet management function decides whether to use an existing O-NSSI or create a new O-NSSI.
4) If using an existing O-NSSI and the existing O-NSSI needs to be modified, slice subnet management function invokes the O-NSSI Modification Procedure (FFS).
5) If creating a new O-NSSI, slice subnet management function creates the MOI for the O-NSSI to be created and then derives the corresponding O-RAN slice subnet constituent (i.e. O-RAN NF, constituent O-NSSI) related requirements and transport network related requirements from the received network slice subnet related requirements.

For each required O-NSSI constituent, steps 6-11 are needed:

6) If the required O-NSSI constituent is constituent O-NSSI, slice subnet management function invokes O-NSSI Allocation Procedure (Clause 6.1).

If the required O-NSSI constituent is a virtual O-RAN NF instance, steps 7-8 are needed:

7) Slice subnet management function derives requirements for O-RAN NF service request
8) If the O-RAN VNF instance needs to be instantiated, slice subnet management function executes O-RAN.WG6.ORCH-USE-CASES Clause 3.2.1 Instantiate NF On O-Cloud [15]. If an existing O-RAN VNF instance needs to be modified, slice subnet management function may execute Clause 3.2.2 Scale Out of NF, 3.2.3 Scale In of NF as defined in O-RAN.WG6.ORCH-USE-CASES [15].
9) Slice subnet management function derives CM requirements for O-RAN NF
10) Slice subnet management function executes O-RAN.WG1.O1-Interface Clause 2.1 Provisioning Management Services [10]
11) Slice subnet management function configures the O-NSSI MOI.

For each transport network requirement, steps 12-13 are needed:

12) If the transport link is within a cloud, slice subnet management function request virtual link establishment within respective O-Cloud via NFO
13) If the transport link is a physical link that needs to be established across clouds, slice subnet management function request transport link establishment from TN management functions.
14) If Non-RT RIC has subscribed for O-NSSI allocation event notifications, slice subnet management function notifies Non-RT RIC with O-NSSI information
15) Slice subnet management function returns appropriate O-NSSI allocation result (see AllocateNssi operation defined in clause 6.5.2 of 3GPP TS 28.531 [5]). If the O-NSSI is created successfully, the result includes the relevant constituent network slice subnet instance information (see NetworkSliceSubnet IOC defined in clause 6.3.2 in TS 28.541 [6]).

6.2 O-RAN Slice Subnet Instance (O-NSSI) Modification Procedure

FFS

6.3 O-RAN Slice Subnet Instance (O-NSSI) Deallocation Procedure

Figure 6.3-1 captures the procedure for deallocation of an O-RAN slice subnet instance to satisfy the O-NSSI requirements.

