O-RAN.WG1.Use-Cases-Detailed-Specification-v05.00

Technical Specification

O-RAN Working Group 1
Use Cases Detailed Specification

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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 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 top level use cases as defined by O-RAN WG1 UCTG (Use Case Task Group). For each use case, the document describes the motivation, resources, steps involved, and the data requirements. These top level use cases are further detailed in relevant WGs along with the requirements for O-RAN components and their interfaces.

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: “Service requirements for the 5G system; Stage 1”, Release 16, March 2020

[3] 3GPP TS 23.501: “System Architecture for the 5G System (5GS); Stage 2”, Release 16, March 2020

[4] 3GPP TS 28.530: “Management and orchestration; Concepts, use cases and requirements”, Release 16, January 2020

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

[6] 3GPP TS 28.552: “3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Management and orchestration; 5G performance measurements”, Release 16, March 2020

[7] 3GPP TS 28.554: “3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Management and orchestration; 5G end to end Key Performance Indicators (KPI)”, Release 16, March 2020

[8] 3GPP TS 37.340 "E-UTRA and NR; Multi-connectivity", Release 16, April 2020

[9] 3GPP TS 38.211: "Physical channels and modulation", Release 15, March 2019

[10] 3GPP TS 38.213: "Physical layer procedures for control ", Release 15, March 2019

[11] 3GPP TR 38.889 "Study on NR-based access to unlicensed spectrum", Release 16, December 2018

[12] ETSI EN 302 637-2: “Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service”, Release 1, November 2010

[13] ETSI EN 302 637-3: “Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service”, Release 1, November 2014

[14] ETSI TS 102 637-3: “Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service”, Release 1, November 2010

[15] GSMA NG.116: “Generic Network Slice Template”, Version 2.0, October 2019

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.

Intents: A declarative policy to steer or guide the behavior of RAN functions, allowing the RAN function to calculate the optimal result to achieve stated objective.

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.

O-CU: O-RAN Central Unit: a logical node hosting O-CU-CP and O-CU-UP

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 management entities (SMO/EMS/MANO) and O-RAN managed elements, for operation and management, by which FCAPS management, Software management, File management shall be achieved.

O2: Interface between management entities and the O-Cloud for supporting O-RAN virtual network functions.

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].

AI/ML	Artificial Intelligence/Machine Learning
CAM	Cooperative Awareness Message
DENM	Decentralized Environmental Notification Message
eNB	eNodeB (applies to LTE)
gNB	gNodeB (applies to NR)
KPI	Key Performance Indicator
MIMO	Multiple Input, Multiple Output
NRT	Neighbor Relation Table
O-CU	O-RAN Central Unit
O-DU	O-RAN Distributed Unit
O-RU	O-RAN Radio Unit
PRB	Physical Resource Block
QoE	Quality of Experience
RAN	Radio Access Network

RIC	O-RAN RAN Intelligent Controller
SINR	Signal-to-Interference-plus-Noise Ratio
SMO	Service Management and Orchestration.
UAV	Unmanned Aerial Vehicle
V2X	Vehicle to Everything

Chapter 2 Objective

This document provides O-RAN WG1 detailed use case descriptions. Any multi-WG use case defined in O-RAN is expected to be documented in "O-RAN WG1 Use Case Analysis Report" and if the use case is to be studied further, it will be covered in this document in detail, and then in relevant WGs. 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.

Chapter 3 Use cases

3.1 Use case 1: Context-Based Dynamic HO Management for V2X

This use case provides the background, motivation, and requirements for the Context-based Dynamic HO Management for V2X use case, allowing operators to adjust radio resource allocation policies through the O-RAN architecture, reducing latency and improving radio resource utilization.

3.1.1 Background and goal of the use case

V2X communication allows for numerous potential benefits such as increasing the overall road safety, reducing emissions, and saving time. Part of the V2X architecture is the V2X UE (SIM + device attached to vehicle) which communicates with the V2X Application Server (V2X AS). The exchanged information comprises Cooperative Awareness Messages (CAMs), (from UE to V2X AS) [12], radio cell IDs, connection IDs, and basic radio measurements (RSRP, RSPQ, etc.)

As vehicles traverse along a highway, due to their high speed and the heterogeneous natural environment V2X UE-s are handed over frequently, at times in a suboptimal way, which may cause handover (HO) anomalies: e.g., short stay, ping-pong, and remote cell. Such suboptimal HO sequences substantially impair the functionality of V2X applications. Since HO sequences are mainly determined by the Neighbour Relation Tables (NRTs), maintained by the xNBs, there is hardly room for UE-level customization.

This UC aims to present a method to avoid and/or resolve problematic HO scenarios by using past navigation and radio statistics in order to customize HO sequences on a UE level. To this end, the AI/ML functionality that is enabled by the Near-RT RIC is employed.

3.1.2 Entities/resources involved in the use case

1) Non-RT RIC:
    a) Retrieve necessary performance, configuration, and other data for constructing/training relevant AI/ML models that will be deployed in Near-RT RIC to assist in the V2X HO management function. For example, this could be a clustering algorithm that classifies traffic situations and radio conditions that (probably) do or do not lead to HO anomalies.
    b) Support deployment and update of AI/ML models into Near-RT RIC xApp.
    c) Support communication of intents and policies (system-level and UE-level) from non-RT RIC to Near-RT RIC.
    d) Support communication of non-RAN data to enrich control functions in Near-RT RIC (enrichment data).
2) Near-RT RIC:
    a) Support update of AI/ML models retrieved from Non-RT RIC.
    b) Support interpretation and execution of intents and policies from Non-RT RIC.
    c) Support necessary performance, configuration, and other data for defining and updating intents and policies for tuning relevant AI/ML models.
    d) Support communication of configuration parameters to RAN.
3) RAN:
    a) Support data collection with required granularity to SMO over O1 interface.
    b) Support near-real-time configuration-based optimization of HO parameters over E2 interface.

c) Report necessary performance, configuration, and other data for performing real-time V2X HO optimization in the Near-RT RIC over E2 interface.

4) V2X Application Server

a) Support data collection with required granularity from V2X UE over V1 interface.

b) Support communication of real-time traffic related data about V2X UE to non-RT RIC as enrichment data.

3.1.3 Solutions

3.1.3.1 Context-based Dynamic Handover Management for V2X

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Drive V2X UE HOs in RAN according to defined intents, policies, and configuration while enabling AI/ML-based solutions.	
Actors and Roles	Non-RT RIC: RAN policy control function. Near-RT RIC: RAN policy enforcement function. RAN: policy enforcement for configuration updates. SMO: termination point for O1 interface. V2X AS: termination point for V1 interface and enrichment data provider.	
Assumptions	All relevant functions and components are instantiated. A1, O1, E2 interface connectivity is established.	
Pre conditions	Network is operational. SMO has established the data collection and sharing process, and Non-RT RIC has access to this data. Non-RT RIC analyzes the historical data from RAN and V2X AS for training the relevant AI/ML models to be deployed or updated in the Near-RT RIC, as well as AI/ML models required for real-time optimization of configuration and policies.	
Begins when	Operator specified trigger condition or event is detected.	
Step 1 (M)	Non-RT RIC deploys/updates the AI/ML model in the Near-RT RIC via O1 or Non-RT RIC assigns/update the AI/ML model for the Near-RT RIC xApp via A1.	
Step 2 (M)	Non-RT RIC communicates relevant policies/intents and enrichment data to the Near-RT RIC over the A1 interface. The enrichment data from the non-RAN data may include V2X UE location, trajectory, navigation information, GPS data, CAMs, DENMs.	
Step 3 (M)	The Near-RT RIC receives the relevant info from the non-RT RIC over the A1 interface and from the RAN over the E2 interface, interprets the policies and updates the AI/ML models.	
Step 4 (M)	The Near-RT RIC infers optimal RAN configuration (UE-specific NRTs) according to the trained AI/ML models and communicates the result to the RAN over E2 interface.	
Step 5 (M)	RAN deploys the configuration received from the Near-RT RIC over the E2 interface.	
Step 4	If required, Non-RT RIC can configure specific performance measurement data to be collected from RAN to assess the performance of the V2X HO management function in Near-RT RIC, or to assess the outcome of the applied policies and configuration.	
Ends when	Operator specified trigger condition or event is satisfied.	
Exceptions	None identified.	
Post Conditions	Non-RT RIC monitors the performance of the V2X HO related function in Near-RT RIC by collecting and monitoring the relevant performance KPIs and counters from the RAN and the V2X AS.	

Table 3.1.3-1: Context-based Dynamic Handover Management for V2X

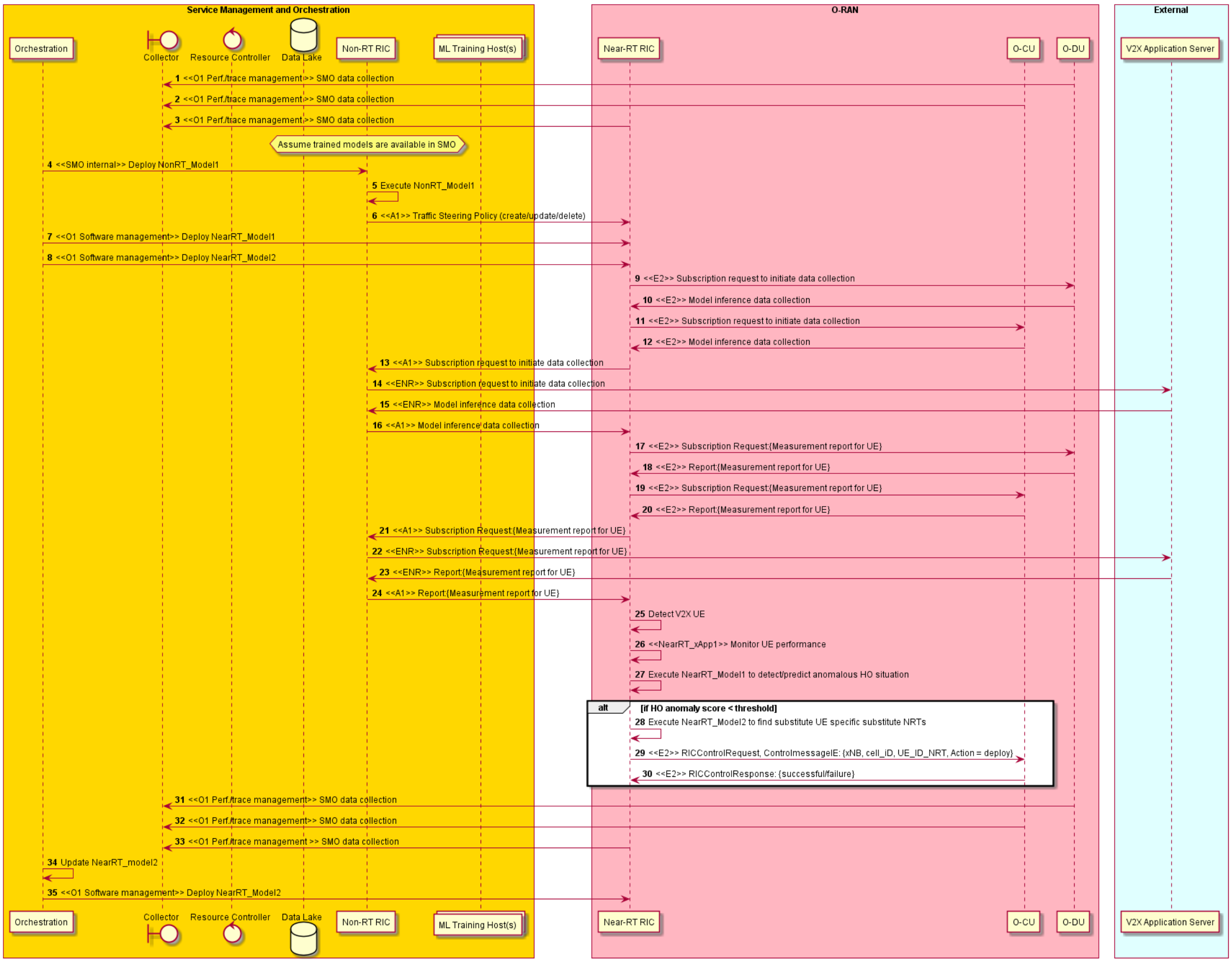


Figure 3.1.3-1: Context-based Dynamic Handover Management for V2X flow diagram

3.1.4 Required data

The measurement counters and KPIs (as defined by 3GPP) should be appropriately aggregated by cell, QoS type, slice, etc.

1) Measurement reports with RSRP/RSRQ/CQI information for serving and neighboring cells.

2) UE connection and mobility/handover statistics with indication of successful and failed handovers and error codes etc.

3) V2X related data: position, velocity, direction, navigation data, CAMs, DENMs [13][14].

3.2 Use case 2: Flight Path Based Dynamic UAV Radio Resource Allocation

This use case provides the background, motivation, and requirements for the support the use case of flight path based dynamic UAV Radio Resource Allocation, allowing operators to adjust radio resource allocation policies through the O-RAN architecture, reducing unnecessary handover and improving radio resource utilization.

3.2.1 Background and goal of the use case

The field trials' results show that the coverage for low altitude is good and can provide various services for terrestrial UEs with good performance. However, since the site along the flight is mainly for terrestrial UEs, the altitude of the UAV is always not within the main lobe of the ground station antenna. And the side lobes give rise to the phenomenon of scattered cell associations particularly noticeable in the sky. The cell association pattern on the ground is ideally contiguous area where the best cell is most often the one closest to the UE. As the UE move up in height, the antenna side lobes start to be visible, and the best cell may no longer be the closest one. The cell association pattern in this particular scenario becomes fragmented especially at the height of 300m and above. Hence, at higher altitudes, several challenges that lead to a different radio environment are:

a) LOS propagation/uplink interference
b) Poor KPI caused by antenna side lobes for base stations
c) Sudden drop in signal strength

These challenges directly impact on the mobility performance of the drone and the service experience of the user. Hence, we would like to support the use case of flight path based dynamic UAV Radio Resource Allocation to resolve the above issues.

Non-Real time RIC can retrieve necessary of Aerial Vehicles related measurement metrics from network based on UE's measurement report and SMO, and flight path information of Aerial vehicle, climate information, flight forbidden/limitation area information and Space Load information etc. from application, e.g. UTM(Unmanned Traffic Management) for constructing/training relevant AI/ML model that will be deployed in RAN. For example, this could be UL/DL interference from/to Aerial vehicles, the detection of Aerial Vehicle UEs, and available radio resource (e.g. frequency, cell, beam, BWP, numerology) prediction. And the Near-Real time RIC can support deployment and execution of AI/ML models from non-RT RIC. Based on this, the Near-Real time RIC can perform the radio resource allocation for on-demand coverage for UAV considering the radio channel condition, flight path information and other application information.

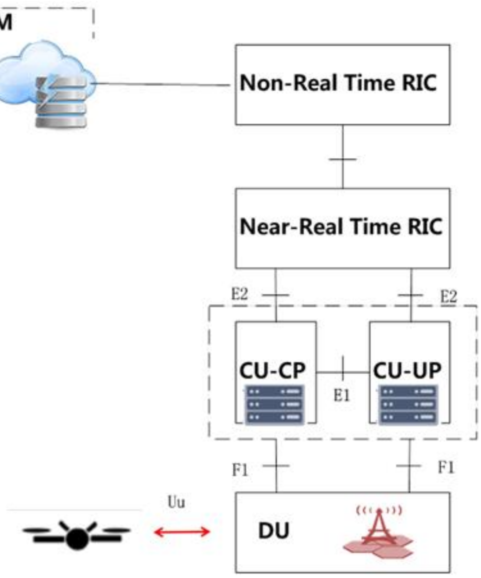


Figure 3.2.1-1: Use case of flight path based dynamic UAV Radio Resource Allocation

Since there is no effective functional module in current eNB/gNB to retrieve the application information, perform machine learning and training based on both the acquired application information and radio environment information, and execute AI/ML models based on above information. And in the O-RAN architecture, the flight path based dynamic UAV Radio

Resource Allocation mechanism can be supported by the RIC function module, i.e. non-real time RIC and near-real time RIC. Therefore, we provide the description of O-RAN support use case for flight path based dynamic UAV Radio Resource.

3.2.2 Entities/resources involved in the use case

1) Non-RT RIC:
    a) Retrieve necessary of O-RAN Support for Aerial Vehicles related measurement metrics from network level measurement report and SMO (may acquire data from application) for constructing/training relevant AI/ML model that will be deployed in Near-RT RIC to assist in the O-RAN Support for Aerial Vehicles function. For example, this could be UL/DL interference from/to Aerial vehicles, the detection of Aerial Vehicle UEs, and available radio resource (e.g. frequency, cell, beam, BWP, numerology) prediction.
    b) Training of potential ML models for O-RAN Support for Aerial Vehicles, which may respectively autonomously control UL/DL interference from/to Aerial vehicles, detect the UE of Aerial Vehicles, and predict available radio resource (e.g. frequency, cell, beam, BWP, numerology) for Aerial Vehicles.
    c) Send policies/intents to Near-RT RIC to drive the O-RAN Support for Aerial Vehicles at RAN level in terms of expected behavior.
2) Near-RT RIC:
    a) Support update of AI/ML models from Non-RT RIC.
    b) Support execution of the AI/ML models from Non-RT RIC.
    c) Support interpretation and execution of intents and policies from Non-RT RIC to derive O-RAN Support for Aerial Vehicles at RAN level in terms of expected behavior.
    d) Support perform the radio resource allocation for on-demand coverage for UAV considering the radio channel condition, flight path information and other application information via the AI/ML models from non-RT RIC.
    e) Sending Aerial Vehicles performance report to Non-RT RIC for evaluation and optimization.
3) RAN:
    a) Support data collection with UE performance report over O1 interface.
    b) Support non-real-time optimization of radio resources allocation parameters over O1 interface.
4) Application server:
    a) Provide application information, e.g. flight path information of Aerial vehicle, climate information, flight forbidden/limitation area information and Space Load information.

3.2.3 Solutions

3.2.3.1 Flight path based dynamic UAV Radio Resource Allocation

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	In the O-RAN architecture, the flight path based dynamic UAV Radio Resource Allocation mechanism can be supported, which can perform the radio resource allocation for on-demand coverage for UAV considering the radio channel condition, flight path information and other application information.	
Actors and Roles	Non-RT RIC: RAN policy control function Near-RT RIC: RAN policy enforcement function RAN: Implementation of updated configuration parameters Application Server: generate RAN side UE-level policies	
Assumptions	All relevant functions and components are instantiated. A1/O1 interface connectivity is established with non-RT RIC.	
Pre conditions	Near-RT RIC and Non-RT RIC are instantiated with A1 interface connectivity being established between them. A certificate is shared between Near-RT RIC and Non-RT RIC for model related data exchange. E2 interface is established between Near-RT RIC and CU/DU.	
Begins when	Operator specified trigger condition or event is detected.	
Step 1 (M)	Application Server sends the application data to Non-RT RIC.	
Step 2 (M)	Non-RT RIC deploys/updates AI/ML models in the Near-RT RIC via O1 or Non-RT RIC assigns/update the AI/ML model for the near-RT RIC xApp via A1.	
Step 3 (M)	Non-RT RIC sends relevant policies/intents and enrichment data to the near-RT RIC over the A1 interface.	
Step 4 (M)	The Near-RT RIC receives the relevant info from the Non-RT RIC over the A1 interface and from the RAN over the E2 interface, interprets the policies and updates the AI/ML models. And the Near-RT RIC converts policy to specific configuration parameter commands.	
Step 5 (M)	RAN executes the command to modify the configuration parameters RAN executes the command to modify the configuration parameters.	
Ends when	Operator specified trigger condition or event is satisfied	
Exceptions	FFS	
Post Conditions	Non-RT RIC collects relevant performance data from eNB / gNB, to observe the data transmission performance improvement brought by the wireless resource configuration optimization policy.	

Table 3.2.3-1: Flight path based dynamic UAV Radio Resource Allocation

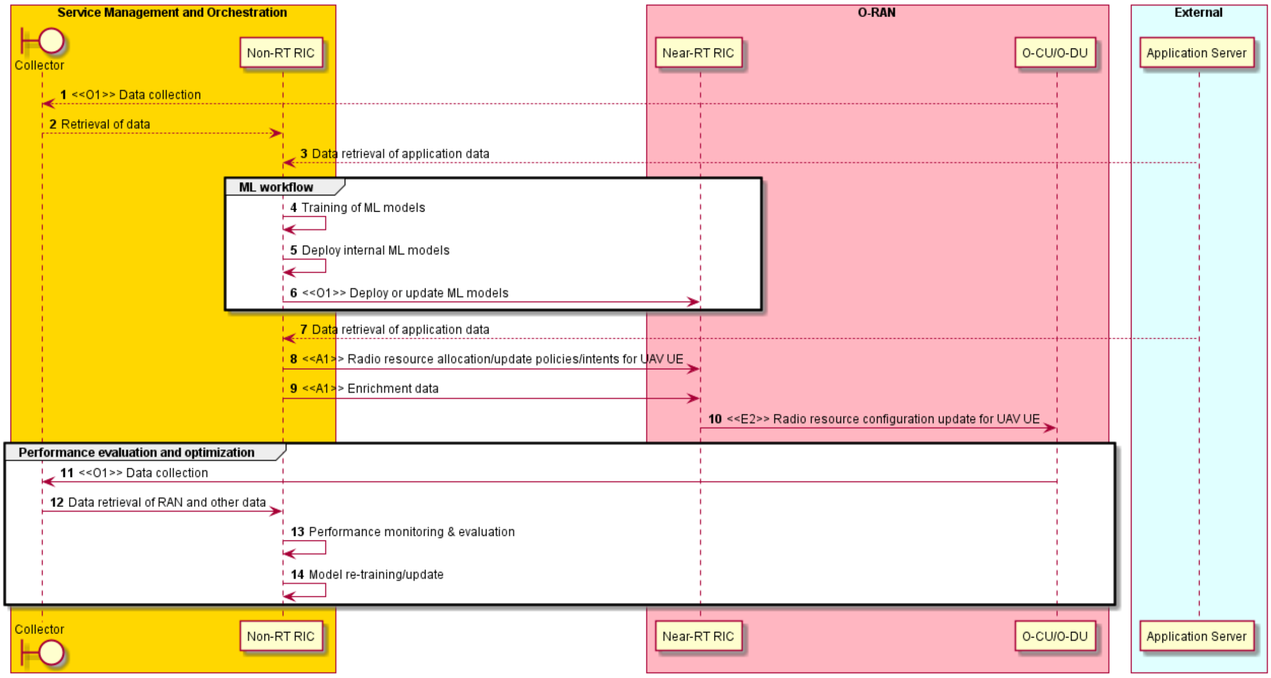


Figure 3.2.3-1: Use case of flight path based dynamic UAV Radio Resource Allocation flow diagram

3.2.4 Required data

Multi-dimensional data are expected to be retrieved for AI/ML model training and policies generation.

1) Network level measurement report, including
   a) UE level radio channel information, mobility related metrics
   b) UE level location information
2) Aerial Vehicles related measurement metrics collected from SMO (may acquire data from application or network, e.g. flight path information of Aerial vehicle, climate information, flight forbidden/limitation area information and Space Load information).

3.3 Use case 3: Radio Resource Allocation for UAV Application Scenario

This use case provides the background, motivation, and requirements for the UAV control vehicle use case, allowing operators to adjust radio resource allocation policies through the O-RAN architecture, reducing latency and improving radio resource utilization.

3.3.1 Background and goal of the use case

As shown in Figure 3.3.1-1, this scenario refers to a Rotor UAV flying at low altitude and low speed, and carrying cameras, sensors and other devices mounted. The Operation terminals work in the 5.8GHz to remote control the UAV for border/forest inspection, high voltage/base station inspection, field mapping, pollution sampling, and HD live broadcast. At the same time, the UAV mobile control stations and the anti-UAV weapons jointly provide the service of fighting against illegal UAVs to ensure low-altitude safety in special areas. The UAV Operation terminals, the anti-UAV weapons, and the UAV mobile control stations are connected with the UAV Control Vehicle using 5G network.

