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Foreword

This Technical Specification (TS) has been produced by O-RAN Alliance and approved by ETSI Technical Committee Mobiles Standards Group (MSG).

The content of the present document is subject to continuing work within O-RAN and may change following formal O-RAN approval. Should the O-RAN ALLIANCE modify the contents of the present document, it will be re-released by O-RAN with an identifying change of version date and an increase in version number as follows:

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where:

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In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document:

- specifies: the overall architecture of O-RAN.
- describes: the O-RAN architecture elements and relevant interfaces that connect them.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

[1] ETSI TS 123 501: "5G; System architecture for the 5G System (5GS) (3GPP TS 23.501)".

[2] ETSI TS 128 622: "Universal Mobile Telecommunications System (UMTS); LTE; 5G; Telecommunication management; Generic Network Resource Model (NRM) Integration Reference Point (IRP); Information Service (IS) (3GPP TS 28.622)".

[3] ETSI TS 132 101: "Digital cellular telecommunications system (Phase 2+) (GSM); Universal Mobile Telecommunications System (UMTS); LTE; Telecommunication management; Principles and high level requirements (3GPP TS 32.101)".

[4] ETSI TS 136 401: "LTE ; Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Architecture description (3GPP TS 36.401)".

[5] ETSI TS 136 420: "LTE; Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 general aspects and principles (3GPP TS 36.420)".

[6] ETSI TS 136 423: "LTE; Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 Application Protocol (X2AP) (3GPP TS 36.423)".

[7] ETSI TS 138 300: "5G; NR; NR and NG-RAN Overall description; Stage-2 (3GPP TS 38.300)".

[8] ETSI TS 138 331: "5G; NR; Radio Resource Control (RRC); Protocol specification (3GPP TS 38.331)".

[9] ETSI TS 138 401: "5G; NG-RAN; Architecture description (3GPP TS 38.401)".

[10] ETSI TS 138 413: "5G; NG-RAN; NG Application Protocol (NGAP) (3GPP TS 38.413)".

[11] ETSI TS 138 420: "5G; NG-RAN; Xn general aspects and principles (3GPP TS 38.420)".

[12] ETSI TS 138 423: "5G; NG-RAN; Xn Application Protocol (XnAP) (3GPP TS 38.423)".

[13] ETSI TS 138 460: "5G; NG-RAN; E1 general aspects and principles (3GPP TS 38.460)".

[14] ETSI TS 138 463: "5G; NG-RAN; E1 Application Protocol (E1AP) (3GPP TS 38.463)".

[15] ETSI TS 138 470: "5G; NG-RAN; F1 general aspects and principles (3GPP TS 38.470)".

[16] ETSI TS 138 473: "5G; NG-RAN; F1 Application Protocol (F1AP) (3GPP TS 38.473)".

[17] O-RAN TR: "Cloud Architecture and Deployment Scenarios for O-RAN Virtualized RAN".

[18] O-RAN TS: "A1 interface: General Aspects and Principles".

[19] O-RAN TS: "Control, User and Synchronization Plane Specification".

[20] O-RAN TS: "Cooperative Transport Interface; Transport Control Plane Specification".

[21] O-RAN TS: "Cooperative Transport Interface; Transport Management Plane Specification".

[22] O-RAN TS: "E2 General Aspects and Principles (E2GAP)".

[23] O-RAN TS: "Hardware Reference Design Specification for Indoor Picocell (FR1) with Split Architecture Option 8".

[24] O-RAN TS: "Management Plane Specification".

[25] O-RAN TS: "Non-RT RIC Architecture".

[26] O-RAN TS: "Near-Real-time RAN Intelligent Controller E2 Service Model (E2SM).

[27] O-RAN TS: "O-Cloud Notification API Specification for Event Consumers".

[28] O-RAN TS: "Operations and Maintenance Architecture".

[29] O-RAN TS: "O-RAN Information Model and Data Models Specification".

[30] O-RAN TS: "O-RAN Operations and Maintenance Interface Specification".