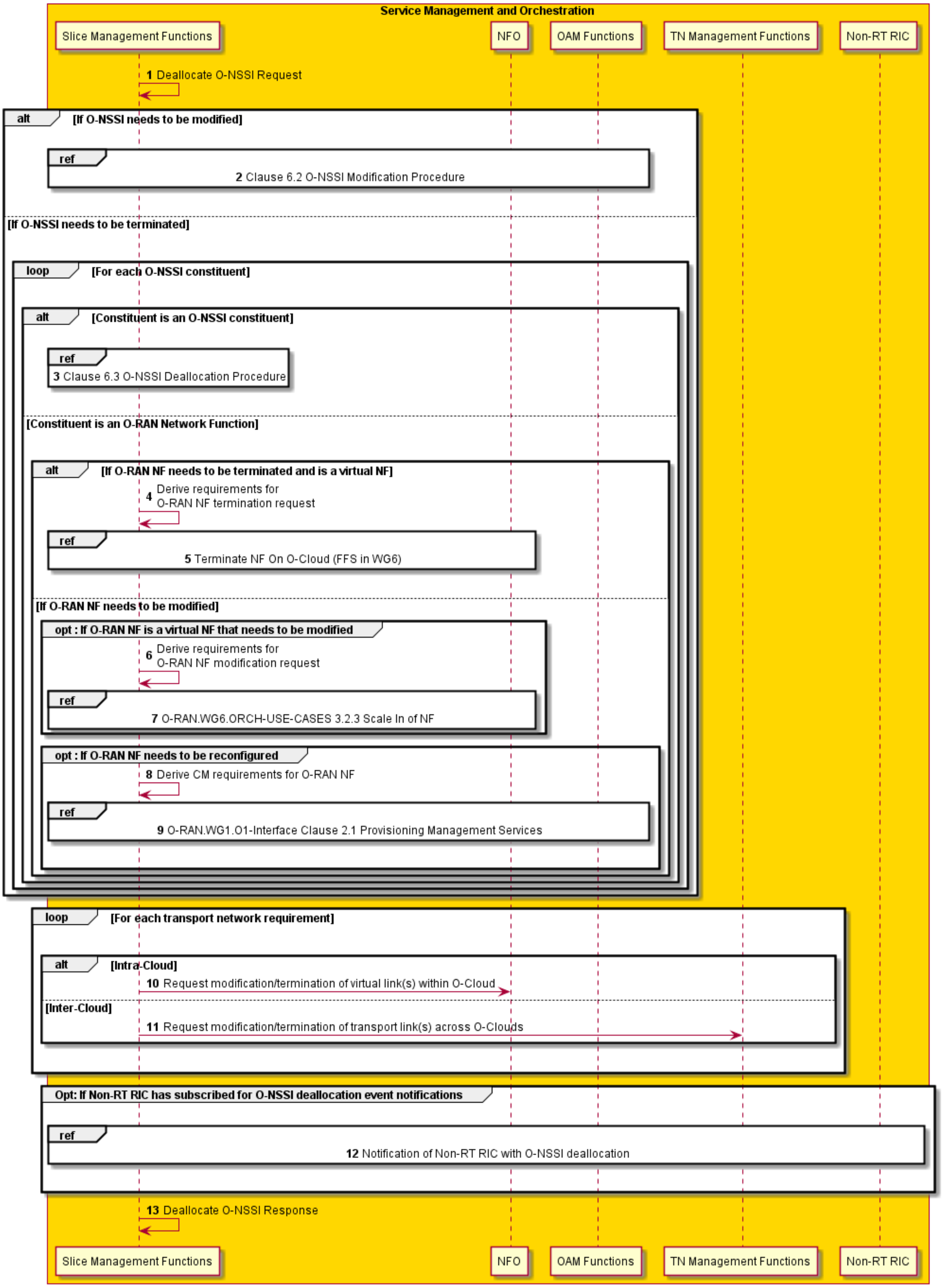

Figure 6.3-2: O-NSSI Deallocation Procedure

1) Slice subnet management function receives a deallocate O-NSSI request (see DeallocateNssi operation defined in clause 6.5.4 in 3GPP TS 28.531 [5]).

   Slice subnet management function decides whether the O-RAN slice subnet instance needs to be modified or terminated. If the O-NSSI needs to be modified, go to step 2 and then step 13, else steps 3-13 are needed.

2) Slice subnet management function invokes the O-NSSI Modification Procedure (FFS).

   For each O-NSSI constituent, steps 3-9 are needed:

3) If the constituent is an O-NSSI constituent, slice subnet management function invokes O-NSSI Deallocation Procedure (Clause 6.3). Then go to step 13.

   If the constituent is an O-RAN NF, steps 4-9 are needed:

   If O-RAN NF needs to be terminated and is a virtual NF, steps 4-5 are needed, else if O-RAN NF needs to be modified go to step 6.

4) Slice subnet management function derives the requirements for O-RAN NF termination request to terminate the NF within the respective O-Cloud.
5) Slice subnet management function invokes relevant procedure for termination of the NF on O-Cloud (FFS in WG6).

   If O-RAN NF is a virtual NF that needs to be modified, steps 6-7 are needed, else go to step 8:

6) Slice subnet management function derives the requirements for O-RAN NF modification request to modify the NF within the respective O-Cloud.
7) Slice subnet management function invokes O-RAN.WG6.ORCH-USE-CASES 3.2.3 Scale In of NF use case [15].