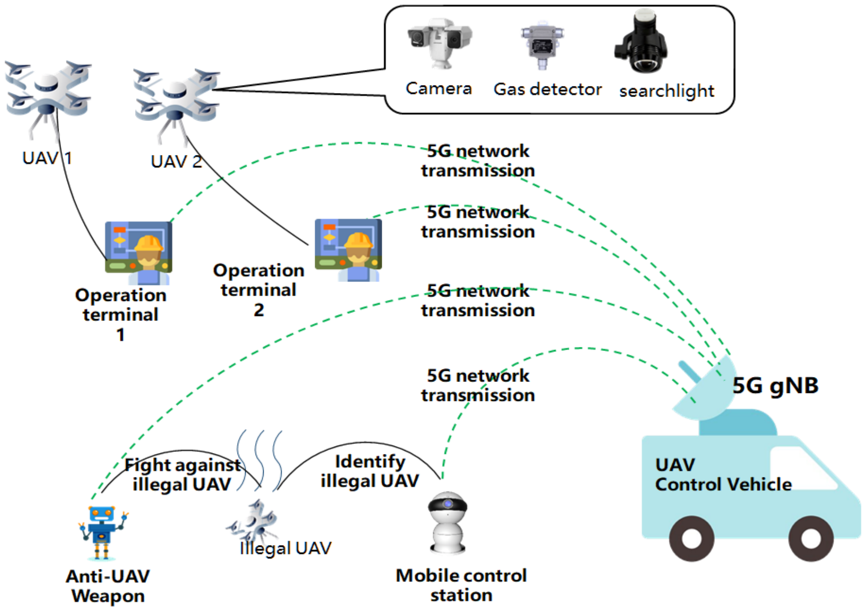


Figure 3.3.1-1: UAV Control Vehicle Application scenario

UAV Control Vehicle deploys network equipment, including O-CU, O-DU, the Non-RT RIC function modules and Application Server (In this use case it is an Edge computing Service Platform) to provide reliable network services through 5G networks. The data transmitted over the network includes control data and application data. The control data includes navigation commands, configuration changes, flight status data reporting, etc. Control data requires low latency and low bandwidth requirements. The application data includes 4K high-definition video data, which has obvious uplink and downlink service asymmetry, and the uplink has high requirements on network bandwidth. The UAV Control Vehicle deploys edge computing services on the 5G gNB side to implement local processing of video and control information. At the same time, real-time data services can be provided with the third-party applications by a video server. The Near RT RIC function module provides radio resource management functions of the gNB side.

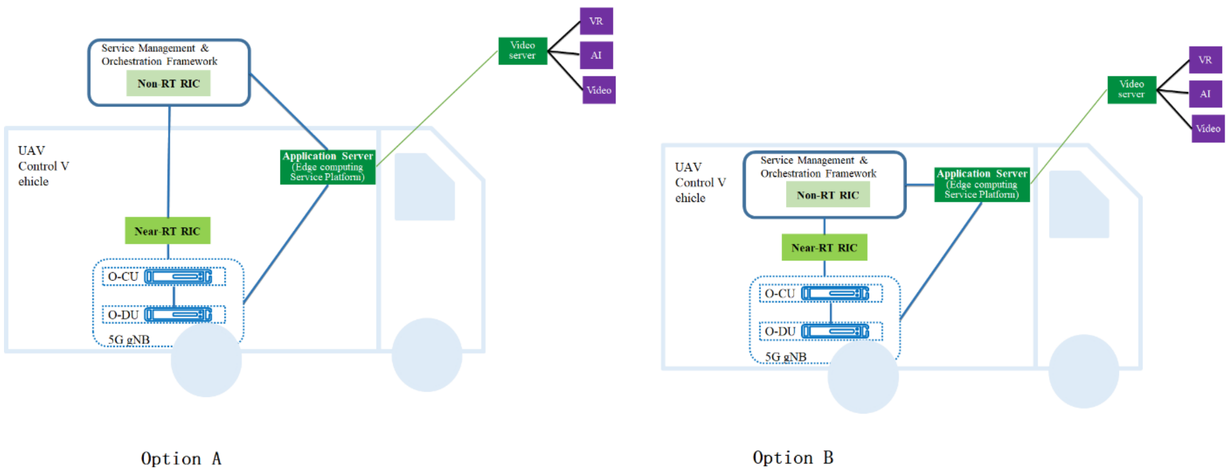


Figure 3.3.1-2: Network architecture for UAV Control Vehicle Application scenario

The 5G network supports real-time high-definition video transmission and remote low-latency control of UAV, and finally provides various industry services such as inspection, security, surveying and mapping. In the UAV Control Vehicle Application scenario, there are a small amount of control data interaction requirements between the terminal and the network interaction, as well as the large bandwidth requirements for uploading HD video.

The service asymmetry raises new requirements for resource allocation of the gNB. At the same time, the existing network operation and maintenance management platform (OSS system) can only optimize the parameters of a specific group of UEs, but not individual users. In the O-RAN architecture, the radio resource requirements for different terminals are sent to the gNB for execution by means of the RIC function module.

The UAV control vehicle has flexible layout features. In this use case, the application service and content is deployed on the edge computing platform instead of the core network; the RIC function module is used to schedule radio resources instead of the core network's QoS mechanism. In this way, the load and overhead of the core network can be reduced, the forwarding and processing time of data transmission can be reduced.

As shown in Figure 3.3.1-2, this scenario involves two options of network architecture. Option A is that gNB and Near-RT RIC are deployed on the Control Vehicle, Non-RT RIC and core network are deployed on the central cloud. The Control Vehicle is connected to the core network and NON RT RIC via fiber optics. Option B is a private network, all the modules, including the gNB, Near-RT RIC, Non-RT RIC and the necessary core network function modules, are deployed in the Control Vehicle.

3.3.2 Entities/resources involved in the use case

1) Non-RT RIC:
    a) Support sending resource allocation requirements to Near-RT RIC.
    b) Support receiving UE-level radio resource adjustment requirements from the Application Server.
    c) Support communication between Non-RT RIC and near-RT RIC with UE-level policies.
2) Near-RT RIC:
    a) Support for receiving resource allocation requests from Non-RT RIC.
    b) Support for the interpretation and execution of the resource allocation policies received from Non-RT RIC.
    c) Support communication with RAN of configuration parameters.
3) RAN:
    a) Support resource allocation requests from the Near-RT RIC.
    b) Support sending terminal registration information to RAN Application Server and Near-RT RIC.
    c) Support non-real-time optimization of radio resources allocation parameters over O1 interface.
    d) Support for adjustment of the resource configuration parameters for a specific UE.
4) Application Server
    a) Support receiving terminal registration information from E2 nodes via SMO.
    b) Support collection of user plane data uploaded from RAN.
    c) Support sending UE-level radio resource adjustment requirements to Non-RT RIC

3.3.3 Solutions

3.3.3.1 UAV Control Vehicle

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	In the UAV control vehicle scenario, the UE-level radio resource configuration optimization is achieved through the delivery of policies and configuration parameters.	
Actors and Roles	Non-RT RIC: RAN policy control function Near-RT RIC: RAN policy enforcement function RAN: Implementation of updated configuration parameters Application Server: generate UE-level resource allocation requirements.	
Assumptions	All relevant functions and components are instantiated. A1/O1 interface connectivity is established with non-RT RIC.	
Pre conditions	The Non-RT RIC sends an instruction through the interface, informing the RAN to allocate the default resource, and establish the cell. The RAN notifies the Near-RT RIC and Application Server of the accessed terminal (UE) information.	
Begins when	Operator specified trigger condition or event is detected.	
Step 1 (M)	Application Server sends requirements of radio resource allocation adjustment to Non-RT RIC. This request can be sent at any time, or it can be sent at regular intervals.	
Step 2 (M)	Non-RT RIC converts the requirements to resource adjustment policy, and distributes the policy to the Near-RT RIC.	
Step 3 (M)	Near-RT RIC converts policy to specific configuration parameter commands.	
Step 4 (M)	RAN executes the command to modify the configuration parameters.	
Step 5 (M)	The specified UE adjusts the uplink rate	
Ends when	Operator specified trigger condition or event is satisfied	
Exceptions	FFS	
Post Conditions	The RAN operates using the newly deployed parameters/models	

Table 3.3.3-1: UAV control vehicle

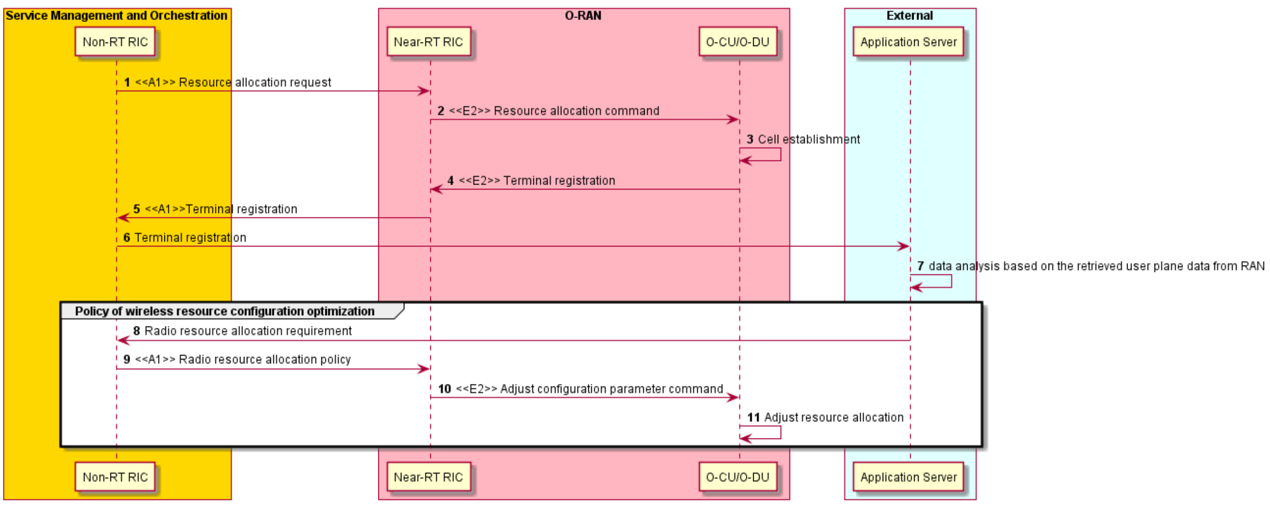


Figure 3.3.3-1: UAV control vehicle

3.3.4 Required data

Multi-dimensional data are expected to be retrieved for policy generation and performance improvements brought by the policy:

1) The number of terminals accessed, the identification information such as an UE ID that distinguishes each UAV connected with UAV the control vehicle), and the resource information assigned by default;

2) UE-level radio resource allocation information, such as the number of PRB resources used in PDSCH/PUSCH scheduling;

3.4 Use case 4: QoE Optimization

This use case provides the background and motivation for the O-RAN architecture to support real-time QoE optimization. Moreover, some high-level description and requirements over Non-RT RIC, A1 and E2 interfaces are introduced.

3.4.1 Background and goal of the use case

The highly demanding 5G native applications like Cloud VR are both bandwidth consuming and latency sensitive. However, for such traffic-intensive and highly interactive applications, current semi-static QoS framework can't efficiently satisfy diversified QoE requirements especially taking into account potentially significant fluctuation of radio transmission capability. It is expected that QoE estimation/prediction from application level can help deal with such uncertainty and improve the efficiency of radio resources, and eventually improve user experience.

The main objective is to ensure QoE optimization be supported within the O-RAN architecture and its open interfaces. Multi-dimensional data, e.g., user traffic data, QoE measurements, network measurement report, can be acquired and processed via ML algorithms to support traffic recognition, QoE prediction, QoS enforcement decisions. ML models can be trained offline and model inference will be executed in a real-time manner. Focus should be on a general solution that would support any specific QoE use case (e.g. Cloud VR, video, etc.).

3.4.2 Entities/resources involved in the use case

1) Non-RT RIC:
    a) Retrieve necessary QoE related measurement metrics from network level measurement report and SMO (may acquire data from application) for constructing/training relevant AI/ML model that will be deployed in Near-RT RIC to assist in the QoE Optimization function. For example, this could be application classification, QoE prediction, and available bandwidth prediction.
    b) Training of potential ML models for predictive QoE optimization, which may respectively autonomously recognize traffic types, predict quality of experience, or predict available radio bandwidth.
    c) Send policies/intents to Near-RT RIC to drive the QoE optimization at RAN level in terms of expected behavior.
2) Near-RT RIC:
    a) Support update of AI/ML models from Non-RT RIC.
    b) Support execution of the AI/ML models from Non-RT RIC, e.g. application classification, QoE prediction, and available bandwidth prediction.
    c) Support interpretation and execution of intents and policies from Non-RT RIC to derive the QoE optimization at RAN level in terms of expected behavior.
    d) Sending QoE performance report to Non-RT RIC for evaluation and optimization
3) RAN:
    a) Support network state and UE performance report with required granularity to SMO over O1 interface.
    b) Support QoS enforcement based on messages from A1/E2, which are expected to influence RRM behavior.

3.4.3 Solutions

3.4.3.1 AI/ML Model training and distribution

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Model training and Distribution	
Actors and Roles	Non-RT RIC, near-RT RIC, SMO, application server	
Assumptions	All relevant functions and components are instantiated. A1/O1 interface connectivity is established with Non-RT RIC.	
Pre conditions	Near-RT RIC and Non-RT RIC are instantiated with A1 interface connectivity being established between them. A certificate is shared between Near-RT RIC and Non-RT RIC for model related data exchange. Editor's Note: security related procedure is FFS.	
Begins when	Operator specified trigger condition or event is detected	
Step 1 (M)	QoE related measurement metrics from SMO (may acquire data from application) and network level measurement report either for instantiating training of a new ML model or modifying existing ML model.	
Step 2 (M)	Non-RT RIC does the model training, obtains QoE related models, and may deploy QoE policy model internally. An example of QoE-related models that can be used at the Near-RT RIC is provided as follows: a) Application Classification Model (optional and may refer to 3rd party's existing functionality) b) QoE Prediction Model c) QoE policy Model d) Available BW Prediction Model	
Step 3 (M)	Non-RT RIC deploys/updates the AI/ML model in the Near-RT RIC via O1 or Non-RT RIC assigns/update the AI/ML model for the Near-RT RIC xApp via A1.	
Step 4 (M)	Near-RT RIC stores the received QoE related ML models in the ML Model inference platform and based on requirements of ML models,	
Step 5 (O)	If required, Non-RT RIC can configure specific performance measurement data to be collected from RAN to assess the performance of AI/ML models and update the AI/ML model in Near-RT RIC based on the performance evaluation and model retraining.	
Ends when	Operator specified trigger condition or event is satisfied	
Exceptions	FFS	
Post Conditions	Near-RT RIC stores the received QoE related ML models in the ML Model inference platform and execute the model for QoE optimization function in Near-RT RIC.	

Table 3.4.3-1: Model training and distribution

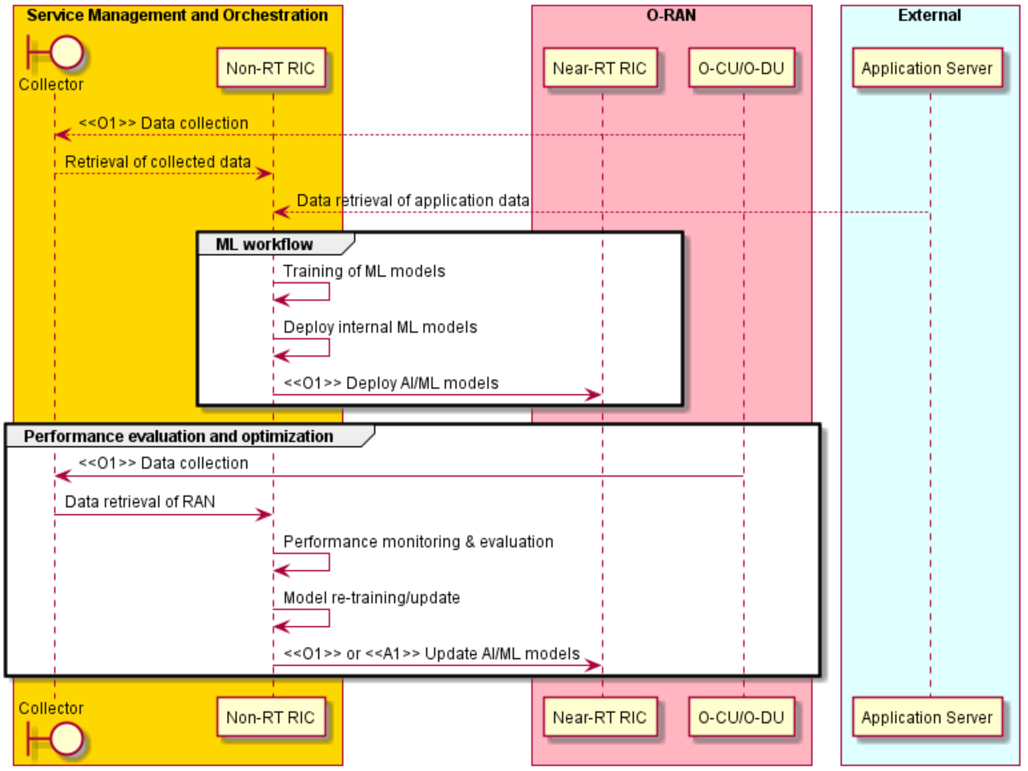


Figure 3.4.3-1: Model training and distribution flow diagram

3.4.3.2 Policy generation and performance evaluation

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Policy generation and performance evaluation	
Actors and Roles	Non-RT RIC, near-RT RIC, SMO	
Assumptions	All relevant functions and components are instantiated. A1/O1 interface connectivity is established with Non-RT RIC.	
Pre conditions	QoE related models have been deployed in Non-RT RIC and Near-RT RIC respectively.	
Begins when	The network operator/manager want to generate QoE policy or optimize QoE related AI/ML models.	
Step 1 (M)	Non-RT RIC evaluates the collected data and generates the appropriate QoE optimization policy.	
Step 2 (M)	Non-RT RIC sends the QoE optimization policy to Near-RT RIC via A1 interface.	
Step 3 (M)	Near-RT RIC receives the policy from the Non-RT RIC over the A1 interface and from the RAN over the E2 interface. And the Near-RT RIC inferences the QoE related AI/ML models and converts policy to specific E2 control or policy commands.	
Step 4 (M)	Near-RT RIC sends the E2 control or policy commands towards RAN for QoE optimization.	
Step 5 (M)	RAN enforces the received control or policy from the near-RT RIC over the E2 interface.	
Step 6 (O)	If required, Non-RT RIC can configure specific performance measurement data to be collected from RAN to assess the performance of the QoE optimization function in near-RT RIC, or to assess the outcome of the applied A1 policies. And then update A1 policy and E2 control or policy.	
Ends when	Operator specified trigger condition or event is satisfied	
Exceptions	FFS	
Post Conditions	Non-RT RIC monitors the performance of the QoE optimization related function in Near-RT RIC by collecting and monitoring the relevant performance KPIs and counters from RAN.	

Table 3.4.3-2: Policy generation and performance evaluation

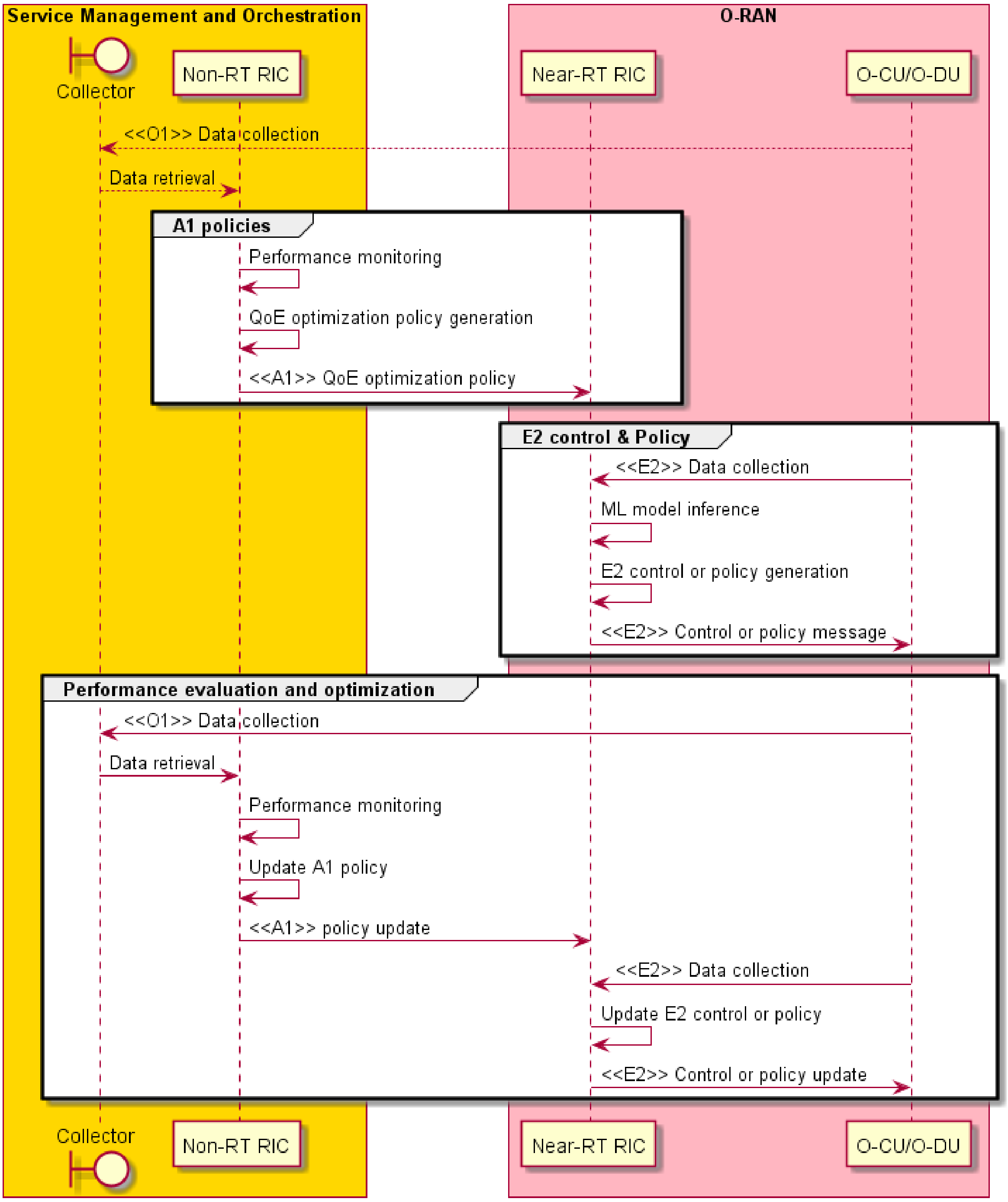


Figure 3.4.3-2: Policy generation and performance evaluation flow diagram

3.4.4 Required data

Multi-dimensional data are expected to be retrieved by Non-RT RIC for AI/ML model training and policies/intents generation.

1) Network level measurement report, including

   c) UE level radio channel information, mobility related metrics

   d) L2 measurement report related to traffic pattern, e.g., throughput, latency, packets per-second, inter frame arrival time

e) RAN protocol stack status: e.g. PDCP buffer status
f) Cell level information: e.g. DL/UL PRB occupation rate

2) QoE related measurement metrics collected from SMO (may acquire data from application or network).
3) User traffic data, which may be obtained via a proprietary interface from existing data collection equipment and is currently out of the scope of A1 or E2.

3.5 Use case 5: Traffic Steering

This use case provides the motivation, description, and requirements for traffic steering use case, allowing operators to specify different objectives for traffic management such as optimizing the network/UE performance, or achieving balanced cell load.