[31] O-RAN TS: "Security Protocols Specifications".

[32] O-RAN TS: "Security Requirements and Controls Specifications".

[33] O-RAN TS: "Security Threat Modeling and Remediation Analysis".

[34] O-RAN TS: "Use Cases Analysis Report".

[35] O-RAN TS: "Use Cases Detailed Specification".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] 3GPP TR 38.801: "Study on new radio access technology: Radio access architecture and interfaces (Release 14)".

[i.2] ETSI TR 121 905: "Digital cellular telecommunications system (Phase 2+) (GSM); Universal Mobile Telecommunications System (UMTS); LTE; 5G; Vocabulary for 3GPP Specifications (3GPP TR 21.905)".

[i.3] NIST SP 800-207 Rose, S., Borchert, O., Mitchell, S., and Connelly, S.: "Zero-Trust Architecture", U.S. NIST, August 2020.

[i.4] O-RAN White Paper: "O-RAN: Towards an Open and Smart RAN", October 2018.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in ETSI TR 121 905 [i.2] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in ETSI TR 121 905 [i.2].

E2 Node: logical node terminating E2 interface

Managed Application: The definition of Managed Application is given in O-RAN Operations and Maintenance Architecture [28].

Managed Element: The definition of a Managed Element (ME) is given in ETSI TS 128 622 [2], Clause 4.3.3.

Managed Function: The definition of a Managed Function (MF) is given in ETSI TS 128 622 [2], Clause 4.3.4.

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. It may include AI/ML (Artificial Intelligence / Machine Learning) workflow including model training, inference and updates.

NOTE: Refer to [22] for more information.

Non-RT RIC (O-RAN Non-Real-Time RAN Intelligent Controller): A logical function within SMO that drives the content carried across the A1 interface. It is comprised of the Non-RT RIC Framework and the Non-RT RIC Applications (rApps) whose functions are defined below.

NOTE: Refer to [18] for more information.

Non-RT RIC Applications (rApps): Modular applications that leverage the functionality exposed via the Non-RT RIC Framework's R1 interface to provide added value services relative to RAN operation, such as driving the A1 interface, recommending values and actions that may be subsequently applied over the O1/O2 interface and generating "enrichment information" for the use of other rApps. The rApp functionality within the Non-RT RIC enables non-real-time control and optimization of RAN elements and resources and policy-based guidance to the applications/features in Near-RT RIC.

NOTE: Refer to [25] for more information.

Non-RT RIC Framework: That functionality internal to the SMO that logically terminates the A1 interface to the Near-RT RIC and exposes to rApps, via its R1 interface, the set of internal SMO services needed for their runtime processing. The Non-RT RIC Framework functionality within the Non-RT RIC provides AI/ML workflow including model training, inference and updates needed for rApps.

NOTE: Refer to [25] for more information.

NMS: Network Management System for the O-RU as specified in O-RAN "Management Plane Specification" [24] to support legacy Open Fronthaul M-Plane deployments (prior to version 5 of O-RAN "Management Plane Specification" [24])

O1: interface between SMO framework as specified in Clause 6.3.1 and O-RAN managed elements, for operation and management, by which FCAPS management, PNF (Physical Network Function) software management, File management shall be achieved

O2: interface between SMO framework as specified in Clause 6.3.1 and the O-Cloud for supporting O-RAN virtual network functions

NOTE: Refer to [17] for more information.

O-Cloud: cloud computing platform comprising a collection of physical infrastructure nodes that meet O-RAN requirements to host the relevant O-RAN functions (such as Near-RT RIC, O-CU-CP, O-CU-UP, and O-DU), the supporting software components (such as Operating System, Virtual Machine Monitor, Container Runtime, etc.) and the appropriate management and orchestration functions

NOTE: Refer to [17] for more information.

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

NOTE: Refer to Clause 6.3.3 for more information.

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

NOTE: Refer to Clause 6.3.4 for more information.

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

NOTE: Refer to Clause 6.3.5 for more information.