   If O-RAN NF needs to be reconfigured, steps 8-9 are needed, else go to step 10:

8) Slice subnet management function derives the CM requirements for the O-RAN NF.
9) Slice subnet management function invokes O-RAN.WG1.O1-Interface Clause 2.1 Provisioning Management Services [10]

   For each transport network requirement, steps 10-11 are needed:

10) If the transport link is within a cloud, slice subnet management function request virtual link modification/termination within respective O-Cloud via NFO
11) If the transport link is a physical link that needs to be modified/terminated across clouds, slice subnet management function request transport link modification/termination from TN management functions.
12) If Non-RT RIC has subscribed for O-NSSI deallocation event notifications, slice subnet management function notifies Non-RT RIC with O-NSSI deallocation.
13) Slice subnet management function returns appropriate O-NSSI deallocation result (see DeallocateNssi operation defined in clause 6.5.4 of 3GPP TS 28.531 [5]).

Annex A (informative): Additional Information

A.1 Implementation Options

This section presents example deployment options for various SMO options.

A.1.1 3GPP and ETSI NFV-MANO based O-RAN Slicing Architecture Implementation Option

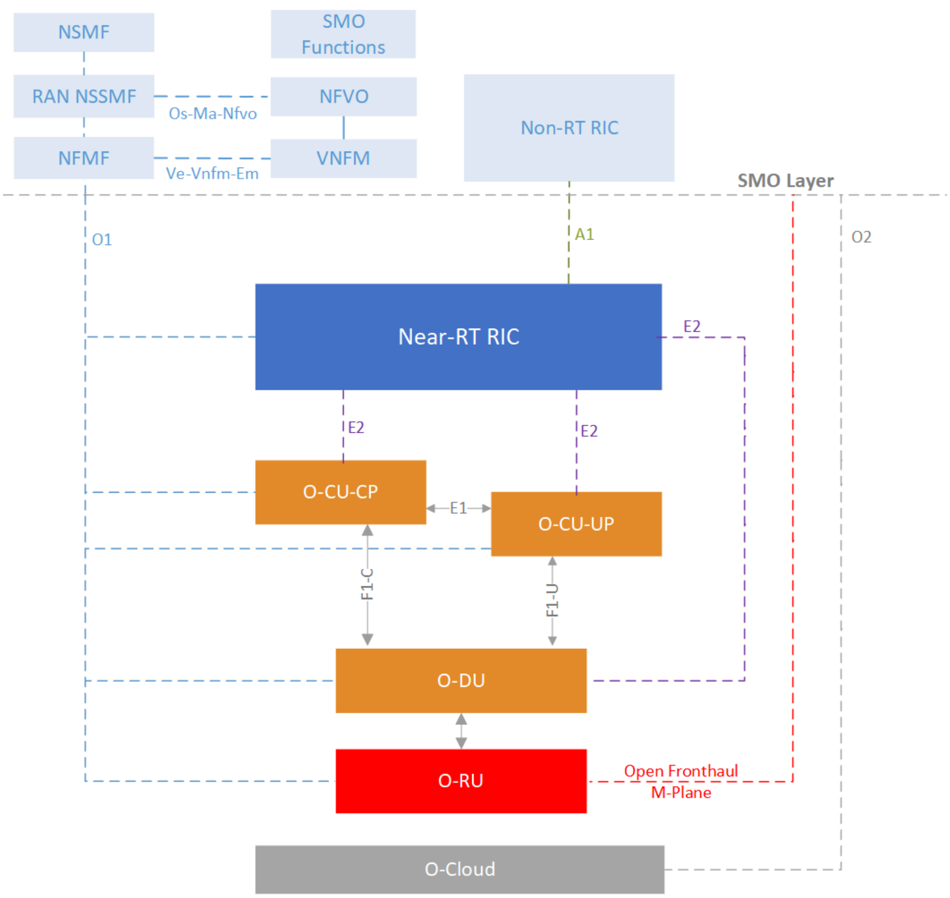

Figure A.1.1-1: O-RAN Slicing Reference Architecture (ETSI NFV-MANO based example)

In Figure A.1.1-1, a 3GPP - ETSI NFV-MANO based example of O-RAN slicing reference architecture and interfaces is shown to describe the relationship between 3GPP defined slice management functions (NSMF, NSSMF), 3GPP defined management functions (Network Function Management Function, NFMF [5]) and O-RAN network functions in terms of slice lifecycle management and slice configuration procedures. Life Cycle Management (LCM) procedures for mobile networks that include virtualized network functions (VNFs) as well as addition of physical network functions (PNFs) to network service (NS) instances are described in 3GPP TS28.526 [4].