3.5.1 Background and goal of the use case

5G systems will support many different combinations of access technologies namely; LTE (licensed band), NR (licensed band), NR-U (unlicensed band), Wi-Fi (unlicensed band) [11]. Several different multi-access deployment scenarios are possible with 5GC to support wide variety of applications and satisfy the spectrum requirements of different service providers;

- Carrier aggregation between licensed band NR (Primary Cell) and NR-U (Secondary Cell)
- Dual connectivity between licensed band NR (Primary Cell) and NR-U (Secondary Cell)
- Dual connectivity between licensed band LTE (Primary Cell) and NR-U (Secondary Cell)
- Dual connectivity between licensed band NR (Primary Cell) and Wi-Fi (Secondary Cell)

Note: The scenario of dual connectivity between NR and Wi-Fi is for future study

The rapid traffic growth and multiple frequency bands utilized in a commercial network make it challenging to steer the traffic in a balanced distribution. Further in a multi-access system there is need to switch the traffic across access technologies based on changes in radio environment and application requirements and even split the traffic across multiple access technologies to satisfy performance requirements. The different types of traffic and frequency bands in a commercial network make it challenging to handle the complex QoS aspects, bearer selection (Master Cell Group (MCG) bearer, Secondary Cell Group (SCG) bearer, Split bearer), bearer type change for load balancing, achieving low latency and best in class throughput in a multi-access scenario with 5GC networks [8]. Typical controls are limited to adjusting the cell reselection and handover parameters; modifying load calculations and cell priorities; and are largely static in nature when selecting the type of bearers and QoS attributes.

Further, the RRM (Radio Resource Management) features in the existing cellular network are all cell-centric. Even in different areas of within a cell, there are variations in radio environment, such as neighboring cell coverage, signal strength, interference status, etc. However, base stations based on traditional control strategies treat all UEs in a similar way and are usually focused on average cell-centric performance, rather than UE-centric.

Such current solutions suffer from following limitations:

- It is hard to adapt the RRM control to diversified scenarios including multi-access deployments and optimization objectives.
- The traffic management strategy is usually passive, rarely taking advantage of capabilities to predict network and UE performance. The strategy needs to consider aspects of steering, switching and splitting traffic across different access technologies in a multi-access scenario.
- Non-optimal traffic management, with slow response time, due to various factors such as inability to select the right set of UEs for control action. This further results in non-optimal system and UE performance, such as suboptimal spectrum utilization, reduced throughput and increased handover failures.

Based on the above reasons, the main objective of this use case is to allow operators to flexibly configure the desired optimization policies, utilize the right performance criteria, and leverage machine learning to enable intelligent and proactive traffic management.

3.5.2 Entities/resources involved in the use case

1) Non-RT RIC:
   a) Retrieve necessary performance, configuration, and other data for defining and updating policies to guide the behavior of traffic management function in Near-RT RIC. For example, the policy could relate to specifying different optimization objectives to guide the carrier/band preferences at per-UE or group of UE granularity.
   b) Support communication of policies to near-RT RIC.
   c) Support communication of measurement configuration parameters to RAN.
2) Near-RT RIC:
   a) Support interpretation and enforcement of policies from Non-RT RIC.
3) E2 nodes:
   a) Support data collection with required granularity to SMO over O1 interface.

3.5.3 Solutions

3.5.3.1 Traffic steering

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Drive traffic management in RAN in accordance with defined intents, policies, and configuration.	
Actors and Roles	Non-RT RIC: RAN policy control function Near-RT RIC: RAN policy enforcement function E2 nodes: Control plane and user plane functions SMO/Collection & Control: termination point for O1 interface.	
Assumptions	All relevant functions and components are instantiated. A1 interface connectivity is established with Non-RT RIC. O1 interface connectivity is established with SMO/ Collection & Control	
Pre conditions	Network is operational. SMO/ Collection & Control has established the data collection and sharing process, and Non-RT RIC has access to this data. Non-RT RIC monitors the performance by collecting the relevant performance events and counters from E2 nodes via SMO/ Collection & Control.	
Begins when	Operator specified trigger condition or event is detected	
Step 1 (O)	If required, Non-RT RIC configures additional, more specific, performance measurement data to be collected from E2 nodes to assess the performance.	
Step 2(M)	Non-RT RIC decides an action and communicates relevant policies to near-RT RIC over A1. The example policies may include: a) QoS targets; b) Preferences on which cells to allocate control plane and user plane c) Bearer handling aspects including bearer selection, bearer type change	
Step 3 (M)	The near-RT RIC receives the relevant info from Non-RT RIC over A1 interface, interprets the policies and enforces them.	
Step 4 (M)	Non-RT RIC decides that conditions to continue the policy is no longer valid.	
Ends when	Non-RT RIC deletes the policy.	
Exceptions	None identified	
Post Conditions	Non-RT RIC monitors the performance by collecting the relevant performance events and counters from E2 nodes via SMO.	

Table 3.5.3-1: Traffic steering

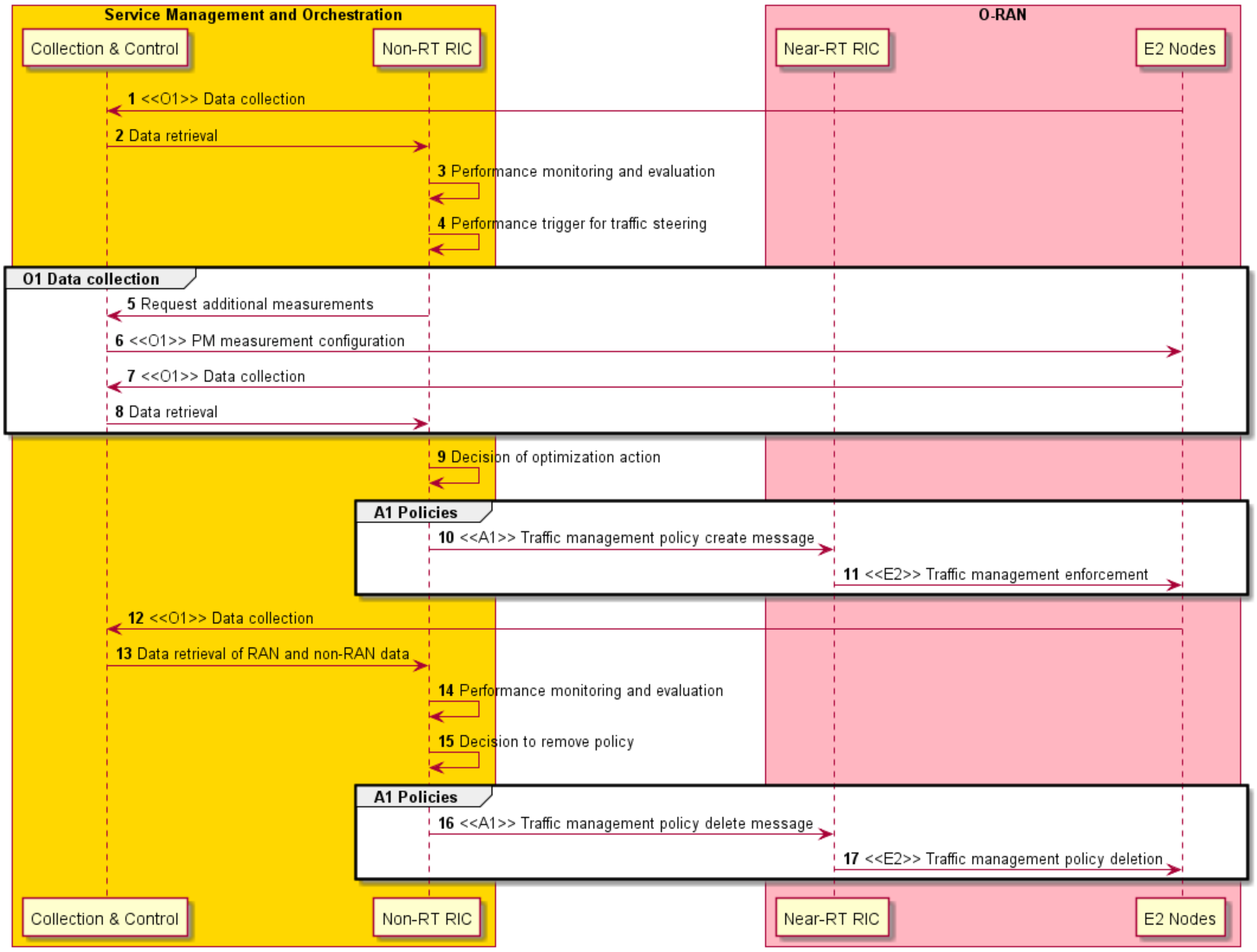


Figure 3.5.3-1: Traffic steering use case flow diagram

3.5.4 Required data

The measurement counters and KPIs (as defined by 3GPP and will be extended for O-RAN use cases) should be appropriately aggregated by cell, QoS type, slice, etc.

1) Measurement reports with RSRP/RSRQ/CQI information for serving and neighboring cells. In multi-access scenarios this will also include intra-RAT and inter-RAT measurement reports, cell quality thresholds, CGI reports and measurement gaps on per-UE or per-frequency.

2) UE connection and mobility/handover statistics with indication of successful and failed handovers etc.

3) Cell load statistics such as information in the form of number of active users or connections, number of scheduled active users per TTI, PRB utilization, and CCE utilization.

4) Per user performance statistics such as PDCP throughput, RLC or MAC layer latency, etc.

3.6 Use case 6: Massive MIMO Beamforming Optimization

This use case provides the motivation, description, and requirements for Non-RT and Near-RT loop Massive MIMO beamforming optimization use case. Massive MIMO system configuration can allow operators to optimize the network performance and QoS by e.g. Non-RT and Near-RT loop balancing cell loads or reducing inter-cell interference and control electromagnetic (EM) emissions.

3.6.1 Background and goal of the use case

Massive MIMO (mMIMO) is among the key levers to increase performance and QoS in 5G networks. Capacity enhancement is obtained by means of beamforming of the transmitted signals, and by spatially multiplexing data streams for both single user (SU) and for multi user (MU) MIMO. Beamforming increases the received signal power, while decreasing the interference generated on other users, hence resulting in higher SINR and user throughputs. Beamforming can be codebook based (mainly for FDD), or non-codebook based (TDD). Grid of Beams (GoB) with the corresponding beam sweeping [9][10] has been introduced to allow beamforming the control channels used during initial access, mainly for high frequency (but can be used also for the sub-6 GHz band) MIMO operation. The codebook and the GoB define the span of the beams, namely the horizontal and vertical aperture in which beamforming is supported, and therefore the coverage area and the shape of the cell. Massive MIMO can be deployed in 5G macro-cells as well as in heterogeneous network, where macro-cells and 3D-MIMO small cells co-exist and complement each other for better aggregated capacity and coverage. In order to obtain an optimal beamforming and cell resources (Tx power, PRB) configuration, one will have to look at a multi-cell environment instead of a single cell. Moreover, different vendors may have different implementations in terms of the number of beams, the horizontal/vertical beam widths, azimuth and elevation range, to achieve the desired coverage. In a multi node/multi-vendor scenario, centralized monitoring and control is required to offer optimal coverage, capacity and mobility performance as well as control over EM emissions in order to comply with regulatory requirements. Additionally, the number of such combinations of adjustable parameters is in the thousands, hence it is prohibitive for the traditional human expert system to work out the optimal configuration, and a new method is in need.

State of the art solutions suffer from the following problems:

mMIMO macro- and small-cells benefit from a flexible way of serving users in their coverage area thanks to beamforming. However the coverage area itself is defined by (vendor specific) fixed mMIMO system parameters such as the azimuth and elevation angle range, or the GoB parameters. Hence due to user and traffic distribution and terrain topology, the mMIMO cell may suffer from e.g.

1) High inter-cell interference
2) Unbalanced traffic between neighboring cells
3) Low performance of cell edge users
4) Poor handover performance

Moreover, load balancing functions may be activated in the network nodes, e.g. gNB adapting mobility parameters in order to distribute load between the beams of the neighbor cells, relying on load information exchange over network interfaces. This approach however is partly limited by the cell footprint statically fixed at the initial configuration.

The objective of this use case is to allow the operator to flexibly configure a mMIMO system parameters by means of policies and configuration assisted by machine learning techniques, according to objectives defined by the operator.

3.6.2 Entities/resources involved in the use case

1) Non-RT RIC:
    a) Retrieve necessary configurations, performance indicators, measurement reports, user activity information and other data from SMO and RAN directly for the purpose of constructing/training relevant AI/ML models that will be deployed in Non-RT and/or Near-RT RIC to assist in the massive MIMO optimization function.
    b) Retrieve necessary user location related information, e.g. GPS coordinates, from the application layer for the purpose of constructing/training relevant AI/ML models.

c) Use the trained AI/ML model to infer the user distribution and traffic distribution of multiple cells and predict the optimal configuration of Massive MIMO parameters for each cell/beam according to a global optimization objective designed by the operator. The Massive MIMO configurable parameters includes horizontal beam width, vertical beam width, beam azimuth and downtilt, maximum and average transmitted power per beam/direction [5].

d) Send the optimal beam pattern configuration to SMO configuration components

e) Retrain the AI/ML model and Re-optimize the beam pattern configurations based on the monitored performance

f) Execute the control loop periodically or event-triggered

2) SMO

a) Collect the necessary configurations, performance indicators, and measurement reports data from RAN nodes triggered by Non-RT RIC if required.

b) Configure the optimized beam parameters via O1 interface.

c) Monitor the performance of all the cells; when the optimization objective fails, initiate fall back procedure; meanwhile, trigger the AI/ML model re-training, data analytics and optimization in Non-RT RIC.

3) Near-RT RIC

a) Support interpretation and enforcement of policies from Non-RT RIC.

b) Support deployment and execution of AI/ML models from Non-RT RIC.

c) Retrieve necessary configurations, performance indicators, measurement reports and other data from SMO and RAN directly for the purpose of training of relevant AI/ML models.

d) Use the trained AI/ML models to infer the user distribution, user mobility and traffic distribution of multiple cells and predict the optimal configuration of Massive MIMO parameters for each cell/beam according to a global optimization objective designed by the operator. The Massive MIMO beam configuration parameters include for instance beam individual offsets for beam mobility.

e) Send the optimal beam configuration policies to E2 nodes

f) Retrain the AI/ML model and re-optimize the beam pattern configurations based on the monitored performance and/or once the Grid-of-Beam configuration is switched.

g) Execute the control loop periodically or event-triggered

4) E2 nodes

a) Collect and report to SMO and/or to Near-RT RIC KPI related to user activity, traffic load, coverage and QoS performance, per beam/area, handover and beam failures statistics.

b) Collect and report to SMO and/or to Near-RT RIC information about beam and resource utilization

c) Apply beam management strategies following SMO and Near-RT RIC configuration and constraints

3.6.3 Solutions

3.6.3.1 Non-RT Massive MIMO GoB Beam Forming optimization

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Enable flexible optimization of the multi-cell M-MIMO beamforming performance (capacity and coverage) by means of configuration parameter change with operator-defined objectives, and allow for AI/ML-based solutions.	
Actors and Roles	Non-RT RIC acting as Massive MIMO beamforming configuration optimization decision making function. SMO acting as the RAN data collection and parameter configuration function. RAN acting as configuration enforcement function.	
Assumptions	O1 interface connectivity is established between RAN and SMO. Network is operational.	
Pre conditions	SMO has processed the collected data and non-RT RIC has access to this data.	
Begins when	Operator specified trigger condition or event is detected	
Step 1 (O)	If required, SMO can initiate the specific measurement data collection request towards RAN for AI/ML model training or to assess the outcome of the applied configuration.	
Step 2 (M)	Non-RT RIC retrieve the data from SMO components and trains the AI/ML model with the collected data from the application, the RAN nodes. Trained AI/ML models are deployed and inferenced for long-term configuration parameters optimization.	
Step 3 (M)	Upon trigger from Non-RT RIC with the optimized beam parameters, SMO configures the parameters towards the RAN via O1 interface. The relevant parameters may include: a) horizontal beam width, vertical beam width, beam azimuth and downtilt b) maximum and average transmitted power per beam/direction	
Step 4 (M)	SMO monitors the network performance. If the algorithm performance is unsatisfactory in terms of predefined objective/requirement, SMO initiates fallback mechanism to restore previous configuration, It can also gather necessary information and data to retrain and update the AI/ML model or trigger the optimization in Non-RT RIC.	
Ends when	Operator specified trigger condition or event is satisfied	
Exceptions	FFS	
Post Conditions	The RAN operates using the newly deployed parameters/models	

Table 3.6.3-1: Massive MIMO GoB Beam Forming optimization

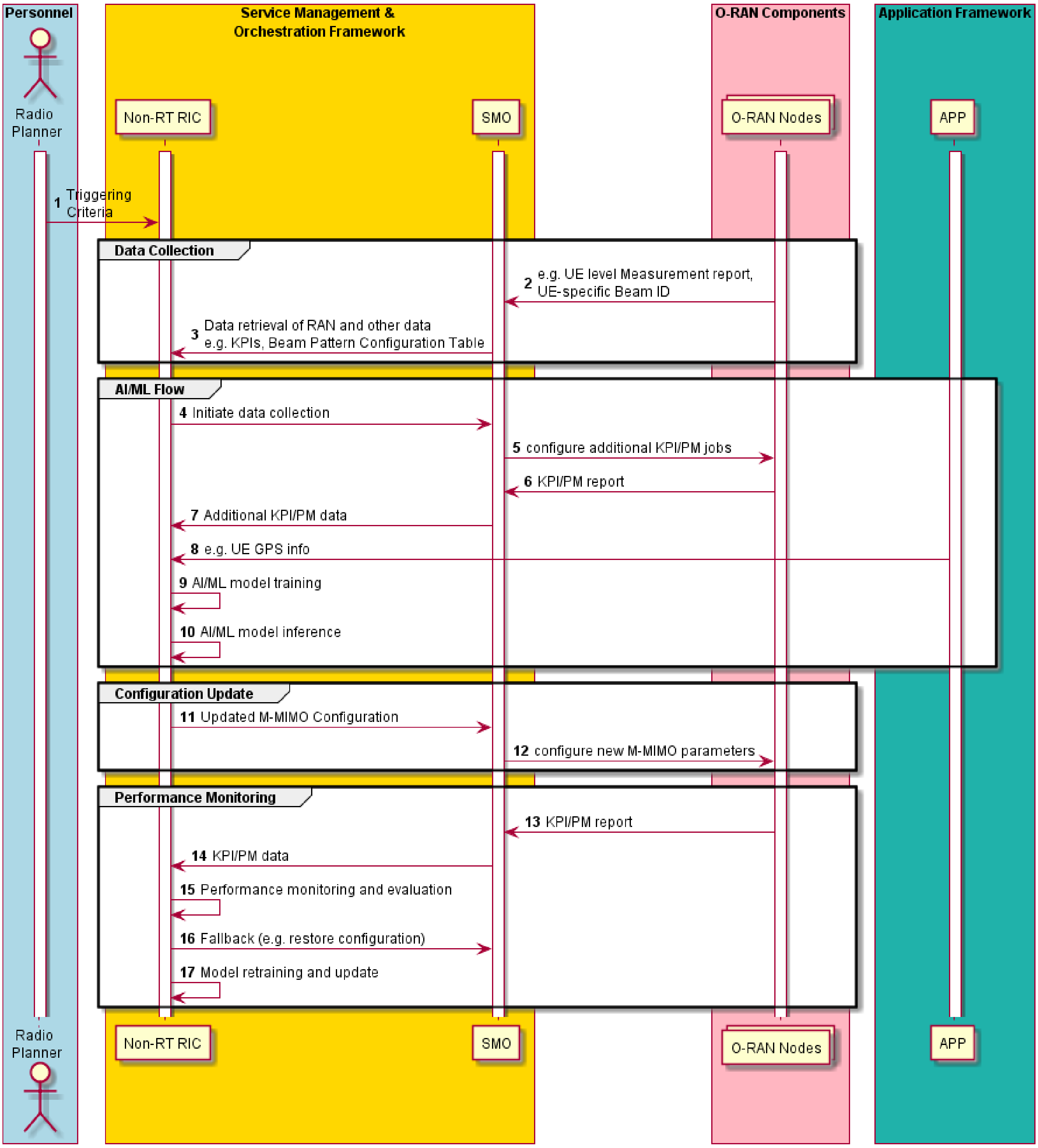


Figure 3.6.3-1: Massive MIMO beamforming optimization flow diagram

3.6.3.2 Near-RT Massive MIMO Beam-based Mobility Robustness Optimization

FFS

3.6.4 Required data

There are different types of data that are required from different parts of the network, and the following list summarizes with some examples:

1) Environment data: Cell site information (location), inter-site distance, BS system configuration, (e.g. operating frequency, bandwidth, frame structure, transmit power, default beam weight configuration); complete set of Massive-MIMO configurations, i.e. Horizontal beamwidth adjustable range, Vertical beamwidth adjustable range, Azimuth angle adjustable range, Elevation angle adjustable range.

2) From RAN to SMO and/or Near-RT RIC

   a) Measurement reports with RSRP/RSRQ/CQI/SINR per beam information for the UEs in cells of interest; the time granularity of data collection should be configurable and satisfy the requirement of the AI/ML model

   b) Network KPIs: e.g. cell downlink/uplink traffic load, RRC connection attempts, average RRC connected UE, maximum RRC connected UE, average active connections (downlink/uplink), DL/UL throughput, DL/UL spectral efficiency, NI (Noise interference); beam resource usage (transmitted power per beam/directions and associated PRB usage), beam based handover and beam failure statistics

3) From Application to SMO

   a) user location related information, e.g. GPS coordinates for the purpose of constructing/training relevant AI/ML models

3.7 Use case 7: RAN Sharing

This use case provides the motivation, description, and requirements for RAN sharing use case. The goal of this use case is to enable multiple operators to share the same O-RAN infrastructure, while allowing them to remotely configure and control the shared resources via a remote O1, O2 and E2 interface.

3.7.1 Background and goal of the use case

RAN sharing is envisioned as an efficient and sustainable way to reduce the network deployment costs, while increasing network capacity and coverage. Among the different RAN sharing models that have been experimented so far, a special focus is put here on the evaluation of the compatibility of the “Geographical Split” RAN sharing model with the O-RAN architecture. In such a model, a coverage area is split between two or more operators; each operator manages the RAN in a specific area, while sharing its RAN infrastructure and computing resources with its partner operators.

Specifically, this use case analyzes the Multi Operator RAN (MORAN) sharing scenario, wherein each operator utilizes a separate carrier in order to achieve more freedom and independency on the control of the radio resources. Accordingly, the goal of this use case is to propose a sharing-compliant O-RAN architecture that lets operators to configure the shared network resources independently from configuration and operating strategies of the other sharing operators. Specifically, it is proposed that a Home Operator (Operator A) makes available its O-RAN infrastructure and computing resources to host the virtual RAN functions (VNF) of a second operator (Operator B), allowing it to configure and control such remote VNFs via a remote O1, O2 and E2 interface.