O-eNB: eNB ETSI TS 136 401 [4] or ng-eNB ETSI TS 138 300 [7] that supports E2 interface

NOTE: Refer to Clause 6.3.7 for more information.

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). Refer to Clause 6.3.6 for more information.

Open FH M-Plane: management interface controlling the O-RU, generally driven from the O-DU but in the case of the hybrid topology also driven from the SMO

NOTE: Refer to [24] for more details.

SMO: Service Management and Orchestration system as described in Clause 6.3.1.

xApp: An application designed to run on the near-RT RIC. Such an application is likely to consist of one or more microservices and at the point of on-boarding will identify which data it consumes and which data it provides. The application is independent of the near-RT RIC and may be provided by any third party. The E2 enables a direct association between the xApp and the RAN functionality [22].

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in ETSI TR 121 905 [i.2] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in ETSI TR 121 905 [i.2].

4G	4th Generation of mobile communications
5G	5th Generation of mobile communications
3GPP	3rd Generation Partnership Project
5GC	5G Core
5GS	5G System
AAL	Accelerator Abstraction Layer
AF	Application Function
API	Application Programming Interface
AI	Artificial Intelligence
AMF	Access and Mobility Functions
C-RNTI	Cell Radio Network Temporary Identifier

CM	Configuration Management
CMTS	Cable Modem Termination System
CP	Control Plane
CSP	Communications Service Provider
CTI	Cooperative Transport Interface
CUS	Control User Synchronization
DC	Dual connectivity
DOCSIS	Data Over Cable Service Interface Specification
DM	Data Model
DTLS	Datagram Transport Layer Security
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EN-DC	E-UTRAN New Radio - Dual Connectivity
EPC	Evolved Packet Core
eNB	evolved Node B
FCAPS	Fault, Configuration, Accounting, Performance, Security
FFT	Fast Fourier Transform
FHGW	Fronthaul Gateway
FHM	Fronthaul Multiplexer
FM	Fault Management
gNB	next generation Node B
gNB-CU	gNB Central Unit
gNB-DU	gNB Distributed Unit
GUAMI	Globally Unique AMF Identifier
GUMMEI	Globally Unique MME Identifier
HARQ	Hybrid Automatic Repeat Request
ID	Identifier
iFFT	inverse Fast Fourier Transform
IM	Information Model
IPSec	Internet Protocol Security
LLS	Lower Layer Split
LTE	Long Term Evolution
MAC	Media Access Control
ME	Managed Element
MeNB	Master eNB
MF	Managed Function
ML	Machine Learning
MME	Mobility Management Entity
Near-RT RIC	Near-Real-Time RAN Intelligent Controller
NETCONF	NETwork CONFiguration Protocol
NG	Next Generation
NG-RAN	Next Generation RAN
NGAP	Next Generation Application Protocol
NIST	National Institute of Standards and Technology
NMS	Network Management System
Non-RT RIC	Non-Real-Time RAN Intelligent Controller
NR	5G New Radio
O-Cloud	O-RAN Cloud
O-CU-CP	O-RAN Central Unit - Control Plane.
O-CU-UP	O-RAN Central Unit - User Plane
O-DU	O-RAN Distributed Unit
O-eNB	O-RAN eNB
O-RAN	Open RAN
O-RU	O-RAN Radio Unit
OAM	Operations, Administration and Maintenance
OLT	Optical Line Terminal
ONU	Optical Network Unit
Open FH	Open FrontHaul
PDCP	Packet Data Convergence Protocol
PHY	Physical layer
PKI	Public Key Infrastructure
PM	Performance Management