A.1.2 ONAP based O-RAN Slicing Architecture Implementation Option

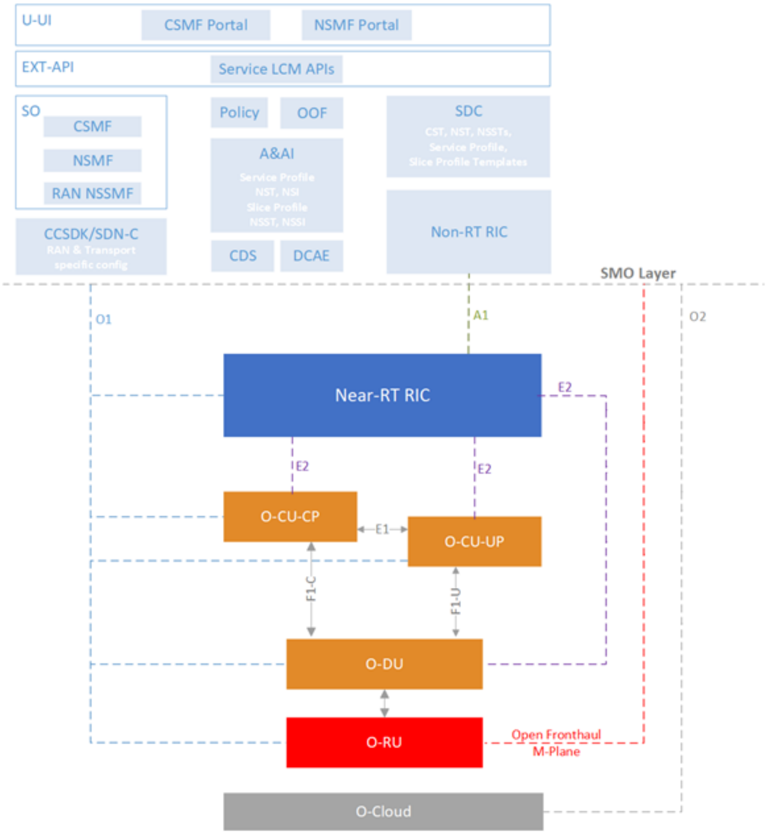

Figure A.1.2-1: Example architecture depiction for ONAP based O-RAN Slicing support

In A.1.2-1, current version of ONAP - O-RAN slicing reference architecture is depicted (based on ONAP G-release). In this architecture, one option is RAN NSSMF being located within SMO and is responsible for the entire RAN subnet, including the O-RAN NFs and the related O-RAN transport network components; Fronthaul interface (FH) beween O-RU and O-DU and Midhaul interface (MH) between O-DU and O-CU. RAN NSSMF determines slice specific configuration of O-RAN NFs based on SliceProfile received from NSMF and determines the necessary slice specific requirements for FH and MH interface triggering Transport Network Management Domain (TN MD) to execute the actual configuration of FH and MH interface. ETSI ZSM based Management Domain approach is adopted for TN management.

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3.1 Members, Contributors and Academic Contributors and their Affiliates are prepared to grant based on a separate Patent License Agreement to each Adopter under Fair, Reasonable And Non-Discriminatory (FRAND) terms and conditions with or without compensation (royalties) a nonexclusive, non-transferable, irrevocable (but subject to Defensive Suspension), non-sublicensable, worldwide license under their Necessary Claims to make, have made, use, import, offer to sell, lease, sell and otherwise distribute Compliant Portions; provided, however, that such license shall not extend: (a) to any part or function of a product in which a Compliant Portion is incorporated that is not itself part of the Compliant Portion; or (b) to any Adopter if that Adopter is not making a reciprocal grant to Members, Contributors and Academic Contributors, as set forth in Section 3.3. For the avoidance of doubt, the foregoing license includes the distribution by the Adopter's distributors and the use by the Adopter's customers of such licensed Compliant Portions.