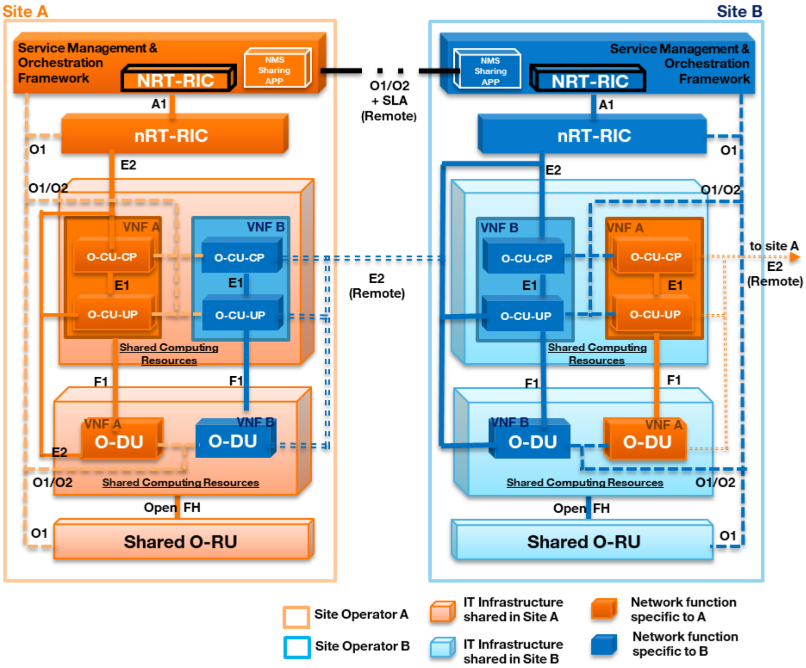


Figure 3.7.1-1: MORAN Use-Case in O-RAN

Figure 3.7.1-1 describes the logic architecture of the proposed MORAN use case. It is assumed that Operator A owns the site A and shares the PHY Layer (LOW) with Operator B (Shared O-RU). Indeed, multiple PLMN IDs are broadcasted, while each operator operates in a different carrier. Moreover, the computing resources of the site A are shared among multiple VNFs, belonging to Operator A and Operator B, respectively.

Each VNF represents a logic implementation of the O-DU and O-CU functionalities and is controlled by each partner operator in an independent manner. While Operator A can directly orchestrate and configure its VNFs, Operator B needs to control its VNFs in a remoted manner. The challenge here is to enable Operator B to configure and control resources in an infrastructure that is owned by another operator.

Accordingly, it is assumed that Operator B can monitor and control the remote radio resources via the RIC node of site B, using an “E2 remote” interface. Note that in the proposed architecture, the RIC nodes are not shared and kept independent at the site A and B respectively.

However, it is assumed that Operator B cannot directly orchestrate its VNFs in site A, but it is allowed to communicate the desired initial VNF configuration via an extended O1, O2 interface, hereafter referred to as “O1, O2 + SLA” interface (O1, O2 remote). Note that the O1, O2 nomenclature is used hereafter to refer to both O1 and O2 messages.

The “O1, O2 remote” interface is connected to a specific “sharing orchestration application”, referred to as “SMO-Sharing APP”, that is located at the Service Management & Orchestration Framework of each operator. Specifically the “SMO-Sharing APP” at site A acts as an SLA (Service Level Agreement) monitoring and filter entity: it checks that O1, O2 requests coming from Operator B are in line with a predefined SLA and finally configures the VNF of Operator B, according to the initial O1, O2 request.

3.7.2 Entities/resources involved in the use case

1) SMO-Sharing APP (site A) :

   a) SLA Monitoring: checks that orchestration/management requests sent by Operator B are in line with the SLA.
   b) Remote provisioning and initial VNF deployment: asks the IMF to instantiate the VNFs for Operator B.

c) Remote management operations via “O1, O2 remote”: configures the VNF of Operator B via the Orchestrator, according to “O1, O2 remote” requests sent by Operator B.
d) Forwards RAN related data, collected from the hosted VNFs, to the SMO-Sharing APP (site B) over the “O1, O2 remote” interface.

2) SMO-Sharing APP (site B) :

a) Detects the “SMO-Sharing-APP” in site A towards which to forward “O1, O2 remote” requests.
b) Sends “O1, O2 remote” commands for initial deployment and configuration of remote VNFs.
c) Forwards RAN related data of Operator B, collected in site A, to the Non-RT RIC.

3) IMF (Site A): Creates VNFs for Operator B in site A on initial request of the SMO-Sharing APP (site A).

4) RAN (site A):

a) Supports data collection from the hosted VNFs with radio state report over “E2 remote” interface.
b) Supports data collection from hosted VNFs with UE KPI report over “O1, O2 remote” interface.

5) Non-RT RIC (site B):

a) Configures the initial network policy template, e.g., default scheduling policy, of the remote VNFs.
b) Elaborates RAN data collected by “SMO-Sharing APP”, e.g., scheduling performance metrics, and sends A1 policy/intentions to the remote virtual O-DU/O-CU (VNF_B) via the near-RT RIC.

6) Near-RT RIC (site B):

a) Monitors and collects E2-related parameters from the remote VNFs.
b) Detects the “E2 remote” interface towards the VNFs hosted in site A.

1 ### 3.7.3 Solutions

2 #### 3.7.3.1 RAN sharing

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Enable two operators to share the same O-RAN infrastructure, while allowing them to remotely configure and control the shared resources via a remote "O1", "O2" and "E2" interface.	
Actors and Roles	Sharing-SMO APP handles remote orchestration operations via "O1, O2 remote" interface. Non-RT RIC (Operator B): updates configuration of VNFs hosted in site A. Near-RT RIC (Op. B): execute remote E2 commands via "E2 remote" interface. RAN (Site A): collects and reports RAN statistics to the RIC of Operator B (RIC_B) for its VNFs hosted in site A.	
Assumptions	All relevant functions and components are instantiated. A1, O1, O2, E2 interface connectivity is established with local SMO, Non-RT RIC and near-RT RIC, respectively. "O1, O2 remote" and "E2 remote" end-to-end connectivity is established with remote SMO and remote near-RT RIC, respectively. The remote interfaces have been secured through appropriate end-to-end security mechanisms (security configuration details are out of scope of this use case). Non-RT RIC_B and near-RT RIC_B are aware of the presence of O-DU_B and O-CU_B in the site A. Near-RT RIC_B is aware of the "E2 remote" interface, to be used to control the remote VNFs hosted in site A.	
Pre conditions	An SLA sharing agreement is established between the home (Operator A) and host operator (Operator B). The SLA defines the amount of physical resources (CPU, memory, etc.), that can be allocated to the host operator and the type of admissible orchestration operations that can be remotely executed by the host operator. Such SLA is translated in appropriate SLA monitoring-check controls to be executed by the SMO-Sharing APP.	
Begins when	Phase 1-2: Host Operator (Operator B) asks to provision and instantiate an O-DU_B and O-CU_B in the site of the Home Operator (Operator A). Phase 3: Host Operator wants to send a new instruction to the shared RAN over the "E2 remote" interface.	
Step 1 (M)	SMO-Sharing APP_B sends a request to SMO-sharing-APP_A for provisioning and deploying a remote virtual O-DU_B and O-CU_B in the site A.	
Step 2 (M)	SMO-Sharing APP_A checks that the request is in line with the predefined SLA and ask the IMF (via the Orchestrator) to instantiate the VNFs for the O-CU_B and O-DU_B.	
Step 3 (O)	IMF creates VNF for Operator B in site A as for the request of the SMO-Sharing APP_A.	
Step 4 (M)	SMO-Sharing APP_B notifies SMO-Sharing APP_A the request to install a default network policy template, e.g., RB scheduling policy, in the remote VNFs.	
Step 5 (M)	SMO-Sharing APP_A checks that Operator B request is in line with the SLA and configures (via the Orchestrator) the O-DU_B/ O-CU_B via an O1 configuration command.	
Step 6 (M)	RAN related data from VNF_B in site A are collected at SMO Collector and forwarded to the SMO-Sharing APP_A, which in turns forwards them to the Non-RT RIC_B, via the SMO-Sharing APP_B.	
Step 7	Non-RT RIC_B decides to update the default network policy of the remote VNFs, e.g., scheduling policy of O-DU_B/O-CU_B and sends an A1 update policy request to the near-RT RIC_B.	
Step 8	Near-RT RIC_B configures the remote O-DU_B/O-CU_B accordingly, over the "E2 remote" interface.	
Ends when	The VNFs of Operator B in site A are instantiated with success and no update-requests are sent by the Host Operator (Operator B).	
Exceptions	None identified.	
Post Conditions	RIC of Operator B monitors relevant radio KPI from the remote O-CU_B and O-DU_B and decides to reconfigure the scheduling policy as for Step 7.	

Table 3.7.3-1: RAN Sharing Use Case

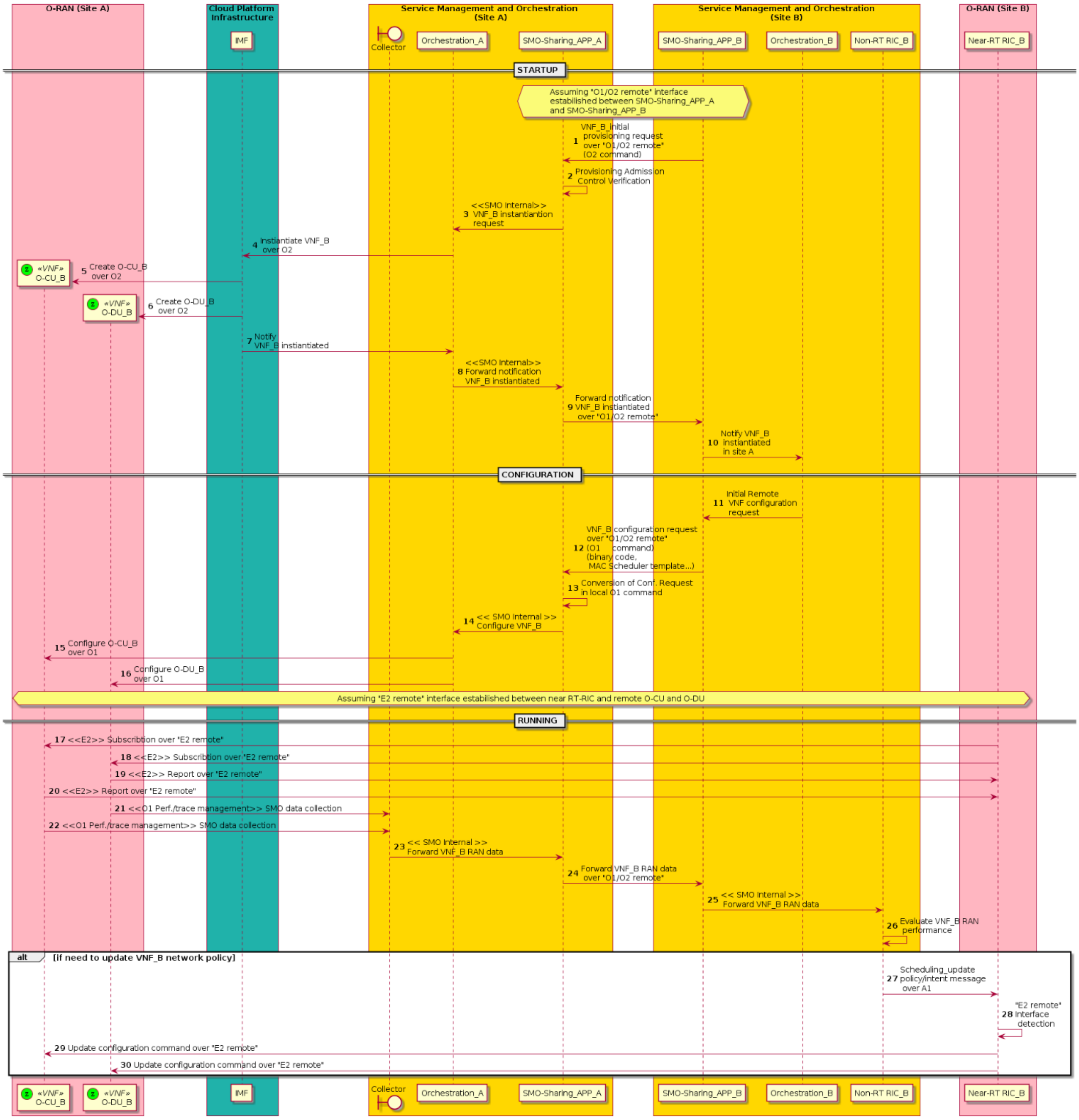


Figure 3.7.3-1: VNF configuration procedure for VNF_B hosted in site A

3.7.4 Required data

Multi-dimensional data are expected to be handled by the SMO-Sharing APP:

1) SLA data needs to be converted in a set of condition steps to be matched for each request of the Host Operator (Operator B).
2) SMO needs to handle O1, O2 messages sent by the Host Operator, converting them in local O1, O2 commands.

The RAN of the home operator needs to report to the RIC_B the network state of the served UEs that belong to the host operator.

3.8 Use case 8: QoS Based Resource Optimization

This use case provides the background and motivation for the O-RAN architecture to support RAN QoS based resource optimization. Moreover, some high-level description and requirements over Non-RT RIC and A1 interfaces are introduced.

3.8.1 Background and goal of the use case

QoS based resource optimization can used when the network has been configured to provide some kind of preferential QoS for certain users. One such scenario can be related to when the network has been configured to support e2e slices. In this case, the network has functionality that ensures resource isolation between slices as well as functionality to monitor that slice Service Level Specifications (SLS) are fulfilled.

In RAN, it is the scheduler that ensures that Physical Resource Block (PRB) resources are isolated between slices in the best possible way and also that the PRB resources are used in an optimal way to best fulfill the SLS for different slices. The desired default RAN behavior for slices is configured over O1. For example, the ratio of physical resources (PRBs) reserved for a slice is configured at slice creation (instantiation) over O1. Also, QoS can be configured to guide the RAN scheduler how to (in real-time) allocate PRB resources to different users to best fulfill the SLS of a specific slice. In the NR NRM this is described by the resource partition attribute.

Instantiation of a RAN sub-slice will be prepared by rigorous planning to understand to what extent deployed RAN resources will be able to support RAN sub-slice SLS. Part of this procedure is to configure RAN functionality according to above. With this, a default behavior of RAN is obtained that will be able to fulfill slice SLSs for most situations. However, even through rigorous planning, there will be times and places where the RAN resources are not enough to fulfill SLS given the default configuration. To understand how often (and where) this happens, the performance of a RAN slice will continuously be monitored by SMO. When SMO detects a situation when RAN SLS cannot be fulfilled, Non-RT RIC can use A1 policies to improve the situation. To understand how to utilize A1 policies and how to resolve the situation, the non RT-RIC will use additional information available in SMO.

Take an emergency service as an example of a slice tenant. For this example, it is understood (at slice instantiation) that 50% of the PRBs in an area should be enough to support the emergency traffic under normal circumstances. Therefore, the ratio of PRBs for the emergency users is configured to 50% as default behavior for the pre-defined group of users belonging to the emergency slice. Also, QoS is also configured in CN and RAN so that video cameras of emergency users get a minimum bitrate of 500 kbps.

Now, suppose a large fire is ongoing and emergency users are on duty. Some of the personnel capture the fire on video on site. The video streams are available to the Emergency Control Command. Because of the high traffic demand in the area from several emergency users (belonging to the same slice), the resources available for the Emergency slice is not enough to support all the traffic. In this situation, the operator has several possibilities to mitigate the situation. Depending on SLAs towards the Emergency slice compared to SLAs for other slices, the operator could reconfigure the amount of PRB reserved to Emergency slice at the expense of other slices. However, there is always a risk that Emergency video quality is not good enough irrespective if all resources are used for Emergency users. It might be that no video shows sufficient resolution due to resource limitations around the emergency site.

In this situation, the Emergency Control Command decides, based on the video content, to focus on a selected video stream to improve the resolution. The Emergency Control System gives the information about which users to up- and down-prioritized to the e2e slice assurance function (through e.g. an Edge API) of the mobile network to increase bandwidth for selected video stream(s). Given this additional information, the Non-RT RIC can influence how RAN resources are allocated to different users through a QoS target statement in an A1 policy. By good usage of the A1 policy, the Emergency Control Command can ensure that dynamically defined group of UEs provides the video resolution that is needed.

3.8.2 Entities/resources involved in the use case

1) Non-RT RIC:
   a) Monitor necessary QoS related metrics from network function and other SMO functions
   b) Send policies to near-RT RIC to drive QoS based resource optimization at RAN level in terms of expected behavior.
2) Near-RT RIC:
   a) Support interpretation and execution of A1 policies for QoS based resource optimization.
3) RAN:
   a) Support network state and UE performance report with required granularity to SMO over O1 interface.
   b) Support QoS enforcement based on messages from E2, which are expected to influence RRM behavior.

3.8.3 Solutions

3.8.3.1 QoS based resource optimization

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Drive QoS based resource optimization in RAN in accordance with defined policies and configuration.	
Actors and Roles	Non-RT RIC: Creates A1 policies Near-RT RIC: Enforces A1 policies RAN: policy enforcement SMO: termination point for O1 interface.	
Assumptions	All relevant functions and components are instantiated and configured according wanted default behavior. A1 interface connectivity is established with Non-RT RIC. O1 interface connectivity is established with SMO. The default configuration will handle most situations	
Pre conditions	Network is operational with default configuration SMO has established the data collection and sharing process, and Non-RT RIC has access to this data. Non-RT RIC analyzes the data from RAN to understand the current resource consumption	
Begins when	Non-RT RIC observes that resources are close to congestion in a certain area	
Step 1 (O)	If needed, Non-RT RIC orders additional RAN observability, SMO configures additional observability over O1	
Step 2	Non-RT RIC evaluates RAN resource utilization for all users in a slice in specific area.	
Step 3	Non-RT RIC asks for additional information from additional SMO functionality, e.g. e2e slice assurance function	
Step 4	Non-RT RIC determines dynamic group of users for which QoS target should be changed	
Step 5	Non-RT issues A1 policy/policies with QoS target based on information from other SMO functionality	
Ends when	Non-RT RIC (through O1 observability) understands that situation of resource constraints within the slice is resolved and the deployed policies are deleted over A1	
Exceptions	FFS	
Post Conditions		

Table 3.8.3-1: QoS based resource optimization

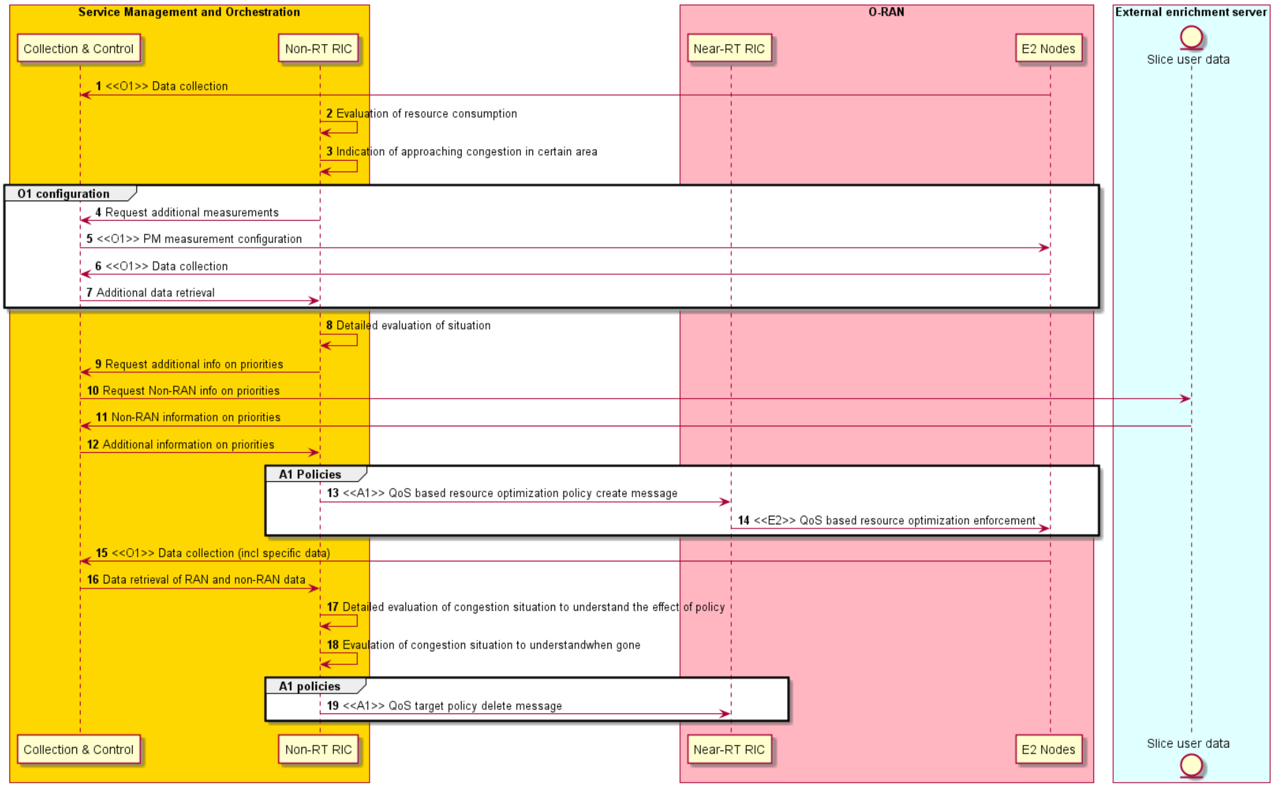


Figure 3.8.3-1: Flow diagram, QoS based resource optimization

3.8.4 Required data

For this use case, different kind of observability need to be reported to Non-RT RIC. First Non-RT RIC should monitor resource consumption in the area. As long as resource consumption is low, the RAN scheduler will be able to give all users in an area the needed resources. When resource consumption in an area increases above a threshold, the risk of that the default configuration of RAN will not be enough to fulfil the requirements. At this point, the Non-RT RIC need to be able to configure more detailed reporting for individual UEs that the Non-RT RIC is interested in. This detailed observability should provide the Non RT RIC better insight in performance for specific users and therefore includes observability of e.g. user throughput and delay. With this more detailed observability, the Non-RT RIC can understand when pre-configured priorities are not enough for the scheduler to solve the problem and when additional (Non RAN) information to solve the prioritization is needed.

3.9 Use case 9: RAN Slice SLA Assurance

The 3GPP standards architected a sliceable 5G infrastructure which allows creation and management of customized networks to meet specific service requirements that may be demanded by future applications, services and business verticals. Such a flexible architecture needs different requirements to be specified in terms of functionality, performance and group of users which may greatly vary from one service to the other. The 5G standardization efforts have gone into defining specific slices and their Service Level Agreements (SLAs) based on application/service type [3]. Since network slicing is conceived to be an end-to-end feature that includes the core network, the transport network and the radio access network (RAN), these requirements should be met at any slice subnet during the life-time of a network slice [4], especially in RAN side. Exemplary slice performance requirements are defined in terms of throughput, energy efficiency, latency and reliability at a high level in SDOs such as 3GPP [2] and GSMA [15]. These requirements are defined as a reference for SLA/contractual agreements for each slice, which individually need proper handling in NG-RAN.

Although network slicing support is started to be defined with 3GPP Release 15, slice assurance mechanisms in RAN needs to be further addressed to achieve deployable network slicing in an open RAN environment. It is necessary to assure the SLAs by dynamically controlling slice configurations based on slice specific performance information. Existing RAN performance measurements [6] and information model definitions [5] are not enough to support RAN slice SLA assurance use cases. This use case is intended to clarify necessary mechanisms and parameters for RAN slice SLA assurance.

3.9.1 Background and goal of the use case

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.