PNF	Physical Network Function
PON	Passive Optical Network
PRACH	Physical Random Access CHannel
PTP	Precision Time Protocol
RAN	Radio Access Network
rApp	Non-RT RIC Application
RAT	Radio Access Technology
RF	Radio Frequency
RIC	RAN Intelligent Controller
RLC	Radio Link Control
RRC	Radio Resource Control
RRH	Remote Radio Head
RRM	Radio Resource Management
RRU	Remote Radio Unit
RT	Real Time
RU	Radio Unit
SBA	Service Based Architecture
SBOM	Software Bill Of Materials
SDAP	Service Data Adaptation Protocol
SMO	Service Management and Orchestration
SRB	Signalling Radio Bearer
SSHv2	Secure SHell 2.0
TLS	Transport Layer Security
TN	Transport Node
TR	Technical Report
TRP	Transmission and Reception Point
TS	Technical Specification
TU	Transport Unit
UE	User Equipment
UL	Up Link
UP	User Plane
UPF	User Plane Function
VM	Virtual Machine
VNF	Virtualized Network Function
WG	Working Group
xApp	Near-RT RIC Application
X2AP	X2 Application Protocol
XnAP	Xn Application Protocol
ZTA	Zero Trust Architecture

4 O-RAN Overview

4.1 Scope and Objectives

O-RAN activities are guided by the following objectives [i.4]:

- Leading the industry towards open, interoperable interfaces, RAN virtualization, and big data and AI enabled RAN intelligence.
- Maximizing the use of common-off-the-shelf hardware and merchant silicon and minimizing proprietary hardware.
- Specifying APIs and interfaces, driving standards to adopt them as appropriate, and exploring open source where appropriate.
- The O-RAN Architecture identifies the key functions and interfaces adopted in O-RAN.

5 General O-RAN Architecture Principles

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

- The O-RAN architecture and interface specifications shall be consistent with 3GPP architecture and interface specifications to the extent possible.
- The present document shall represent the O-RAN architecture at the time of its publication and may evolve as deemed appropriate by the O-RAN community.

6 O-RAN Architecture

6.1 Overall Architecture of O-RAN

Figure 6.1-1 below provides a high-level view of the O-RAN architecture. It shows that the four key interfaces - namely, A1, O1, Open Fronthaul M-plane and O2 - connect SMO (Service Management and Orchestration) framework to O-RAN network functions and O-Cloud. As depicted in this figure, the O-Cloud includes the O-Cloud Notification interface [27] which is available for the relevant O-RAN network functions (e.g. Near-RT RIC, O-CU-CP, O-CU-UP and O-DU) to receive O-Cloud related notifications.

Figure 6.1-1 below also illustrates that the O-RAN network functions can be VNFs (Virtualized Network Function), i.e. VMs or Containers, sitting above the O-Cloud and/or PNFs (Physical Network Function) utilizing customized hardware. All O-RAN network functions, except O-RU, are expected to support the O1 interface when interfacing the SMO framework. The Open Fronthaul M-plane interface, between SMO and O-RU, is to support the O-RU management in hybrid mode, as specified in [24].

The Near-RT RIC in Figure 6.1-1 provides RAN analytics information services via Y1 interface. Y1 consumers can consume the RAN analytics information services by subscribing to or requesting the RAN analytics information via Y1 interface. Y1 consumers could be Application Functions (AFs) when they are in an O-RAN trusted domain. Or the RAN analytics information could be provided to AFs in a secure manner via an exposure function, e.g. as in ETSI TS 123 501 [1], Clause 5.20.