3.2 Notwithstanding the above, if any Member, Contributor or Academic Contributor, Adopter or their Affiliates has reserved the right to charge a FRAND royalty or other fee for its license of Necessary Claims to Adopter, then Adopter is entitled to charge a FRAND royalty or other fee to such Member, Contributor or Academic Contributor, Adopter and its Affiliates for its license of Necessary Claims to its licensees.

3.3 Adopter, on behalf of itself and its Affiliates, shall be prepared to grant based on a separate Patent License Agreement to each Members, Contributors, Academic Contributors, Adopters and their Affiliates under FRAND terms and conditions with or without compensation (royalties) a nonexclusive, non-transferable, irrevocable (but subject to Defensive Suspension), non-sublicensable, worldwide license under their Necessary Claims to make, have made, use, import, offer to sell, lease, sell and otherwise distribute Compliant Portions; provided, however, that such license will not extend: (a) to any part or function of a product in which a Compliant Portion is incorporated that is not itself part of the Compliant Portion; or (b) to any Members, Contributors, Academic Contributors, Adopters and their Affiliates that is not making a reciprocal grant to Adopter, as set forth in Section 3.1. For the avoidance of doubt, the foregoing license includes the distribution by the Members', Contributors', Academic Contributors', Adopters' and their Affiliates' distributors and the use by the Members', Contributors', Academic Contributors', Adopters' and their Affiliates' customers of such licensed Compliant Portions.

SECTION 4: TERM AND TERMINATION

4.1 This Agreement shall remain in force, unless early terminated according to this Section 4.

4.2 O-RAN Alliance on behalf of its Members, Contributors and Academic Contributors may terminate this Agreement if Adopter materially breaches this Agreement and does not cure or is not capable of curing such breach within thirty (30) days after being given notice specifying the breach.

4.3 Sections 1, 3, 5 - 11 of this Agreement shall survive any termination of this Agreement. Under surviving Section 3, after termination of this Agreement, Adopter will continue to grant licenses (a) to entities who become Adopters after the date of termination; and (b) for future versions of O-RAN Specifications that are backwards compatible with the version that was current as of the date of termination.

SECTION 5: CONFIDENTIALITY

Adopter will use the same care and discretion to avoid disclosure, publication, and dissemination of O-RAN Specifications to third parties, as Adopter employs with its own confidential information, but no less than reasonable care. Any disclosure by Adopter to its Affiliates, contractors and consultants should be subject to an obligation of confidentiality at least as restrictive as those contained in this Section. The foregoing obligation shall not apply to any information which is: (1) rightfully known by Adopter without any limitation on use or disclosure prior to disclosure; (2) publicly available through no fault of Adopter; (3) rightfully received without a duty of confidentiality; (4) disclosed by O-RAN Alliance or a Member, Contributor or Academic Contributor to a third party without a duty of confidentiality on such third party; (5) independently developed by Adopter; (6) disclosed pursuant to the order of a court or other authorized governmental body, or as required by law, provided that Adopter provides reasonable prior written notice to O-RAN Alliance, and cooperates with O-RAN Alliance and/or the applicable Member, Contributor or Academic Contributor to have the opportunity to oppose any such order; or (7) disclosed by Adopter with O-RAN Alliance's prior written approval.

SECTION 6: INDEMNIFICATION

Adopter shall indemnify, defend, and hold harmless the O-RAN Alliance, its Members, Contributors or Academic Contributors, and their employees, and agents and their respective successors, heirs and assigns (the "Indemnitees"), against any liability, damage, loss, or expense (including reasonable attorneys' fees and expenses) incurred by or imposed upon any of the Indemnitees in connection with any claims, suits, investigations, actions, demands or judgments arising out of Adopter's use of the licensed O-RAN Specifications or Adopter's commercialization of products that comply with O-RAN Specifications.