3.9.2 Entities/resources involved in the use case

1) Non-RT RIC:
    a) Retrieve RAN slice SLA target from respective entities such as SMO, NSSMF
    b) Long term monitoring of RAN slice performance measurements
    c) Training of potential ML models that will be deployed in Non-RT RIC for slow loop optimization and/or Near-RT RIC for fast loop optimization.
    d) Support deployment and update of AI/ML models into Near-RT RIC
    e) Receive slice control/slice SLA assurance xApps from SMO
    f) Create A1 policies based on RAN intent A1 feedback.
    g) Send A1 policies and enrichment information to Near-RT RIC to drive slice assurance
    h) 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) Receive slice SLA assurance xApps from SMO
    d) Support interpretation and execution of policies from Non-RT RIC
    e) Perform optimized RAN (E2) actions to achieve RAN slice 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

3.9.3 Solutions

3.9.3.1 Creation and deployment of RAN slice SLA assurance models and control apps

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Training and distribution of the model, or distribution of control apps	
Actors and Roles	Non-RT RIC, Near-RT RIC, SMO	
Assumptions	All relevant functions and components are instantiated. A1, O1 interface connectivity is established.	
Pre conditions	Near-RT RIC and Non-RT RIC are instantiated with A1 interface and connectivity has been established between them. O1 interface has been established between SMO and Near-RT RIC.	
Begins when	A RAN slice is activated.	
Step 1 (M)	Non-RT RIC retrieves a RAN slice SLA from SMO (NSSMF).	
Step 2a	Non-RT RIC starts to collect performance measurements (PMs) via O1. Examples of the PMs are CSI, PRB usage, L2 throughput, RAN latency, etc. Applicable PMs are defined in [6].	Step 2 and 3 are mandatory in case of using the AI/ML model
Step 2b (O)	Non-RT RIC starts to collect enrichment information (EIs) from external applications. Examples of the external applications are public safety application triggering slice priority during an emergency event, or location-based enrichment information, etc.	
Step 2c	Non-RT RIC analyzes collected PMs and/or EIs for long term monitoring, such as during the day or over the weekend.	
Step 3	Non-RT RIC does the model training using the collected data in step 2 and obtains RAN slice SLA assurance models.	
Step 4a	In case of using the AI/ML model, Non-RT RIC deploys the trained model internally for slow loop optimization and/or distributes it to the Near-RT RIC via O2 for fast loop optimization.	Step 4a or 4b is Mandatory
Step 4b	In case of using the control app, the control app is deployed by SMO to Non-RT RIC for slow loop optimization and/or Near-RT RIC via O2 for fast loop optimization.	
Step 5 (M)	Non-RT RIC receives feedback internally or from Near-RT RIC via A1 to update the model or control apps based on it.	
Ends when	A RAN slice is deactivated	
Exceptions	FFS	
Post Conditions	FFS	

Table 3.9.3-1: Creation and deployment of RAN slice SLA assurance models and control apps

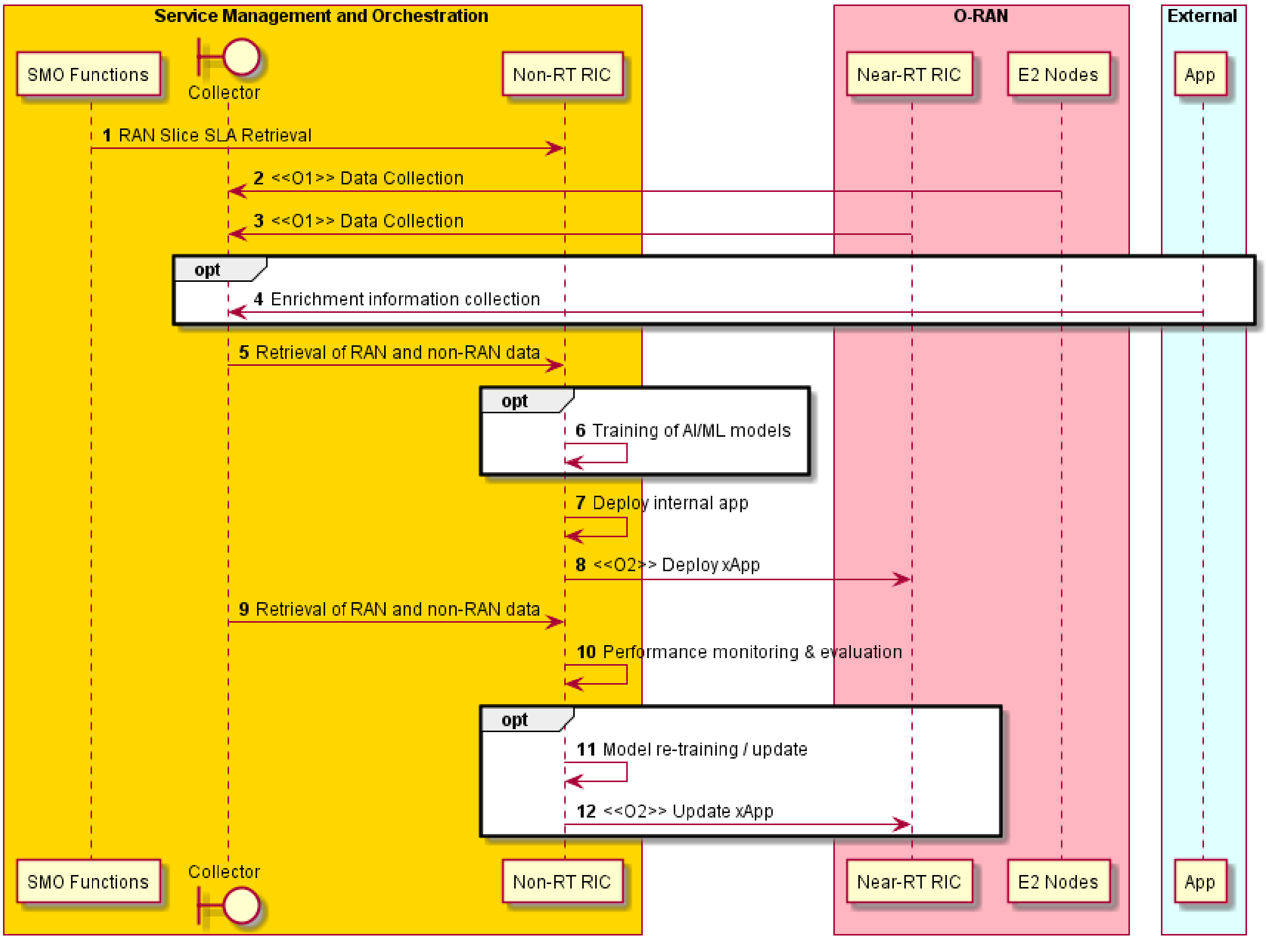


Figure 3.9.3-1: Flow diagram, Creation and deployment of RAN slice SLA assurance models and control apps

1 ### 3.9.3.2 Slow loop RAN Slice SLA optimization

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Slow loop RAN Slice SLA optimization	
Actors and Roles	Non-RT RIC, Near-RT RIC, SMO, RAN	
Assumptions	All relevant functions and components are instantiated. A1, O1, E2 interface connectivity is established.	
Pre conditions	Near-RT RIC and Non-RT RIC are instantiated with A1 interface connectivity being established between them. O1 interfaces are established between SMO and Near-RT RIC, and SMO and RAN nodes. RAN slice SLA assurance models or control apps have been deployed in Non-RT RIC and Near-RT RIC respectively.	
Begins when	A RAN slice is activated	
Step 1a	Non-RT RIC decides that RAN should be reconfigured based on long term trends collected via O1 using PMs and/or EIs. Examples of the PMs are layer 2 throughput, PRB usage, CSI, RAN latency	Config update Step 1a or 1b is mandatory
Step 1b	Non-RT RIC decides to create slice specific A1 policies based on RAN slice SLA requirements and/or operator-defined RAN intents, A1 feedback from Near-RT RIC, EI from external app server and O1 based long term trends. The policies include scope identifiers (e.g. S-NSSAI, Flow ID, Cell ID) and/or policy statements (e.g. slice specific KPI targets).	Policy update
Step 2a	The model or control app in Non-RT RIC requests SMO to update slice configuration of Near-RT RIC and/or RAN nodes through O1.	Config request
Step 2b	SMO sends the updated slice configuration to Near-RT RIC and/or RAN nodes via O1. Examples of the slice configuration are the number of allocated PRBs, number of flows, slice priorities.	Config delivery Step 2b or 2c is mandatory
Step 2c	Non-RT RIC sends the updated A1 policies to Near-RT RIC.	Policy delivery
Step 3a	Near-RT RIC and RAN nodes process and execute the updated slice configuration.	Config execution Step 3a or 3b is mandatory
Step 3b	Near-RT RIC receives the updated A1 policy, controls RAN nodes based on the A1 policy and sends the feedback to Non-RT RIC via A1.	Policy execution
Ends when	A RAN slice is deactivated	
Exceptions	FFS	
Post Conditions	FFS	

2 **Table 3.9.3-2: Slow loop RAN Slice SLA optimization**

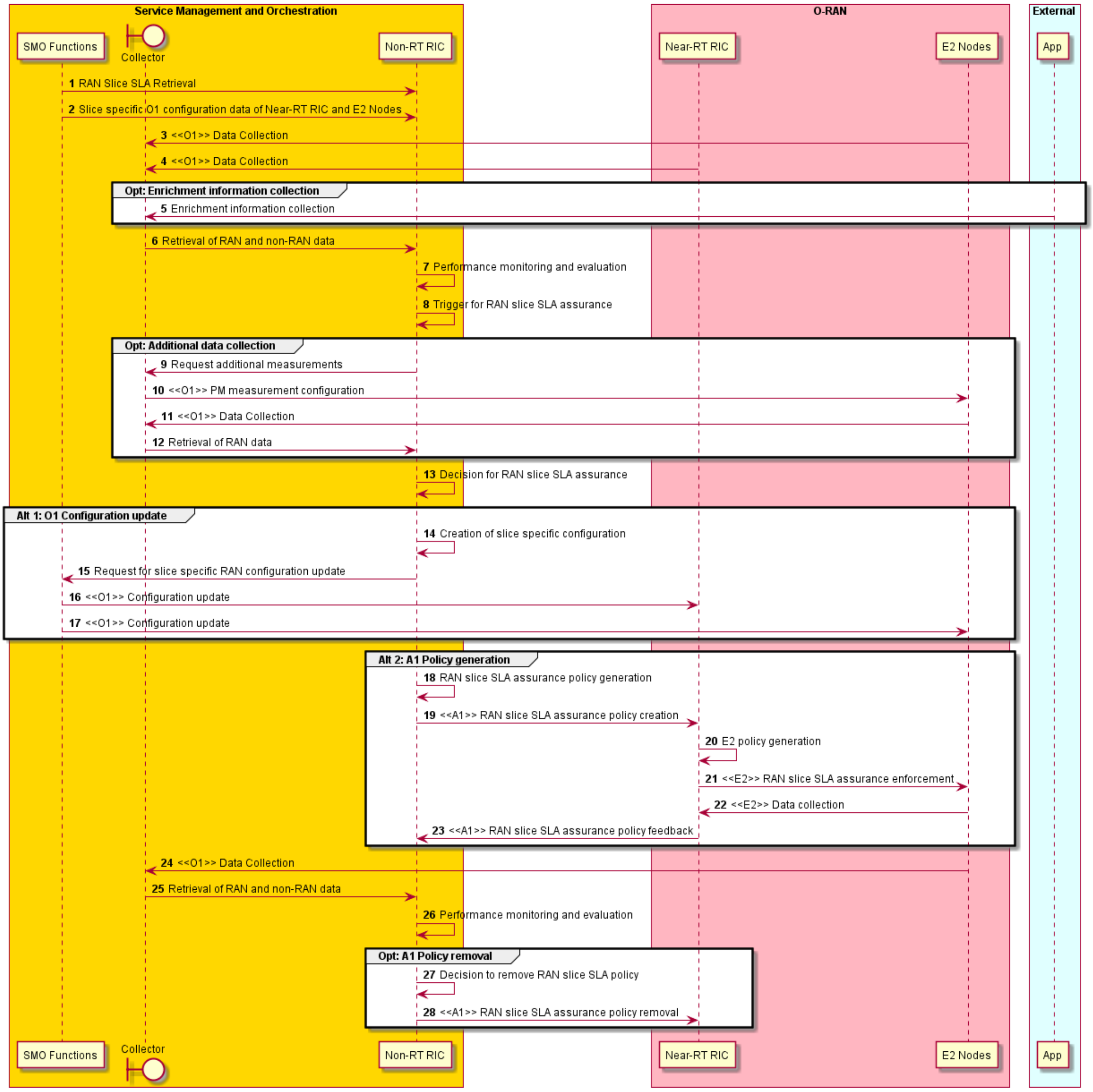


Figure 3.9.3-2: Flow diagram, Slow loop RAN Slice SLA optimization

3.9.3.3 Fast loop RAN Slice SLA optimization

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Fast loop RAN Slice SLA optimization	
Actors and Roles	Non-RT RIC, Near-RT RIC, SMO, RAN	
Assumptions	All relevant functions and components are instantiated. A1, O1, E2 interface connectivity is established.	
Pre conditions	Near-RT RIC and Non-RT RIC are instantiated with A1 interface connectivity being established between them. O1 interfaces are established between SMO and Near-RT RIC, and SMO and RAN nodes. RAN slice SLA assurance models or control apps have been deployed in Near-RT RIC.	
Begins when	A RAN slice is activated	
Step 1	Non-RT RIC decides to generate a policy for Near-RT RIC slice SLA assurance based on RAN slice SLA requirements and/or operator-defined RAN intents, A1 feedback from Near-RT RIC, EI from external app server and O1 based long term trends.	
Step 2	Near-RT RIC receives slice specific O1 configuration and A1 policies from SMO and Non-RT RIC respectively. The former is static and default, the latter is dynamic, optimized and converted from slice SLA. The policies consist of scope identifiers (e.g. S-NSSAI, Flow ID, Cell ID) and policy statements (e.g. slice specific KPI targets). In case of using EIs, Near-RT RIC also receives the EIs from Non-RT RIC via A1-EI interface.	
Step 3	Near-RT RIC starts to collect PMs via E2. Examples of the PMs are CSI, PRB usage, L2 throughput, RAN latency, etc. Applicable PMs are defined in [6].	
Step 4	The model or control app in Near-RT RIC analyzes collected PMs, A1 policies from Non-RT RIC (and optionally EIs from A1-EI interface) to guide RAN nodes via E2 to meet the slice SLA.	
Step 5	Near-RT RIC sends A1 feedback to Non-RT RIC.	
	A RAN slice is deactivated	
	FFS	
	FFS	

Table 3.9.3-3: Fast loop RAN Slice SLA optimization

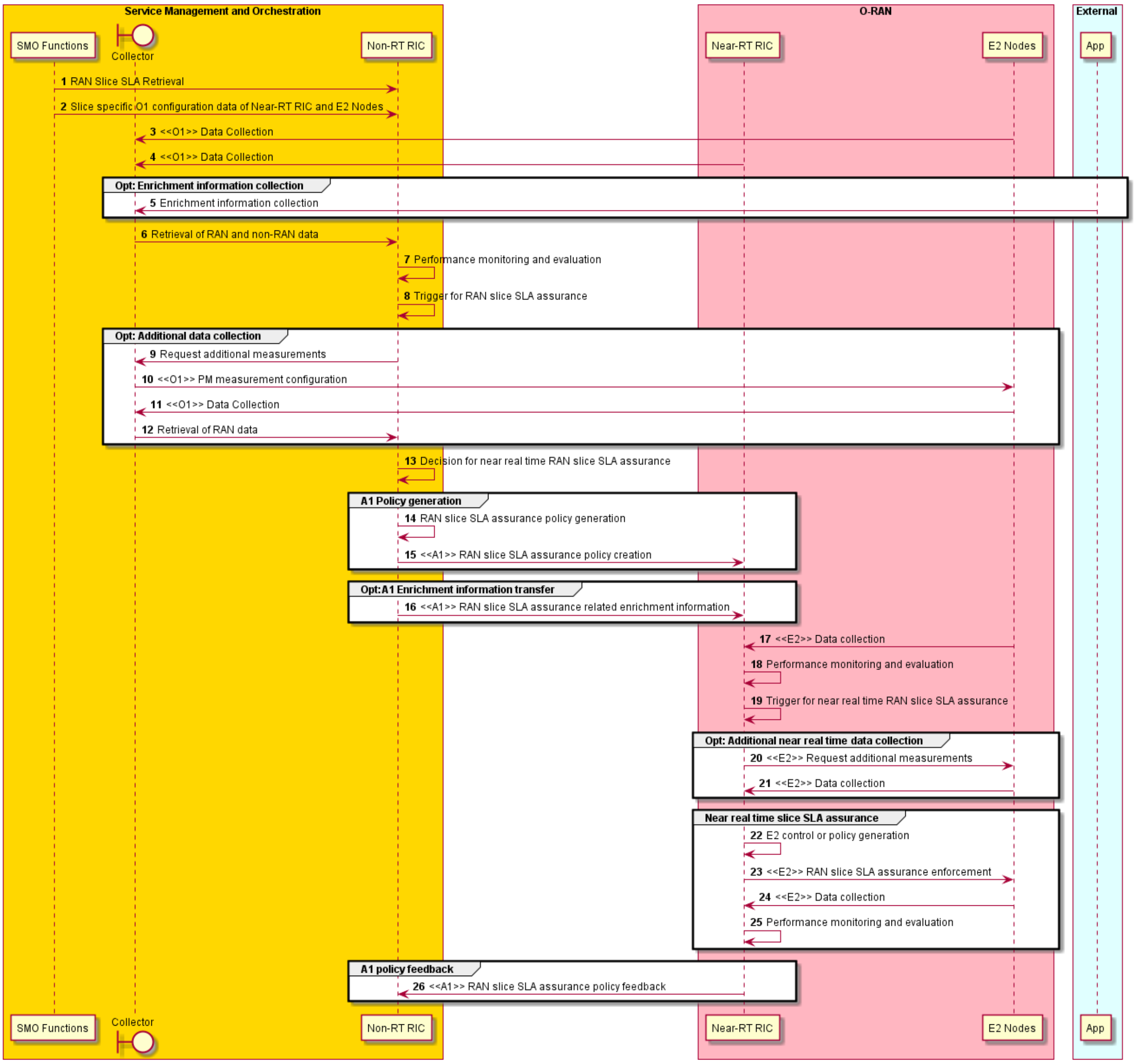


Figure 3.9.3-3: Flow diagram, Fast loop RAN Slice SLA optimization

3.9.4 Required data

The measurement counters and KPIs (as defined by 3GPP and will be extended for O-RAN use cases) should be appropriately aggregated by cell, QoS type, slice, etc.

1) Per-UE CSI

2) Per slice performance statistics such as PDCP throughput, PRB usage

3.10 Use case 10: Multi-vendor Slices

This use case "Multi-vendor slices" is a case that vO-DU and vO-CU functions composing each slice is provided from different vendor. In this sub section, concept, motivation and benefits of introducing "Multi-vendor slices" are explained and candidate solutions are studied.

3.10.1 Background and goal of the use case

Proposed use case enables multiple slices with functions provided from multi- vendors, such as slice #1 is composed with DU and CU provided from vendor A and slice #2 is composed with DU and CU provided from vendor B.

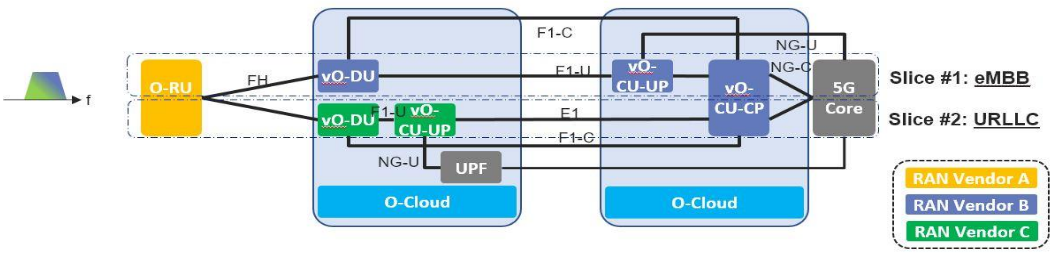


Figure 3.10.1-1: Multi-vendor Slices

When providing multiple slices, it is assumed that suitable vO-DU/scheduler and vO-CU treat each slice respectively. A vendor who providing 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

   Operator can maximize options to choose suitable vO-DU/scheduler and vO-CU to offer various slice. For example, some vendor has a strength of a scheduler for eMBB service and the other has 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 operator can choose vO-DU and vO-CU functions from vendor A to meet their service requirement.

   Also, when operator will add a new service/slice, new functions from a new vendor can be introduced with less consideration for existing vendor if multi-vendor circumstance was realized. This may lead to 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 lead to expand opportunity reaching agreement of RAN sharing among operators. With expansion of RAN sharing, CAPEX and OPEX by operator will be optimized and additional investment can be done more.

3) Reducing supply chain risk

   If existing vendor providing a certain pair of vO-DU and vO-CU functions would withdraw of their market due to business reason, operator can deploy new vO-DU and vO-CU functions alternatively from other vendor under this multi-vendor circumstance. This can reduce a risk for operators' business continuity.

3.10.2 Entities/resources involved in the use case

1) SMO Multi-vendor Slice App:
   a) Configures vO-DU and vO-CU
   b) Configures O-RU to connect to vO-DU
2) Near-RT RIC:
   a) Shares MAC related data unique for UE among vO-DUs.
   b) Support communication of configuration parameters to RAN
3) E2 Nodes (vO-CU, vO-DU, O-RU):
   a) Primary vO-DU processes SRB (Signalling Radio Bearer), DRB (Data Radio Bearer) and other vO-DU related functions. Secondary vO-DU processes only DRB related functions. Note that vO-DU and vO-CU are created as part of network slice creation procedure.