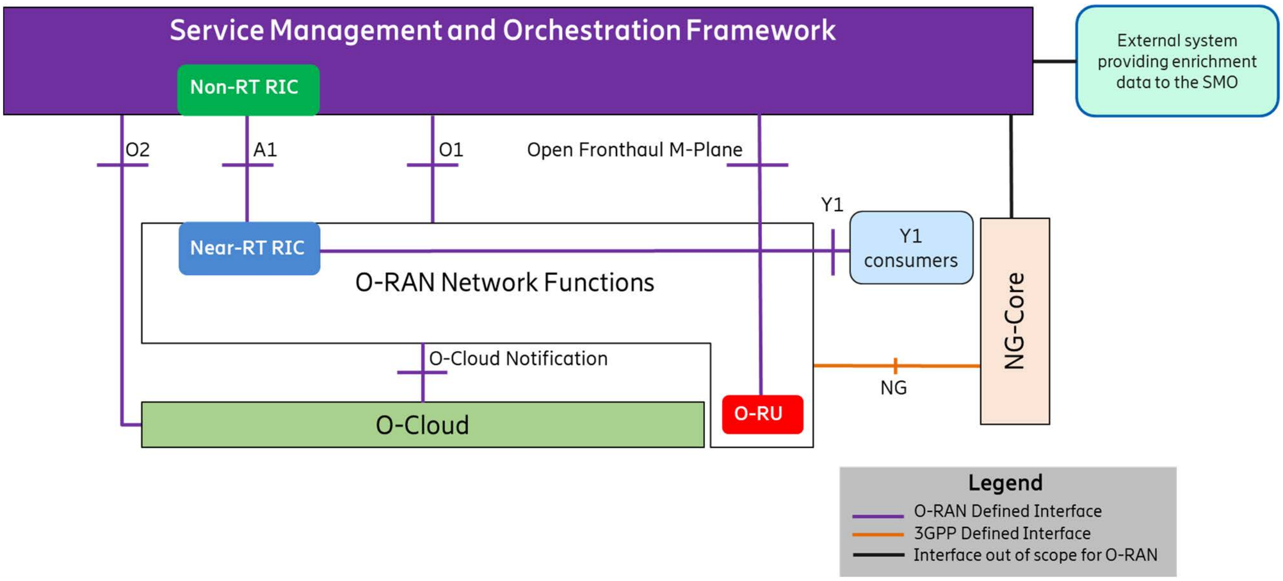


Figure 6.1-1: High Level Architecture of O-RAN

Within the logical architecture of O-RAN, as shown in Figure 6.1-2 below, the radio side includes Near-RT RIC, O-CU-CP, O-CU-UP, O-DU, and O-RU functions. The E2 interface connects O-eNB to Near-RT RIC. Although not shown in this figure, the O-eNB does support O-DU and O-RU functions with an Open Fronthaul interface between them. The Near-RT RIC, in Figure 6.1-2, supports Y1 interface towards Y1 consumers.

As stated earlier, the management side includes SMO Framework containing a Non-RT-RIC function. The O-Cloud, on the other hand, is a cloud computing platform comprising a collection of physical infrastructure nodes that meet O-RAN requirements to host the relevant O-RAN functions (such as Near-RT RIC, O-CU-CP, O-CU-UP and O-DU, etc.), the supporting software components (such as Operating System, Virtual Machine Monitor, Container Runtime, etc.) and the appropriate management and orchestration functions. The virtualization of O-RU is not supported in the present document.

As shown in Figure 6.1-2, the O-RU terminates the Open Fronthaul M-Plane interface towards the O-DU and SMO as specified in [24].

NOTE: The LLS (O-DU to O-RU interface) specified in Clauses 6.3.5 and 6.3.6 (Split Option 7-2x) is the Open Fronthaul interface described in the O-RAN Open Fronthaul Specification [19]. Other LLS options [i.1] may be considered for reference designs when the relevant interfaces are described in specifications created by related open industry initiatives (e.g. the Small Cell Forum for Split Option 6) or in O-RAN white-box hardware specifications (e.g. Split Option 8).