SECTION 7: LIMITATIONS ON LIABILITY; NO WARRANTY

EXCEPT FOR BREACH OF CONFIDENTIALITY, ADOPTER'S BREACH OF SECTION 3, AND ADOPTER'S INDEMNIFICATION OBLIGATIONS, IN NO EVENT SHALL ANY PARTY BE LIABLE TO ANY OTHER PARTY OR THIRD PARTY FOR ANY INDIRECT, SPECIAL, INCIDENTAL, PUNITIVE OR CONSEQUENTIAL DAMAGES RESULTING FROM ITS PERFORMANCE OR NON-PERFORMANCE UNDER THIS AGREEMENT, IN EACH CASE WHETHER UNDER CONTRACT, TORT, WARRANTY, OR OTHERWISE, AND WHETHER OR NOT SUCH PARTY HAD ADVANCE NOTICE OF THE POSSIBILITY OF SUCH DAMAGES.

O-RAN SPECIFICATIONS ARE PROVIDED "AS IS" WITH NO WARRANTIES OR CONDITIONS WHATSOEVER, WHETHER EXPRESS, IMPLIED, STATUTORY, OR OTHERWISE. THE O-RAN ALLIANCE AND THE MEMBERS, CONTRIBUTORS OR ACADEMIC CONTRIBUTORS EXPRESSLY DISCLAIM ANY WARRANTY OR CONDITION OF MERCHANTABILITY, SECURITY, SATISFACTORY QUALITY, NONINFRINGEMENT, FITNESS FOR ANY PARTICULAR PURPOSE, ERROR-FREE OPERATION, OR ANY WARRANTY OR CONDITION FOR O-RAN SPECIFICATIONS.

SECTION 8: ASSIGNMENT

Adopter may not assign the Agreement or any of its rights or obligations under this Agreement or make any grants or other sublicenses to this Agreement, except as expressly authorized hereunder, without having first received the prior, written consent of the O-RAN Alliance, which consent may be withheld in O-RAN Alliance's sole discretion. O-RAN Alliance may freely assign this Agreement.

SECTION 9: THIRD-PARTY BENEFICIARY RIGHTS

Adopter acknowledges and agrees that Members, Contributors and Academic Contributors (including future Members, Contributors and Academic Contributors) are entitled to rights as a third-party beneficiary under this Agreement, including as licensees under Section 3.

SECTION 10: BINDING ON AFFILIATES

Execution of this Agreement by Adopter in its capacity as a legal entity or association constitutes that legal entity's or association's agreement that its Affiliates are likewise bound to the obligations that are applicable to Adopter hereunder and are also entitled to the benefits of the rights of Adopter hereunder.

SECTION 11: GENERAL

This Agreement is governed by the laws of Germany without regard to its conflict or choice of law provisions.

This Agreement constitutes the entire agreement between the parties as to its express subject matter and expressly supersedes and replaces any prior or contemporaneous agreements between the parties, whether written or oral, relating to the subject matter of this Agreement.

Adopter, on behalf of itself and its Affiliates, agrees to comply at all times with all applicable laws, rules and regulations with respect to its and its Affiliates' performance under this Agreement, including without limitation, export control and antitrust laws. Without limiting the generality of the foregoing, Adopter acknowledges that this Agreement prohibits any communication that would violate the antitrust laws.

By execution hereof, no form of any partnership, joint venture or other special relationship is created between Adopter, or O-RAN Alliance or its Members, Contributors or Academic Contributors. Except as expressly set forth in this Agreement, no party is authorized to make any commitment on behalf of Adopter, or O-RAN Alliance or its Members, Contributors or Academic Contributors.

In the event that any provision of this Agreement conflicts with governing law or if any provision is held to be null, void or otherwise ineffective or invalid by a court of competent jurisdiction, (i) such provisions will be deemed stricken from the contract, and (ii) the remaining terms, provisions, covenants and restrictions of this Agreement will remain in full force and effect.

Any failure by a party or third party beneficiary to insist upon or enforce performance by another party of any of the provisions of this Agreement or to exercise any rights or remedies under this Agreement or otherwise by law shall not be construed as a waiver or relinquishment to any extent of the other parties' or third party beneficiary's right to assert or rely upon any such provision, right or remedy in that or any other instance; rather the same shall be and remain in full force and effect.

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