3.10.3 Solutions

3.10.3.1 Data transmission call flow example for Multi-vendor slices use case

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	UE communicates on slice #1 and #2 respectively	
Actors and Roles	- SMO Multi-vendor Slice App configures vO-DU and v-O-CU with radio resource assignment (via Orchestrator) and collects KPI data. - Near-RT RIC configures vO-DU and vO-CU for resource assignment and shares MAC related information unique for UE among vO-DUs. - Primary vO-DU processes SRB (Signalling Radio Bearer), DRB (Data Radio Bearer). Secondary vO-DU processes only DRB.	
Assumptions	- All relevant functions and components are instantiated. - Slice #1 is created over primary vO-DU and vO-CU with Logical Channel ID #1 and #2, and slice #2 is created over secondary vO-DU and vO-CU with Logical Channel ID #3. - O-RU is shared between primary vO-DU and secondary vO-DU with one component carrier. - CU-CP is shared between primary vO-CU-UP and secondary vO-CU-UP. - TDD operation is assumed. - UE tries to transmit data on slice #1 and #2.	
Pre conditions	- Slice #1 and #2 are created and activated on primary vO-DU, vO-CU and secondary vO-DU, vO-CU respectively - Slice #1 is tied with Scheduling Request Resource 1 and Logical Channel ID #1 and #2, and slice #2 is tied with Scheduling Request Resource 2 and Logical Channel ID #3 - Primary vO-DU and secondary vO-DU know which timing/resource block they can utilize on for slice #1 and #2 respectively by direction from SMO via O1 interface. - UE has already performed RACH procedure with primary vO-DU.	
Begins when	UE tries to perform registration procedure with RRC Connection Request message.	
Step 1 (M)	[UE performs registration procedure]	

	UE sends RRC Connection Request message to primary vO-DU and vO-CU through O-RU. Primary vO-CU and vO-DU responds with RRC Connection Setup. UE sends RRC connection Setup Complete message. Primary vO-DU sends initial RRC message and shared information such as C-RNTI to near RT-RIC. Near RT-RIC determines to transfer it to secondary vO-DU over E2 interface. Other registration procedure is performed.	
Step 2 (M)	[PDU session establishment] UE starts PDU session establishment procedure with PDU session establishment request message with primary vO-DU and vO-CU. UE initiates PDU session establishment procedure with S-NSSAI 2 for Slice #2 via primary vO-DU. UE Context Modification is made at secondary vO-DU.	
Step 3 (M)	[U-plane data transmission between primary vO-DU and O-RU] At allocated timing/resources, primary vO-DU sends Scheduling Command message to O-RU to start transfer and receive DL and UL Data. UE sends Scheduling Request message on PUCCH with Scheduling Request Resource 1 to primary vO-DU over Open fronthaul. Primary vO-DU responds with UL Grant message to the UE.	ORAN-WG4.CUS.0-v02.00 "Figure 6-5: C-Plane and U-Plane message transfer procedure (DL & UL shown)"
Step 4 (M)	[Buffer notification and transmission user data] UE notices buffer with Buffer Status Request message to primary vO-DU. Primary vO-DU acknowledges with UL Grant message. UE sends user data on PUSCH with Logical Channel ID #1 and #2 Primary vO-DU acknowledges with Ack or Nack. UE repeats step 3 until buffer becomes empty.	
Step 5 (M)	[U-plane data transmission between secondary vO-DU and O-RU] At allocated timing/resources, secondary vO-DU sends Scheduling Command message to O-RU to start transfer and receive DL and UL Data. UE sends Scheduling Request message on PUCCH with Scheduling Request Resource 2 to secondary vO-DU over Open fronthaul. Secondary vO-DU responds with UL Grant message to the UE.	ORAN-WG4.CUS.0-v02.00 "Figure 6-5: C-Plane and U-Plane message transfer procedure (DL & UL shown)"
Step 6 (M)	[Buffer notification and transmission user data] UE notices buffer with Buffer Status Request message to secondary vO-DU. Secondary vO-DU acknowledges with UL Grant message. UE sends user data on PUSCH with Logical Channel ID #3. Secondary vO-DU acknowledges with Ack or Nack. UE repeats step 5 until buffer becomes empty.	
Step 7 (M)	[Collect Data] RAN related data from RAN nodes are collected at SMO Collector via O1 interface.	
Ends when	UE finishes data transmission until buffer becomes empty.	
Exceptions	None identified.	
Post Conditions	None identified	

Table 3.10.3.1-1: Data transmission call flow example for Multi-vendor slices use case

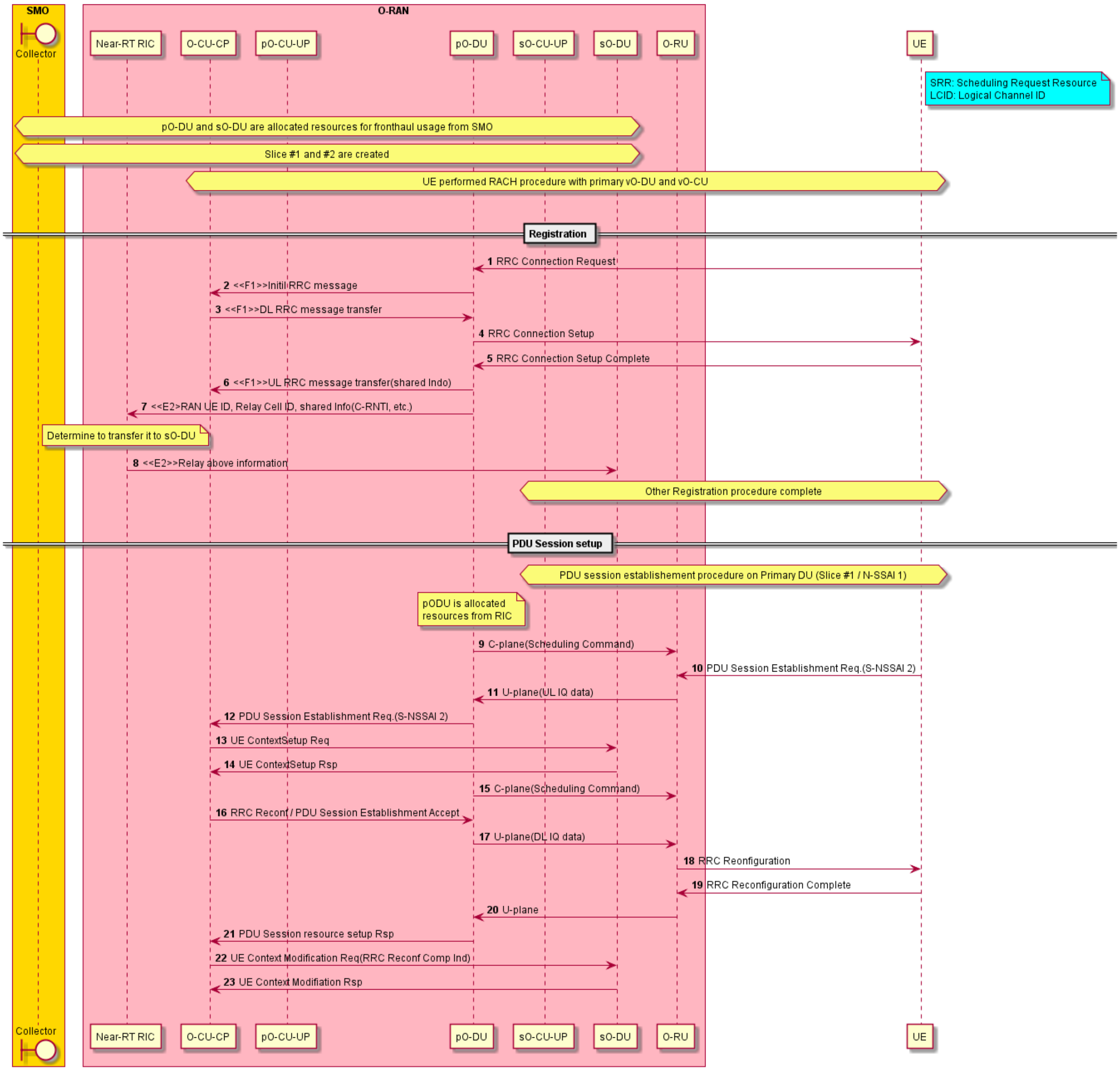


Figure 3.10.3.1-1: Data transmission call flow example for Multi-vendor slices use case – Part 1 of 2

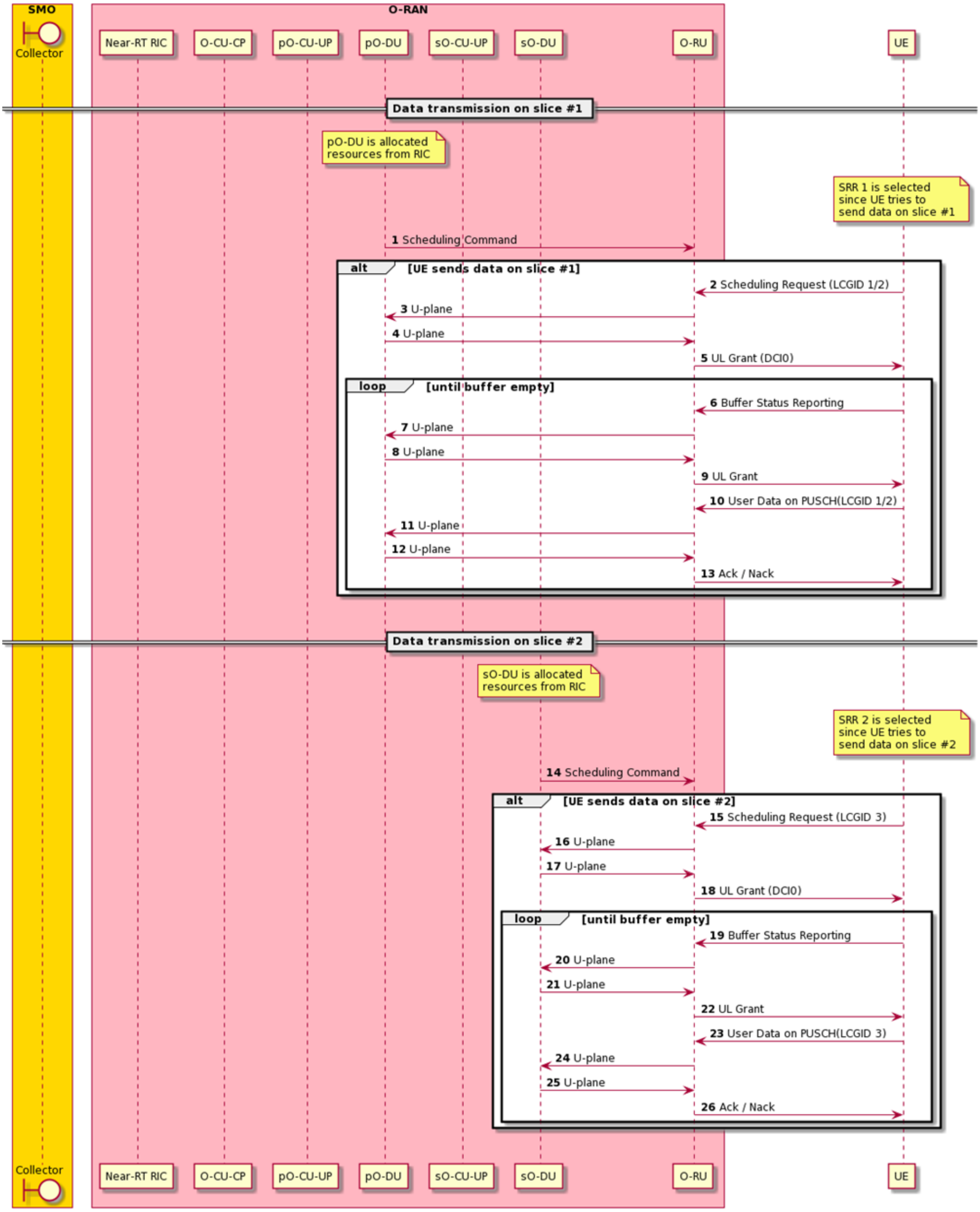


Figure 3.10.3.1-2: Data transmission call flow example for Multi-vendor slices use case – Part 2 of 2

3.10.3.2 Data transmission call flow example for RAN sharing use case

Use Case Stage	Evolution / Specification	<<Uses>> Related use

Goal	UE communicates on secondary vO-DU and vO-CU with PLMN #2	
Actors and Roles	- SMO Multi-vendor Slice App configures vO-DU and v-O-CU with radio resource assignment (via Orchestrator) and collects KPI data - Near-RT RIC configures vO-DU and vO-CU for resource assignment and shares MAC related information unique for UE among vO-DUs. - Primary vO-DU processes SRB (Signalling Radio Bearer), DRB (Data Radio Bearer). Secondary vO-DU processes only DRB.	
Assumptions	- All relevant functions and components are instantiated. - PLMN #1 is assigned to primary vO-DU and vO-CU, and PLMN #2 is assigned to secondary vO-DU and vO-CU respectively. - O-RU is shared between primary vO-DU and secondary vO-DU with one component carrier. - CU-CP is shared between primary vO-CU-UP and secondary vO-CU-UP. - TDD operation is assumed. - UE tries to transmit data with PLMN #2.	
Pre conditions	- PLMN #1 and #2 are assigned to primary vO-DU, vO-CU and secondary vO-DU, vO-CU respectively - Primary vO-DU and vO-CU advertise PLMN #1 and #2 over the air. - Primary vO-DU and secondary vO-DU know which timing/resource block they can utilize on for PLMN #1 and #2 respectively by direction from SMO via O1 interface. - UE has already performed RACH procedure with primary vO-DU.	
Begins when	UE tries to perform registration procedure with RRC Connection Request message.	
Step 1 (M)	[UE performs registration procedure with PLMN #2] UE sends RRC Connection Request message to primary vO-DU and vO-CU through O-RU. Primary vO-CU and vO-DU responds with RRC Connection Setup. UE sends RRC connection Setup Complete message with PLMN#2 in selected PLMN-Identity. Primary vO-DU sends initial RRC message with PLMN-Identity and shared information such as C-RNTI to near RT-RIC. Near RT-RIC determines to transfer it to secondary vO-DU over E2 interface. Other registration procedure is performed through secondary vO-DU.	
Step 2 (M)	[PDU session establishment] UE starts PDU session establishment procedure with PDU session establishment request message through secondary vO-DU and vO-CU.	
Step 3 (M)	[U-plane data transmission between secondary vO-DU and O-RU] At allocated timing/resources, secondary vO-DU sends Scheduling Command message to O-RU to start transfer and receive DL and UL Data. UE sends Scheduling Request message on PUCCH with Scheduling Request Resource 2 to secondary vO-DU over Open fronthaul. Secondary vO-DU responds with UL Grant message to the UE.	ORAN-WG4.CUS.0-v02.00 “Figure 6-5 : C-Plane and U-Plane message transfer procedure (DL & UL shown)”
Step 4 (M)	[Buffer notification and transmission user data] UE notices buffer with Buffer Status Request message to secondary vO-DU. Secondary vO-DU acknowledges with UL Grant message. UE sends user data on PUSCH with Logical Channel ID #2. Secondary vO-DU acknowledges with Ack or Nack. UE repeats step 3 until buffer becomes empty.	
Step 5 (M)	[Collect Data] RAN related data from RAN nodes are collected at SMO Collector via O1 interface.	
Ends when	UE finishes data transmission until buffer becomes empty.	

Exceptions	None identified.	
Post Conditions	None identified	

Table 3.10.3.2-1: Data transmission call flow example for RAN sharing use case

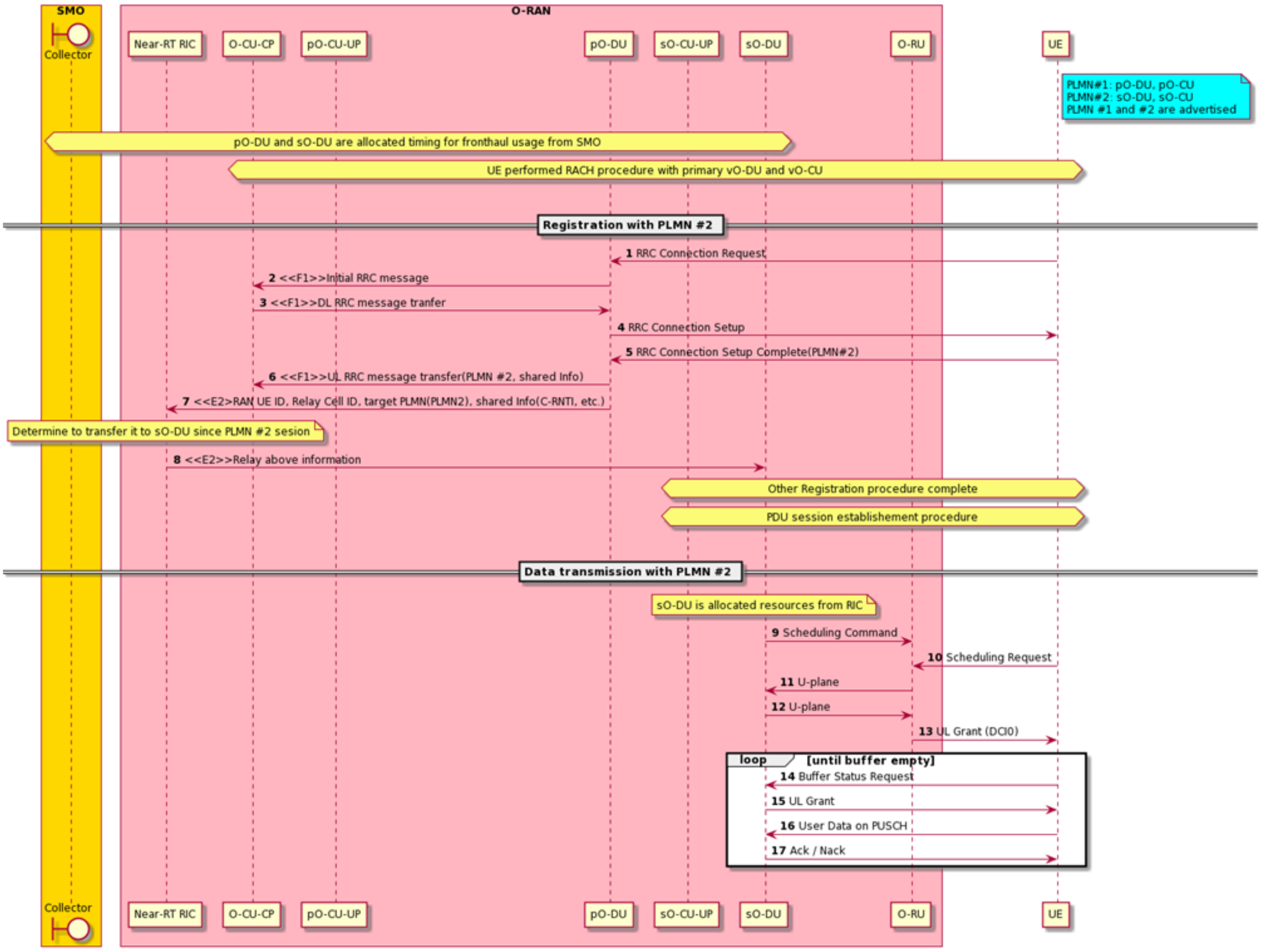


Figure 3.10.3.2-1: Data transmission call flow example for RAN sharing use case

3.10.4 Required data

The measurement counters and KPIs (as defined by 3GPP and will be extended for O-RAN use cases) should be appropriately aggregated by cell, QoS type, slice, etc.

1) Per-UE CSI
2) Per slice performance statistics such as PDCP throughput, PRB usage

3.11 Use case 11: Dynamic Spectrum Sharing

This use case provides the background, motivation, and requirements to realize Dynamic Spectrum Sharing (DSS) over the ORAN architecture. This is to enable operators to adapt radio resource allocation policies and control to dynamically share radio spectrum between 4G and 5G networks.

3.11.1 Background and goal of the use case

As we transition from 4G to 5G, the spectral resources used for 5G deployment is a key consideration and this situation varies from one operator to another. Though, new C-band resources between 3-6 GHz and mmWave bands have been acquired by operators, these bands suffer from great propagation and penetration loss, limiting their coverage to those users close to the cell, this situation worsens in the UL as the UE device is power constrained. A cost-effective way to address this is the 5G deployment on lower bands (i.e., below 2GHz), which are also used in 4G LTE deployments today. Operating on lower bands along with non-standalone mode of 5G deployment helps to cover large geography, enables seamless mobility between 4G and 5G while being sensitive to overall cost of deployment. In addition, DSS offers the advantage of dynamically sharing the available spectrum adapting to the varying workloads of the 4G and 5G network.

DSS is compelling considering the need for operators to dynamically share already deployed spectral resources between LTE and NR devices without degrading the QoE of the current 4G subscribers while offering the same level of coverage and necessary QoS to NR devices, under the assumption that the two networks will co-exist in the near term. The objective of this use case is to propose DSS in the context of the ORAN architecture, specifically to realize it as an application in the RIC framework.

This would particularly benefit vRAN implementations when the 4G/5G CU/DU are from different vendors and one could leverage RAN data over O-RAN's framework for traffic prediction, DSS related resource management and conduct control functions. Towards this, the intelligent control functions are identified, which can be realized as a DSS application to augment the L3/L2/L1 control functions defined as part of LTE-NR coexistence in Rel-15/16 [3][8].

In Figure 3.11.1-1, the architectural context is set for this discussion. DSS enables 4G and 5G UEs to operate over the same spectrum identified as X (typically low band), while 5G itself could operate on new bands Y (typically high band) not used by current 4G deployment. In a typical setting, Y would offer higher capacity, low latency and smaller coverage, while X would be used to offer reasonable capacity along with larger coverage. 3GPP specifications offers DSS support over X2/Xn interface to enable dynamic sharing of the spectrum resource in addition to the L2/L1 adaptation for 5G-NR to co-exist with LTE.

Considering the scenario of incremental deployment - in the 5G NSA mode, the 5G UE is required to have dual connectivity capability and be able to connect to eNBs on LTE bands for control plane requirements and user plane connectivity towards the LTE and/or 5G depending on deployment requirements. In the scenario where gNB only operates on 5G C or mmWave bands, the sharing of the LTE frequency band between 4G and 5G UEs can be solely fulfilled by eNB MAC scheduler, as the UE is expected to be dual stacked. While, if the gNB is required to operate on lower LTE bands as well, then spectral sharing needs to be coordinated between the LTE and 5G schedulers.

When DSS is enabled in the SA mode, 5G UE would be capable of operating on lower LTE bands (below 2GHz), C and mmWave bands and connects only to the gNBs. The sharing of the LTE bands between LTE and 5G data channels are achieved by both 4G scheduler and 5G scheduler using resource management and interference mitigation functions in the RIC between them.

The use case proposes to conduct DSS related policy, configuration, resource management and control functions using the non-RT and near-RT functions over open interfaces proposed by ORAN.

An abstracted view of how DSS application can be realized using the Non-Real Time and Near-Real Time RIC components is shown in Figure 3.11.1-2. The DSS over RIC can be realized as multiple applications considering its multiple optimization and operational objectives. One possible logical breakdown is as a traffic prediction and resource management application (DSS-App) managing the shared spectrum resource adapting to dynamic 4G and 5G specific workload requirements in various local contexts, and another application (RAT-App) to configure, control and monitor DSS related functions in the CU/DU corresponding to the LTE and 5G cells. The DSS-App engineers at the non-RT RIC level translates the global DSS policies based on workload requirements for a region and time-of-day to spectrum sharing policies such as max/min bandwidth threshold at a local level (e.g. edge or central office). The RAT-App at the non-RT RIC level also translates the DSS-App's resource policies to RAT specific configuration and policies at the near-RT RIC and the CU/DU entities. The DSS-App at the near-RT RIC uses the data collected by the RAT-app to make dynamic resource sharing decisions that are enforced by the RAT-app using the E2 control APIs.

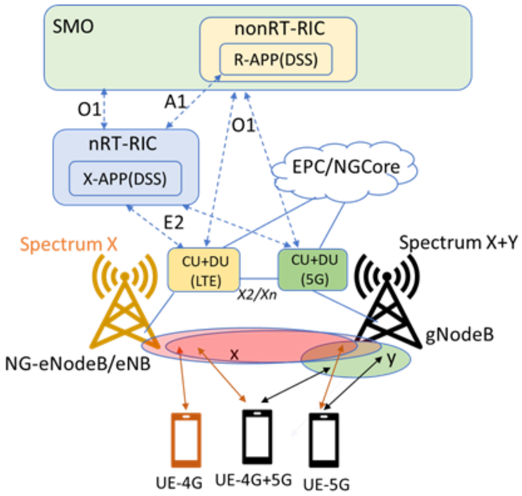


Figure 3.11.1-1: RIC Based DSS Architecture

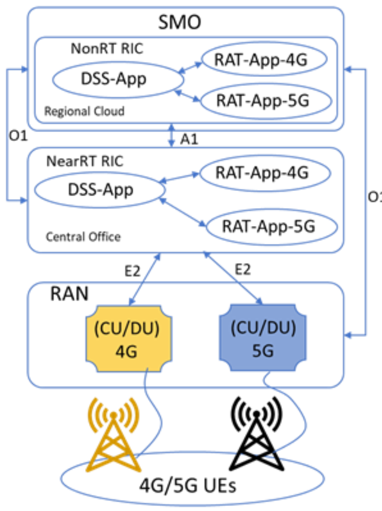


Figure 3.11.1-2: RIC Based DSS Realization

The main goal of the non-RT DSS-App is to provide long-term scheduling policy to 4G and 5G scheduler considering business, user, spatial and temporal workload factors.

The main functionality of non-RT RAT-App is to translate the global DSS policies from non-RT DSS-App to RAT specific policies to the RAT-App in the near-RT RIC over A1.

The main functionalities of the near-RT DSS-App include policy translation between non-RT DSS-App to RAT specific configuration to the near-RT RAT-App. Furthermore, it is actively involved in closed loop decision using the KPIs from the RAN adapting to the needs of the 4G and 5G cells.

The main functionality of near-RT RAT-App is to perform RAT specific configuration, control and data subscription over E2 interface with RAN (CU/DU components).