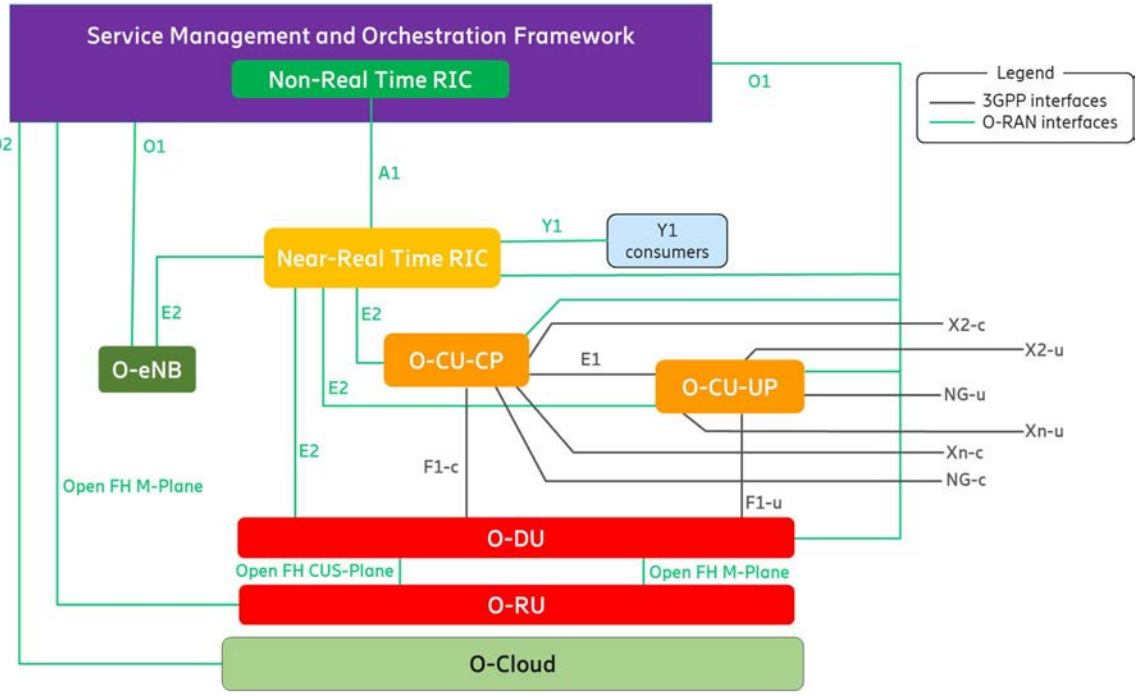


Figure 6.1-2: Logical Architecture of O-RAN

Figure 6.1-3 shows the Uu interface between UE and O-RAN components as well as between UE and O-eNB. As shown in Figure 6.1-3 below, the dotted box denotes all the O-RAN functions required to support the Uu interface for NR. The O-eNB, on the other hand, terminates the Uu interface for LTE. Refer to Clause 6.4.17 for more details.