3.11.2 Entities/resources involved in the use case

1) Non-RT RIC:
    a) Receive SMO's DSS specific service requirement for the RAN and translate them into resource sharing policies.
    b) Provide long-term policies in terms of scheduling guidance to 4G and 5G scheduler over A1 to near-RT RIC, considering business, user, spatial and temporal workload factors, policies related to expected performance and actions when it deviates based on KPIs from the 4G and 5G network.
    c) Develop and train AI/ML models with the help of SMO functions for the near-RT RIC to predict the short-term traffic demand for 4G and 5G network based on near real time metrics from RAN. Deployment of these ML model over O1 and xApps over O2 to the near-RT RIC.
    d) Receive policy feedback from near-RT RIC and update policy and re-train ML models whenever required.
2) Near-RT RIC:
    a) Support deployment, execution and ability to update DSS xApps from non-RT RIC.
    b) Support interpretation of policies related to RAT specific resource allocation.
    c) Translate RAT specific SLA policy to configuration, control and data subscription over E2 interface to E2 Nodes (O-CU, O-DU).
    d) Share resource allocation performance and policy feedback report with non-RT RIC for further evaluation and optimization over O1/A1.
3) RAN:
    a) Support discovery of DSS related configuration of E2 nodes over E2 interface.
    b) Share the data collection over O1 interface.
    c) Support resource management related metrics collection over E2 interface.
    d) Support control and policy enforcement from near-RT RIC over E2 interface.

1 ## 3.11.3 Solutions

2 ### 3.11.3.1 Dynamic Spectrum Sharing for 4G and 5G

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Enable operators to dynamically share spectrum in the existing 4G deployment with 5G systems, based on the dynamic loads of both networks and resource sharing policies.	
Actors and Roles	Non-RT RIC: spectrum resource sharing policy function Near-RT RIC: executes resource sharing models and algorithms, translating RAT specific policy to configuration, control and data subscription over E2 interface with RAN RAN: executes resource sharing enforcement rules and policies, collects and reports RAN statistics and performance over E2 and O1	
Assumptions	All relevant functions and components are instantiated. DSS xApps are deployed over O1 with initial configuration A1, E2 interface connectivity is established with non-RT RIC and RAN respectively. Data report, policy and control subscription established on E2 interface	
Pre conditions	Network is operational. SMO has established the data collection and sharing interface with non-RT RIC. Non-RT RIC analyzes the historical data from RAN, develops, trains with help of SMO functions and deploys the relevant AI/ML models or algorithm as xApps to the near-RT RIC	
Begins when	Operator specified trigger condition or event is detected.	
Step 1 (M)	Near-RT RIC collects DSS related RAN function capabilities and configuration parameters from RAN over E2 interface	
Step 2 (M)	Non-RT RIC communicates DSS relevant policies to the near-RT RIC over the A1 interface.	
Step 3 (M)	Near-RT RIC communicates RAT specific DSS relevant configuration, control policies to RAN over the E2 interface.	
Step 4 (M)	RAN deploys the configuration and control policies received from the near-RT RIC over the E2 interface.	
Step 5 (M)	Near-RT RIC collects relevant observability data from RAN, executes xApp and outputs the optimal resource allocation and cell level resource scheduling decisions to RAN over E2 and policy feedback to non-RT RIC over A1	
Step 6 (M)	RAN deploys the updated control policies received from the near-RT RIC over the E2 interface and continues reporting data to SMO over O1 and E2 as configured	
Step 7 (M)	Non-RT RIC adjusts the policy based on PM data from SMO and feedback from near-RT RIC	
Step 8 (M)	Non-RT RIC updates the resource sharing policy to near-RT RIC over A1	
Step 9 (O)	Non-RT RIC re-trains/updates the AI/ML model with new data and performance, and deploys the new model or new model configurations to near-RT RIC	
Ends when	Operator specified trigger condition or event is satisfied	
Exceptions	None identified	
Post Conditions	Non-RT RIC monitors loads and relevant KPI performance metrics of eNB/gNB to observe the resource sharing efficiency and sets up new policies based on the metrics and business needs. Near-RT RIC executes the resource sharing model or algorithm. RAN operates with the scheduling guidance from RIC and reports performance data to RIC	

3 **Table 3.11.3-1: Dynamic Spectrum Sharing for 4G and 5G**

4

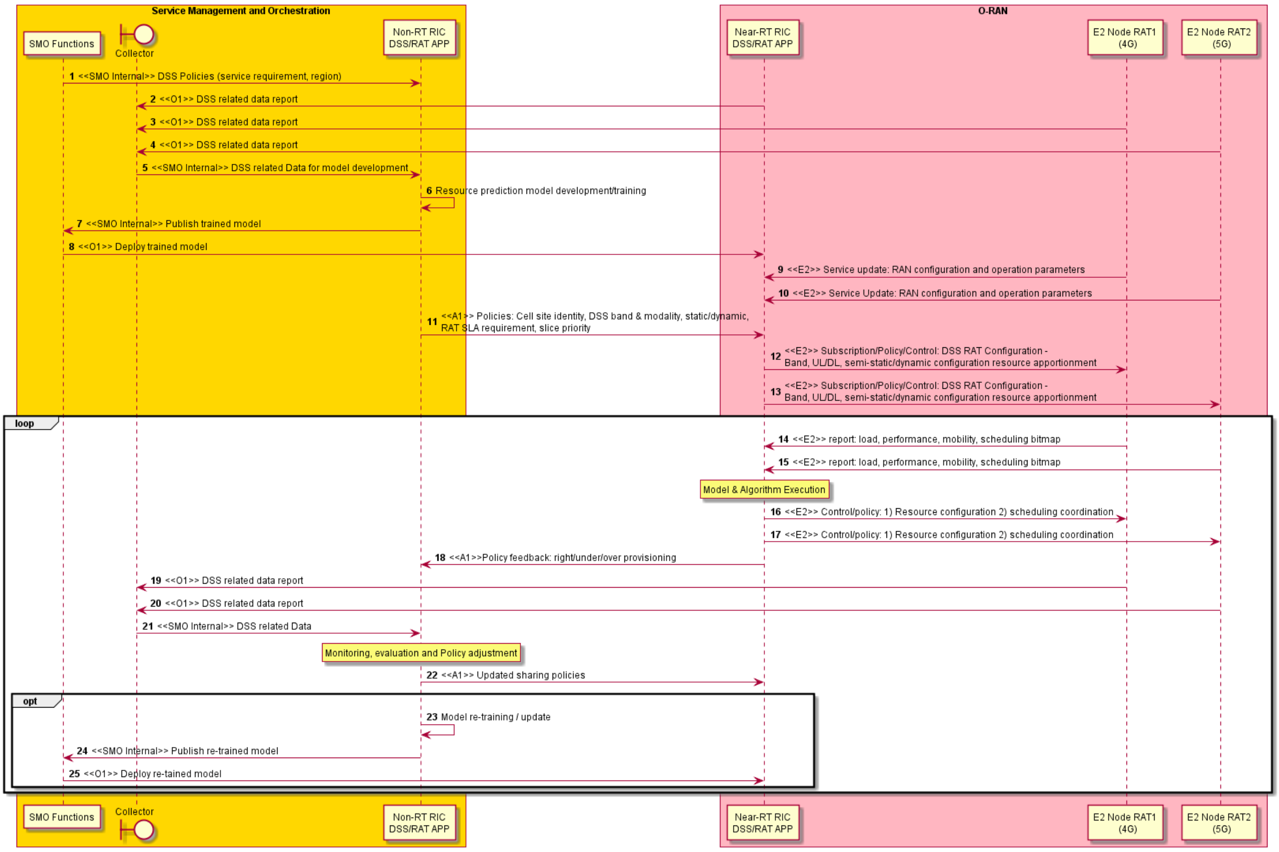


Figure 3.11.3-1: Flow diagram, Dynamic Spectrum Sharing for 4G and 5G

3.11.4 Required data

Multiple observability data from RAN need to be reported to SMO, non-RT RIC and near-RT RIC for DSS to operate.

Category	Parameters/Measurements	RAT	Source/Interface	Reference
4G/5G DSS configuration and operation parameters	Geography location (e.g., cell site)	4G/5G	External server	TBD
	DSS modality (static, semi-static (MBSFN), dynamic (sub-frame level))	4G/5G	E2	TS 38.211 TS 38.213
	Cell configuration information (e.g., FDD/TDD, Band, Signaling/RS Allocation Bitmap)	4G/5G	E2	TS 36.423 TS 38.211 TS 38.213
4G/5G scheduling information	Physical resource block used/reserved/requested/blocked Bitmap information	4G/5G	E2	TS 36.423
4G/5G cell load statistics	Number of active UEs (total, UL/DL, per QCI)	4G	E2 and O1	TS 36.314

	Mean/Max number of Active UEs (DL/UL, total, per DRB(mapped 5QI))	5G	E2 and O1	TS 38.314 TS 32.425
	Traffic demand/buffer size (Total, per QCI/5QI)	4G/5G	E2 and O1	TBD
	PRB usage (DL, UL, Total, per QCI/5QI)	4G/5G	E2 and O1	TS 36.314 TS 36.423 TS 28.552
	PDCCH CCE usage	4G/5G	E2 and O1	TS 36.423
	RRC connection number	5G	E2 and O1	TS 28.552 TS 32.425
4G/5G QoS configuration and parameters	QoS Classes	4G/5G	E2	TS 23.501 (5G) TS 36.300, TS 23.401, TS 23.203(4G)
	Slice types	5G	E2	TS 23.501
UE performance statistics	Scheduled IP Throughput (DL, UL, per QCI)	4G	E2 and O1	TS 36.314
	Data Volume (DL/UL per CQI)	4G	E2 and O1	TS 36.314
	UL/DL PDCP SDU Data Volume	5G	E2 and O1	TS 28.552
	PDCP Packet Delay DL/UL per CQI/QCI	4G/5G	E2 and O1	TS 36.314(4G), 5G(TBD)
UE mobility statistics	RSRP/RSRQ/SINR/RSSI	4G/5G	E2 and O1	TS 36.214 TS 36.331
	UE Location Information	45/5G	External Server	TBD
	UE Capability	4G/5G	E2 and O1	TS 36.331

Table 3.11.4-1: Required data for DSS use case

3.12 Use case 12: NSSI Resource Allocation Optimization

This use case provides the background, motivation, description, and requirements for the NSSI resource allocation optimization use case, allowing operators to optimize the allocation resources to NSSI(s) with wide range service requirements.

3.12.1 Background and goal of the use case

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 the various services. However, as eMBB, URLLC, and mMTC services in 5G are typically realized as NSI (Network Slice instance). Therefore, the resources allocated to NSSI (Network Slice Subnet Instance) to support the O-RAN nodes can be optimized according 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 time 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, and automatically re-allocates the network resources ahead of the network issues surfaced.

Figure 3.12.1-1 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, for example including the following performance measurements that are measured on per NSSI (TS 28.552 [6]):
    - 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 [5]), etc.) for the NSSI at the given time, and location.
3) Execution: execute the actions to reallocate the NSSI resources that include:

    3a. Re-configure the NSSI attributes via the O1 interface

    3b. Update the cloud resources via the O2 interface

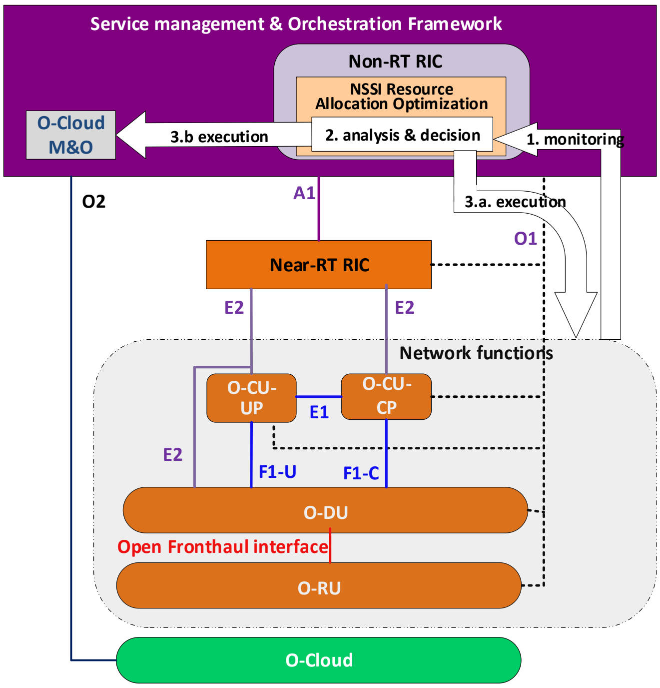


Figure 3.12.1-1: The realization of NSSI resource allocation optimization over Non-RT RIC

3.12.2 Entities/resources involved in the use case

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 [5]), 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) RAN Nodes (O-CU-CP, O-CU-UP, O-DU, 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.

3.12.3 Solutions

3.12.3.1 NSSI Resource Allocation Optimization

Use Case stage	Evolution/Specification	<<Uses>> Related use
Goal	To automatically optimize the NSSI resource allocation by leveraging the AI/ML model that was trained via the analysis of performance measurements collected from the RAN nodes.	
Actors and Roles	Non-RT RIC: analysis of performance measurements and AI/ML model training RAN nodes (O-CU-CP, O-CU-UP, O-DU, O-RU): performance measurements collection and configuration changes execution O-Cloud M&O: the cloud resources modification via the O2 interface	
Assumptions	- All relevant functions and components are instantiated. - Non-RT RIC is able to receive performance measurements from RAN nodes via the O1 interface.	
Pre-conditions	- RAN is operational. - Non-RT RIC has been collecting the RAN performance measurements from RAN nodes.	
Begins when	An AI/ML model has been trained based on the analysis of performance measurements predict of the traffic demand patterns of NSSI at different times and locations.	
Step 1 (M)	Non-RT RIC determines the action based on model inference to update the NSSI resources that may include the following information: a) the time/date, b) locations (e.g. gNB ID), c) NSSI ID, d) slice subnet attributes, e) VNF resources update (e.g. scaling in/out)	
Step 2 (M)	Non-RT RIC executes the action at the time determined by the model inference by performing the following operations: a) re-configure the slice subnet attributes via the O1 interface, b) request O-Cloud M&O to update the O-Cloud resources via the O2 interface.	
Ends when	All the steps identified above are successfully completed.	
Exceptions	One of the steps identified above fails.	
Post-conditions	Near-RT RIC continues monitoring the NSSI resource usages.	

Table 3.12.3-1: NSSI Resource Allocation Optimization

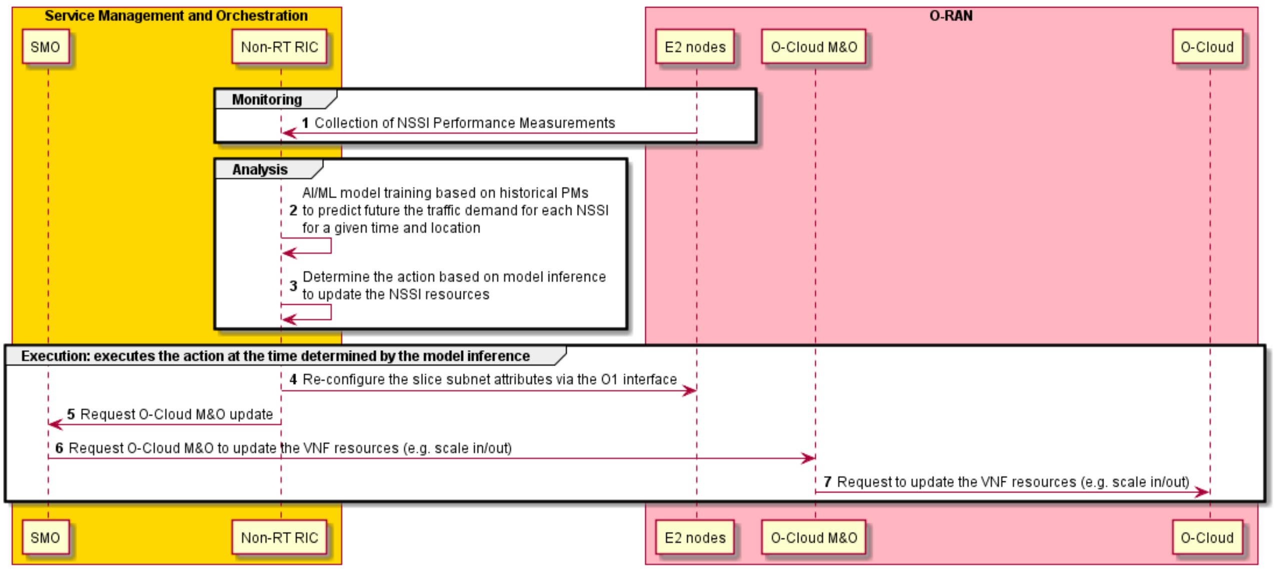


Figure 3.12.3-1: Flow diagram, NSSI Resource Allocation Optimization

3.12.4 Required data

The measurement counters, as defined by 3GPP TS 28.552 [6], which are measured on per slicing subnet instances include:

- 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

3.13 Use case 13: Local Indoor Positioning in RAN

FFS

3.14 Use case 14: Massive SU/MU-MIMO Grouping Optimization

FFS

3.15 Use case 15: O-RAN Signalling Storm Protection

This use case provides the background, motivation, and requirements for the O-RAN Signaling Storm Protection use case, allowing protecting the mobility network against signaling storms initiated by devices.

3.15.1 Background and goal of the use case

Society is increasingly dependent on network connectivity at any time and in any place and increasing diversity of device types ranging from complex devices such as smart phone to very simple and low-cost IoT devices are connecting to the network. The sheer number of connected devices, as well as the wide range of device types, makes the mobility network subject to accidental or intentional attacks that may disrupt the regular usage of the network. Given that life-critical applications are moving to wireless networks, such network disruptions are not only an inconvenience but may have impact on life and health of individuals. The O-RAN architecture offers an opportunity to address such security challenges in customizable and creative ways by utilizing the near-RT RIC xApps and non-RT RIC rApps.

Currently, the main defense mechanism standardized in 3GPP against attacks coming from the devices toward the network is based on configuration of the devices themselves and trust that the devices will indeed comply with restrictions defined by mobility standards. One such defense mechanism is the back-off timer that restricts the number of repeated device registrations, thus preventing devices from overloading the network with attaches. If this trust is breached there are no other options for defending the network rather than rejecting (denying service) randomly to both benign and malicious devices, a state which is equivalent to DDoS. Unfortunately, even today the network has few hundreds of device types that under certain conditions accidently breach this trust and allow devices to aggressively attach to the network in a rate of few thousand times per hour (the maximum allowed number by standard is less than 20 attaches per hour). An attacker that finds a way to manipulate vulnerabilities in a large set of these devices remotely can cause an attach storm that could lead to a long outage of large parts of the network. Furthermore, this attacker can continue this attack over many hours, each time picking few thousand of devices from a large pool of millions of vulnerable devices connected to the same carrier network; the network carrier will not be able to stop this attack without intelligent and fine-grained controls to act against a certain patterns of behavior.

Fortunately detecting these aggressive devices is possible as their behavior is very different from the other devices in the network. What the network really needs is to apply dynamic restriction over these devices to prevent them from overloading the control plane of the network. This restriction should be smart enough to still allow benign devices to register to the network without interruption. Having smart security control at the RAN can stop such attack and without overloading deeper parts of the network in the core.

The goal of this use case is utilize O-RAN to detect and mitigate signaling storms DDoS quick and as close to the network edge, thus minimizing affected network nodes. The near-RT RIC would detect these signaling storms by analyzing signaling events from RAN nodes it controls. When such a storm is detected the near-RT RIC creates fine grained filters, which cover the aggressive UEs that cause the storm. These UEs registration requests will then be blocked/throttled while the behaving UEs will continue to get service as usual. In some cases the attack may be spread across many locations. It could be that the volume of signaling per location has not crossed a critical threshold but the moderate increase in many locations do cause an overload of central nodes such as the network core elements. In this case a network-wide view is required; thus the non-RT performs the network-wide analysis and in the case of a network signaling storm, it pushes policies to the local near-RT RIC to adjust detection parameters to reduce the moderate increase of signaling from a set of one or more E2 Nodes. This combined view of both non-RT RIC and near-RT RIC ensures quick reaction to local signaling storms as well as response to widely distributed attacks.

While flows in this use case focus on the signaling storm scenario, they could be easily extend to include other attack scenarios both in terms of detection and mitigation. For example, the scenario where rogue devices report false CQI measurements that indicate high values while the real channel quality is poor. When exploited by attackers and applied to large set of devices this attack can cause to waste of radio resources and eventually to DoS. Detection of the attack may be achieved by analyzing anomalous CQI reports or abnormal volume of NACK messages based on signaling messages. For mitigation actions either rejecting the rogue devices or limiting radio resources can be applied.

3.15.2 Entities/resources involved in the use case

1) Non-RT RIC in SMO domain:
   a) Maintains overall view of network wide phenomenon of signaling storms using Signaling Storm Detection rApp. The detection of distributed signaling storms that spread over many geographical locations and are more difficult to be observed locally. This overall view is broken down by location and corresponding policies are pushed to specific instances of near-RT RIC to respond to abnormal signaling activity in affected geographical areas, over the A1 interface.
   b) Uses enrichment data from non-RAN source (i.e. 5G core or probing framework) to maintain global view and support more accurate detection and classification of attacks.
   c) Utilizes AI/ML models in the Signaling Storm Detection rApp that monitor network-level signaling behavior to support signaling anomalies detection.
2) Near-RT RIC in RAN domain:
   a) Monitors E2 interface for connection establishment messages and identifies abnormal levels of signaling activity using the Signaling Storm Detection xApp.
   b) Signaling Storm Mitigation xApp utilizes policies over E2 to enforce appropriate mitigation action (e.g. reject, throttle, alert) over misbehaving UEs connection establishment.
   c) Signaling Storm Detection xApp utilizes AI/ML models that monitor cell-level signaling behavior to support signaling anomalies detection.

d) Applies appropriate detection policy based on policies received from non-RT RIC (e.g. false-positive levels, UE thresholds, throttling ratios).

3) E2 Nodes in RAN domain:

a) Support sending connection establishment messages over the E2 interface.

b) Support control and policy enforcement from near-RT RIC over E2 interface

3.15.3 Solutions

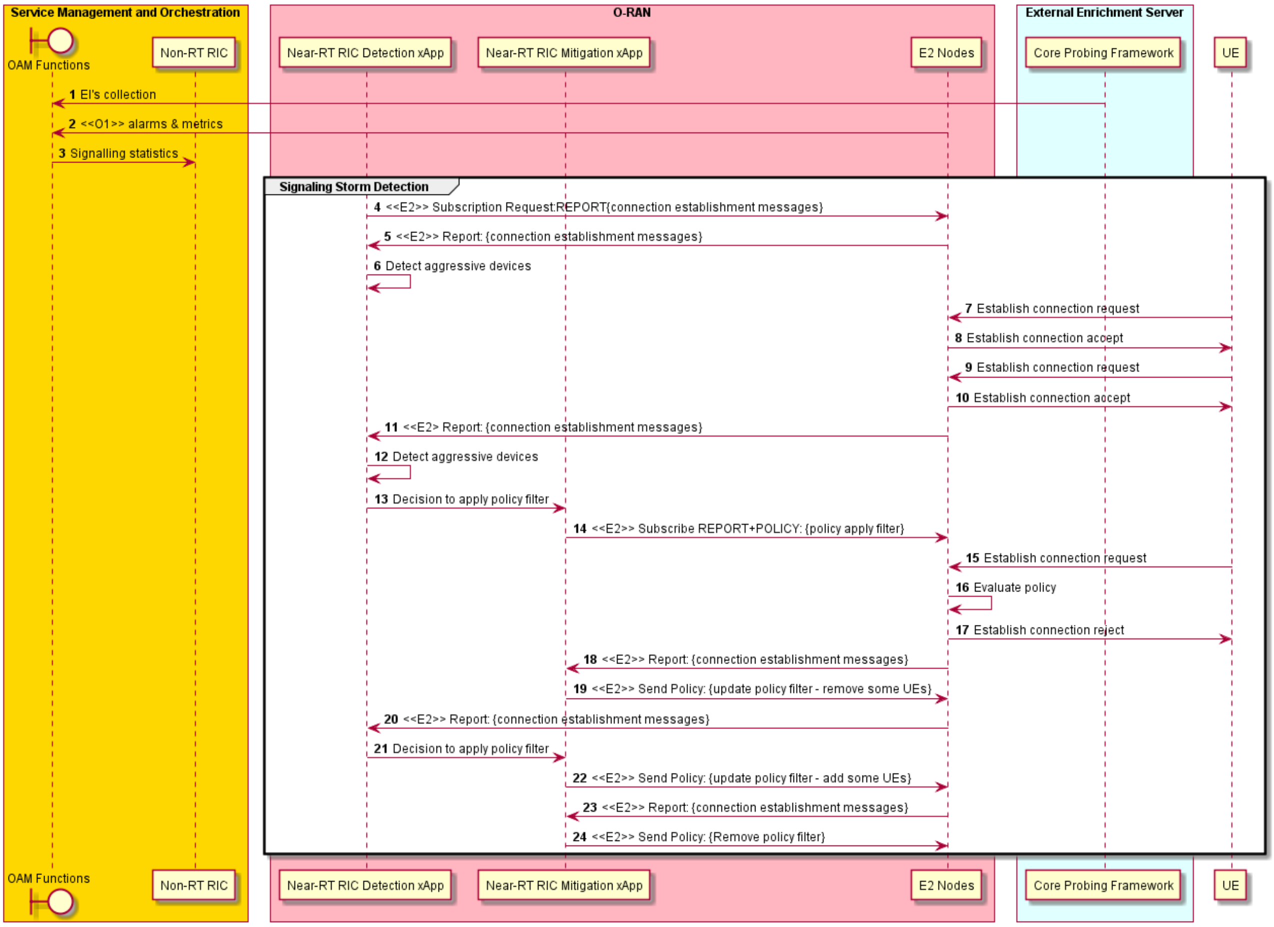
3.15.3.1 Mode 1 – Local Signaling Storm Protection Policy

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Detect localized signaling storms based on “default parameters” and apply policy to mitigate the attack.	
Actors and Roles	Near-RT RIC: detection of local cell-level signaling storms; execution of mitigation policies and controls, maintenance of cell-level normal behavior models E2 Nodes: execute mitigation policies, collects and reports RAN signaling events and policy specific statistics over E2	
Assumptions	All relevant functions and components are instantiated. Signaling Storms Detection and Signaling Storm Mitigation xApps are deployed over E2 with initial configuration E2 interface connectivity is established with non-RT RIC and RAN respectively. Data report, policy and control subscription established on E2 interface	
Pre conditions	Network is operational. SMO has established the data collection and sharing interface with non-RT RIC. Near-RT RIC already established relevant detection mechanisms of normal signaling behavior and adjusted detection parameters accordingly. Non RT-RIC analyzes the historical data from RAN, develops, trains with help of SMO functions and deploys the models or algorithm as part of the Signaling Storm Detection xApp to the near-RT RIC	
Begins when	Network is in normal state (attack is described later on)	
Step 1 (M)	Signaling Storm Detection xApp subscribes on connection establishment signaling messages report from the RAN over the E2 interface.	
Step 2 (M)	E2 Node sends report to Signaling Storm Detection xApp.	
Step 3 (M)	Near-RT RIC Signaling Storm Detection xApp monitors reports to detect aggressive UEs that act with abnormal signaling	
Steps 4-7 (M)	UEs send establish connection messages and E2 Node accepts these requests	
Step 8 (M)	E2 Node sends a connection establishment reports	
Step 9 (M)	Signaling Storm Detection xApp detects aggressive activity	
Step 10 (M)	Signaling Storm Detection xApp updates Signaling Storm Mitigation xApp.	
Step 11 (M)	Near-RT RIC Signaling Storm Mitigation xApp creates a filter to block/throttle signaling messages from the aggressive UEs. Filter is applied in the E2 Nodes as POLICY + REPORT to track filter activity. Near-RT RIC should notify the Non-RT RIC to avoid conflicts.	
Step 12 (M)	Aggressive UE sends connection establishment message	
Step 13 (M)	E2 Node evaluate policy with respect to the connection establishment message	
Step 14 (M)	E2 Node rejects/throttles connection establishment request	
Step 15 (M)	Near-RT RIC Signaling Storm Mitigation xApp receives relevant signaling messages that the POLICY filter blocked/ throttled to track changes in attack status and aggressive devices (list of UEs blocked, blocked signaling volume, trend)	
Step 16 (M)	Near-RT RIC Signaling Storm Mitigation xApp is finds that some devices are no longer aggressive or no longer present. It decides to update filter by updating the E2 Node POLICY.	

Step 17-19 (M)	Near-RT RIC Signaling Storm Detection xApp detects a new set of aggressive devices and updates the Signaling Storm Mitigation xApp, which updates the filter by updating the E2 Node POLICY.	
Step 20-21 (M)	Near-RT RIC Signaling Storm Mitigation xApp evaluates signaling level and decides that there is no more aggressive UE activity. The xApp removes the E2 Node policy.	
Ends when	Attack is over and signaling messages level is back to normal.	
Exceptions	None identified	
Post Conditions	Return to normal signaling activity monitoring (Step 1)	

1 **Table 3.15.3-1: Local Signaling Storm Protection Policy**

2



3

4 **Figure 3.15.3-1: Local Signaling Storm Protection Policy flow diagram**

5 ## 3.15.3.2 Mode 1 – Local Signaling Storm Protection Insert-Control (Optional)

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Detect localized signaling storms based on “default parameters” and apply control to mitigate the attack.	
Actors and Roles	Near-RT RIC: detection of local cell-level signaling storms; execution of mitigation policies and controls, maintenance of cell-level normal behavior models E2 Nodes: execute UE level mitigation policies, collects and reports RAN signaling events and policy specific statistics over E2	

Assumptions	All relevant functions and components are instantiated. Signaling Storms Detection and Signaling Storm Mitigation xApps are deployed over E2 with initial configuration E2 interface connectivity is established with non-RT RIC and RAN respectively. Data report, policy and control subscription established on E2 interface	
Pre conditions	Network is operational. SMO has established the data collection and sharing interface with non-RT RIC. Near-RT RIC already established relevant detection mechanisms of normal signaling behavior and adjusted detection parameters accordingly. Non RT-RIC analyzes the historical data from RAN, develops, trains with help of SMO functions and deploys the models or algorithm as part of the Signaling Storm Detection xApp to the near-RT RIC	
Begins when	Network is in normal state (attack is described later on)	
Step 1 (M)	Signaling Storm Detection xApp subscribes on connection establishment signaling messages report from the RAN over the E2 interface.	
Step 2 (M)	E2 Node sends report to Signaling Storm Detection xApp.	
Step 3 (M)	Near-RT RIC Signaling Storm Detection xApp monitors reports to detect aggressive UEs that act with abnormal signaling	
Steps 4-7 (M)	UEs send establish connection messages and E2 Node accepts these requests	
Step 8 (M)	E2 Node sends a report indicating aggressive devices behavior	
Step 9 (M)	Signaling Storm Detection xApp detects aggressive activity	
Step 10 (M)	Signaling Storm Detection xApp updates Signaling Storm Mitigation xApp.	
Step 11 (M)	Signaling Storm Mitigation xApp updates subscription to INSERT-CONTROL. Use control filter to block/throttle aggressive UEs by rejecting some of the messages.	
Step 12 (M)	E2 Node receives another connection establishment from an aggressive UE.	
Step 13 (M)	E2 Node forwards the message to the Signaling Storm Mitigation xApp	
Step 14 (M)	Signaling Storm Mitigation xApp determines that message is from an aggressive device	
Step 15 (M)	Signaling Storm Mitigation xApp sends a reject/throttle message to the E2 Node.	
Step 16 (M)	E2 Node rejects/throttles connection establishment request	
Step 17 (M)	Signaling Storm Mitigation xApp continues to monitor its control filter	
Step 18 (M)	Near-RT RIC DDoS Mitigation xApp evaluates signaling level and decides that there is no more aggressive UE activity. The xApp updates subscription back to REPORT.	
Ends when	Attack is over and signaling messages level is back to normal.	
Exceptions	None identified	

Table 3.15.3-2: Local Signaling Storm Protection Insert-Control

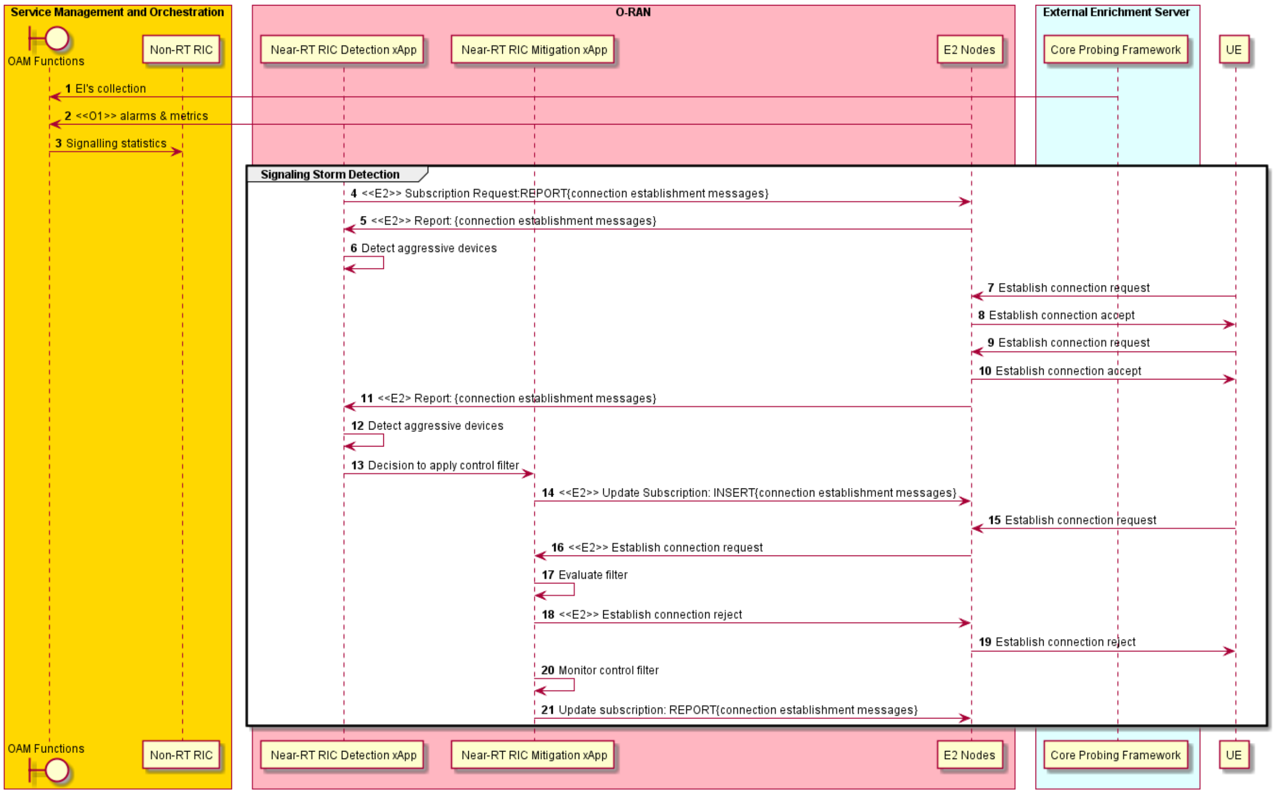


Figure 3.15.3-2: Local Signaling Storm Protection Insert-Control flow diagram

3.15.3.3 Mode 2 – Distributed Signaling Storm Protection

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal	Detect distributed signaling using Non-RT RIC and A1 policy initiates Mode 2 handling in Near-RT RIC with "stricter parameters" mitigation.	
Actors and Roles	Non-RT RIC: detection of network-level distributed signaling storms, maintenance of cell-level, network slice level and node level normal behavior models. Near-RT RIC: detection of local cell-level signaling storms; execution of mitigation policies and controls, maintenance of cell-level normal behavior models RAN: executes UE level or network slice level mitigation policies, collects and reports RAN signaling events and policy specific statistics over E2	
Assumptions	All relevant functions and components are instantiated. Signaling Storms Detection and Signaling Storms Mitigation xApps are deployed over E2 with initial configuration A1, E2 interface connectivity is established with non-RT RIC and RAN respectively. Data report, policy and control subscription established on E2 interface	
Pre conditions	Network is operational. SMO has established the data collection and sharing interface with non-RT RIC. Non-RT RIC and near-RT RIC already established relevant detection mechanisms of normal signaling behavior and adjusted detection parameters accordingly. Non-RT RIC analyzes the historical data from RAN, develops, trains with help of SMO functions and deploys the models or algorithm as xApps to the near-RT RIC	
Begins when	Network is in normal state when (attack is described later on)	
Step 1 (M)	OAM Functions start to collect enrichment information (EIs) from external sources (e.g. network core probing framework).	
Step 2 (M)	OAM Functions start to collect alarms & metrics from E2 Nodes.	

Step 3 (M)	OAM Functions sends signaling statistics based on collected information to Non-RT RIC.	
Step 4 (M)	Non-RT RIC uses AI/ML model to analyze overall network signaling activity levels based on signaling statistics.	
Step 5 (M)	Non-RT RIC applies initial configurations to all near-RT RIC elements regarding detection and mitigation parameters, including: accepted signaling volume thresholds, throttle/block ratio, accepted false negative levels, filter pause periods, etc.	
Step 6 (M)	Non-RT RIC detects distributed signaling storm activity originated from a list of locations.	
Step 7 (M)	Non-RT RIC updates configuration to a stricter one in the relevant near-RT RIC locations over A1 interface..	
Step 8 (M)	Near-RT RIC performs detection and mitigation as described in 3.15.3.1 or 3.15.3.2 with stricter configuration (e.g. lower thresholds).	
Step 9 (M)	Non-RT RIC determines that distributed signaling storm attack is over based on signaling statistics information.	
Step 10 (M)	Non-RT RIC updates Near-RT RICs back to initial configuration parameters over the A1 interface.	
Step 11 (M)	Near-RT RIC Signaling Storm Detection xApp observed aggressive behavior where temporal identifiers cannot be correlated with the underlying devices.	
Step 12 (M)	Near RT RIC alarms the OAM Functions over O1.	
Step 13 (M)	OAM Functions report suspicious behavior to Non-RT RIC.	
Step 14 (M)	Non-RT RIC sends Enrichment Information to near-RT RIC over A1-EI to support detection of aggressive devices.	
Step 15 (M)	Near-RT RIC performs detection and mitigation as described in 3.15.3.1 or 3.15.3.2 with stricter configuration (e.g. lower thresholds).	
Step 16 (M)	Non-RT RIC evaluates data and decides that there is no more distributed signaling storm activity.	
Step 17 (M)	Non-RT updates configuration of relevant near-RT RICs over the A1 back to normal.	
Ends when	Attack is over and signaling messages level is back to normal.	
Exceptions	None identified	
Post Conditions	Non-RT RIC monitors network-level signaling messages statistics Near-RT RIC monitors cell-level signaling messages statistics	

Table 3.15.3-1: Distributed Signaling Storm Protection

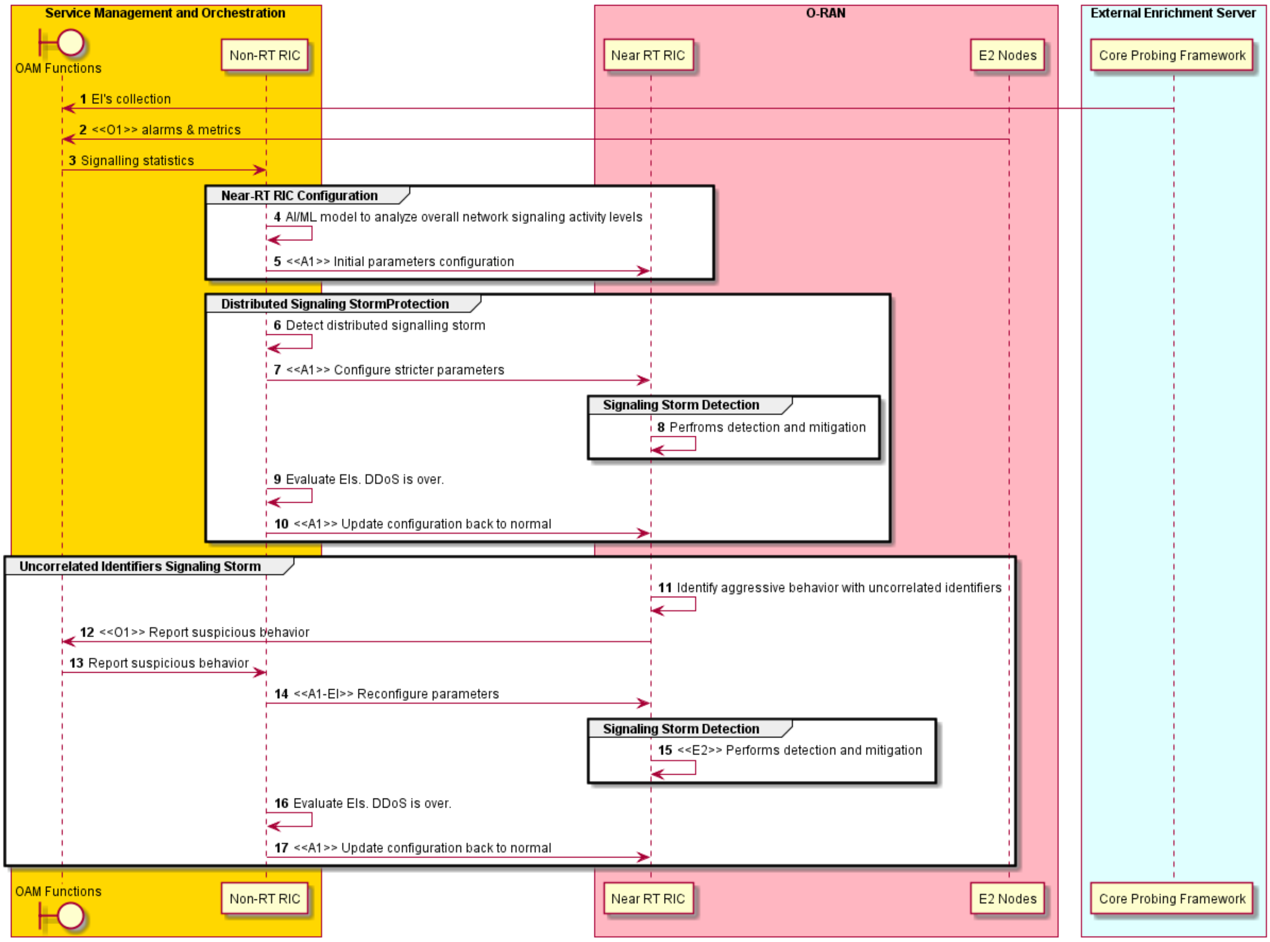


Figure 3.15.3-1: Distributed Signaling Storm Protection flow diagram

3.15.4 Required data

The measurement counters, Detection within the near-RT RIC is based upon analyzing per UE connection establishment messages events that include the following data:

1) Basic registration event parameters: timestamp, cell ID, temporary ID (e.g. C-RNTI, 5G-GUTI)
2) RAN parameters to correlate between a UE and registration events: e.g. RSRP/RSRQ, Timing Advance, Beam ID

Tracking status of ongoing attack by monitoring statistics of active filters that include the following data:

3) Number of UEs in the filter, number of requests blocked, trend (change over last x periods of time).

Enrichment information from a non-RAN source regarding network-wide DDoS information:

4) Overloaded regions, overloaded sites, severity (% above normal)

3.16 Use case 16: Congestion Prediction and Management

FFS

3.17 Use case 17: Industrial IoT Optimization

FFS

3.18 Use case 18: BBU Pooling to achieve RAN Elasticity

FFS

Annex A (informative): Additional Information

A.1 Traffic Steering use case A1 interface usage example

Note: Please refer to WG2 Use Cases and Requirements Specification for more details and up to date definitions of this use case A1 interface usage examples.

An example scenario is here used to describe the use of A1 for traffic steering, implying the Non-RT RIC sending policies for allocation of the control plane (RRC) and the user plane for different services, identified by their 5QI.

In the scenario a UE with UEid=1, belonging to a subnet slice identified by S-NSSAI=1, having a Voice (5QI=1) and an MBB (5QI=9) connection established, enters an area covered by four frequency bands. The Non-RT RIC understands the requirements and characteristics of the services and decides to let the Voice and RRC connection reside on the low band (here covered by a macro cell B becoming the PCell), while the MBB connection should preferably use the higher band (here provided by a smaller cell C and D becoming the SCells) and avoid the low band if possible. Cell A is used for MBB if required for coverage reasons.

Policies are sent to any cell of concern, e.g. where the UE resides and may move.

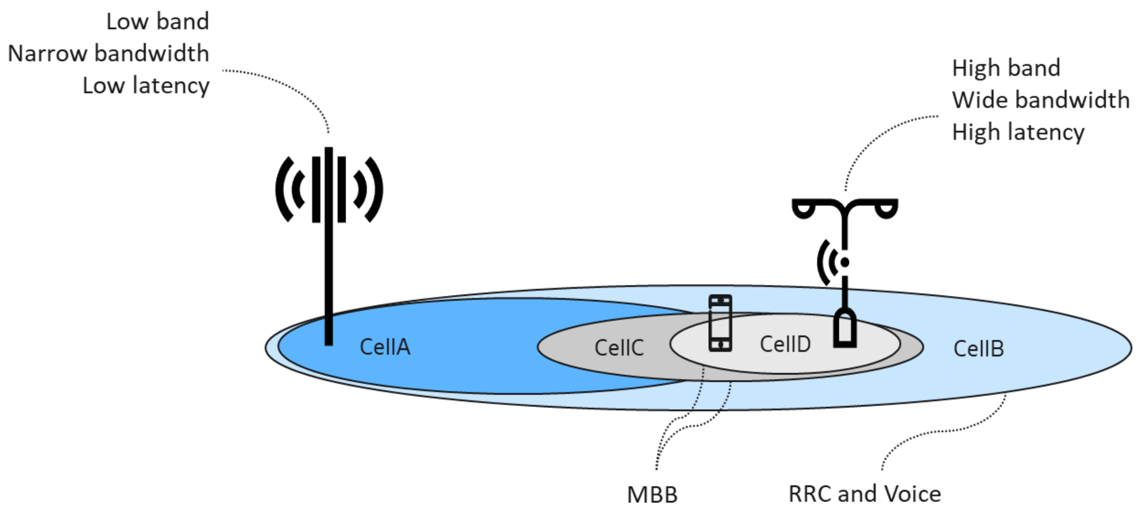


Figure A.1-1 Desired use of the cells

Two policies over A1 are needed to accomplish the desired behavior, described in JSON format below. Note that as part of the scope, the cell_id is optional, and if omitted it is up to the Near-RT RIC to locate the UE and there enforce the policy.

```
{
    "policy_id": "1",
    "scope": {
      "ue_id": "1",
      "slice_id": "1",
      "qos_id": "1",
      “cell_id”: ”X” // Policy for Cell X, where X is one of A, B, C or D
    },
    "statement": {
      "cell_id_list": "B",
      "preference": "Shall",
      "primary": true   // Control plane on Cell B (becoming PCell)
```

```
    },
    "statement": {
      "cell_id_list ": "B",
      "preference": "Shall",
      "primary": false  // Voice on Cell B
    }
}
```

```
{
    "policy_id": "2",
    "scope": {
      "ue_id": "1",
      "slice_id": "1",
      "qos_id": "9",
      “cell_id”: ”X” // Policy for Cell X, where X is one of A, B, C or D
    },
    "statement": {
      "cell_id_list ": {"B", “A”},
      "preference": "Avoid",
      "primary": false  // Avoid MBB on Cell A and Cell B
    },
    "statement": {
      "cell_id_list": {“C”, “D”},
      "preference": "Prefer",
      "primary": false  // Prefer MBB on Cell C and Cell D
    }
}
```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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.