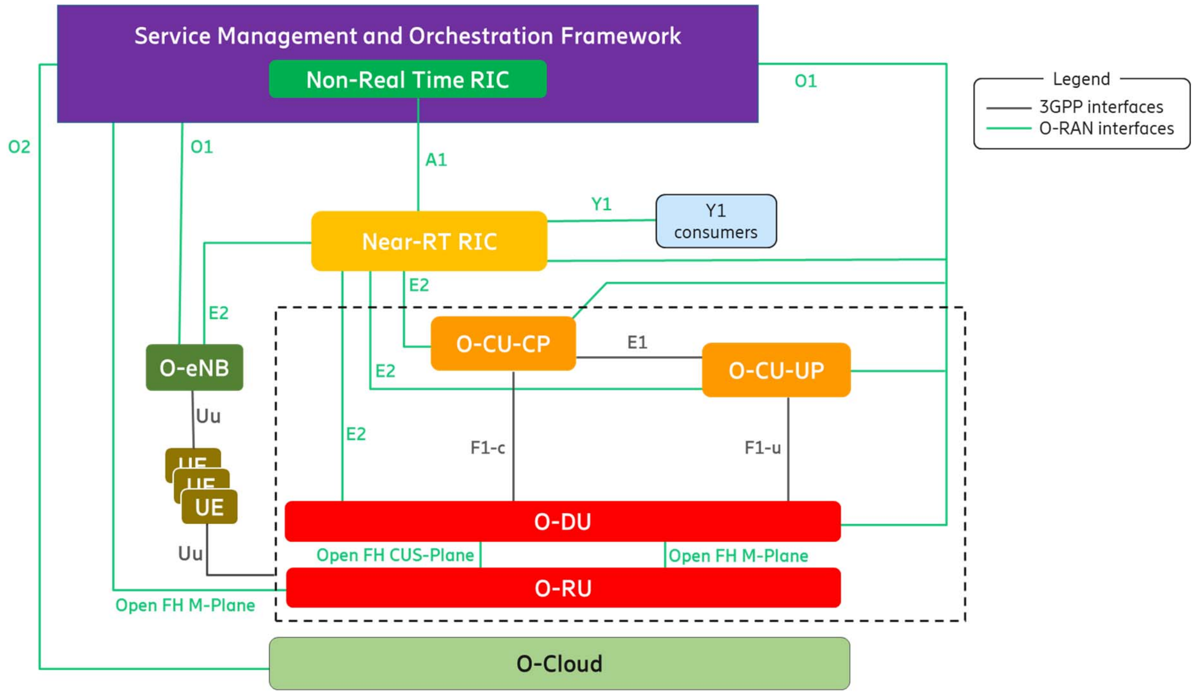


Figure 6.1-3: Uu interface for O-RAN components and O-eNB

6.2 O-RAN Control Loops

The O-RAN architecture supports at least the following control loops involving different O-RAN functions:

- Non-RT (Non-Real Time) control loops.
- Near-RT (Near-Real Time) control loops.
- RT (Real Time) control loops.

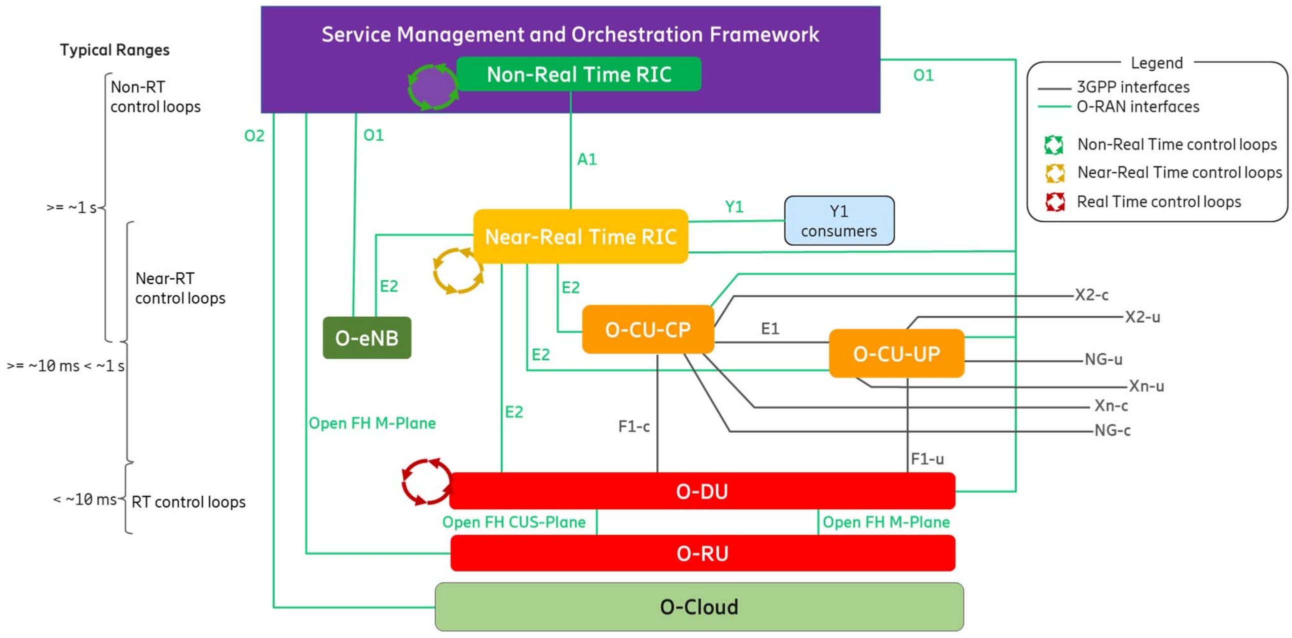


Figure 6.2-1: O-RAN Control Loops

As shown in Figure 6.2-1 above, the control loops are defined based on the controlling entity and the architecture shows the other logical nodes with which the control loop host interacts.

Control loops exist at various levels and run simultaneously. Depending on the use case, they may or may not interact with each other. The use cases for the Non-RT and Near-RT control loops and the interaction between the RICs for these use cases are fully defined by O-RAN Use Cases Analysis Report [34]. This report [34] also defines relevant interaction for the O-CU-CP and O-DU control loops, responsible for call control and mobility, radio scheduling, HARQ, beamforming, etc. along with slower mechanisms involving SMO management interfaces.
The timing of these control loops is use case dependent. Typical execution time for use cases involving the Non-RT control loops are 1 second or more; Near-RT control loops are in the order of 10 milliseconds or more; control loops in the E2 Nodes can operate below 10 milliseconds. (e.g. O-DU radio scheduling).

For any specific use case, however, a stable solution would require the loop time in the non-RT RIC and/or SMO management plane processes to be significantly longer than the loop time for the same use case in the control entities stated above.

6.3 Description of O-RAN Functions

6.3.1 Service Management and Orchestration (SMO)

6.3.1.1 SMO Architecture Principles

Service Based Architecture (SBA) introduces the roles of service producer and service consumer together with standardized service-based interfaces. These standardized service-based interfaces enable interoperability within the SMO. SBA is not concerned with the implementation, but it defines logical functions in their service producer and consumer roles. When properly applied the SBA approach can enable the following:

- Validates produced services with consumer use cases.
- Identifies service operations with their information model defining semantic behaviour.
- Specifies the API and a data model for a syntactic interface.
- Identifies common services that can be produced by a single producer such as those that are commonly used by multiple internal consumers (e.g. authentication, authorization, service registration and discovery, data management, etc.).

6.3.1.2 SMO Functionality

6.3.1.2.1 Introduction to SMO Functionality

This clause describes the functionality provided by the SMO in O-RAN. In a Service Provider's Network, there can be many management domains such as RAN management, Core Management, Transport Management, End to End Slice Management, etc. In the O-RAN architecture, SMO is responsible for RAN domain management. The SMO description in this architecture document is focused on the SMO services that support the RAN. The key capabilities of the SMO that provide RAN support in O-RAN are:

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

The SMO performs these services through four key interfaces to the O-RAN Elements:

- A1 Interface between the Non-RT RIC in the SMO and the Near-RT RIC for RAN Optimization.
- O1 Interface between the SMO and the O-RAN Network Functions for FCAPS support.
- In the hybrid model, Open Fronthaul M-plane interface between SMO and O-RU for FCAPS support.
- O2 Interface between the SMO and the O-Cloud to provide platform resources and workload management.

SMO does not define any formal interface towards the Non-RT RIC. An SMO deployment, therefore, may make its own design choice for creating a boundary towards the Non-RT RIC Framework, or choose not to implement a clear boundary at all.

The following definitions apply to the functionality of the SMO:

- Non-RT RIC Framework Anchored Functionality - This functionality is associated with the Non-RT RIC Framework itself. Examples include the A1 and R1 interfaces (see Clause 6.3.1.2.3).
- O-RAN SMO Framework Anchored Functionality - This functionality is not associated with the Non-RT RIC Framework. Examples include the O1, Open FH M-plane and O2 interfaces.
- Non-anchored Functionality - This functionality may or may not be associated with the Non-RT RIC Framework.

These terms and the relationships between the functions are illustrated in Figure 6-3-1 below. Extending the "Functions that enable rApps" outside the Non-RT RIC (i.e. into the SMO Framework), as shown in this figure, denotes that the R1 services being exposed may either come from the Non-RT RIC or the SMO.

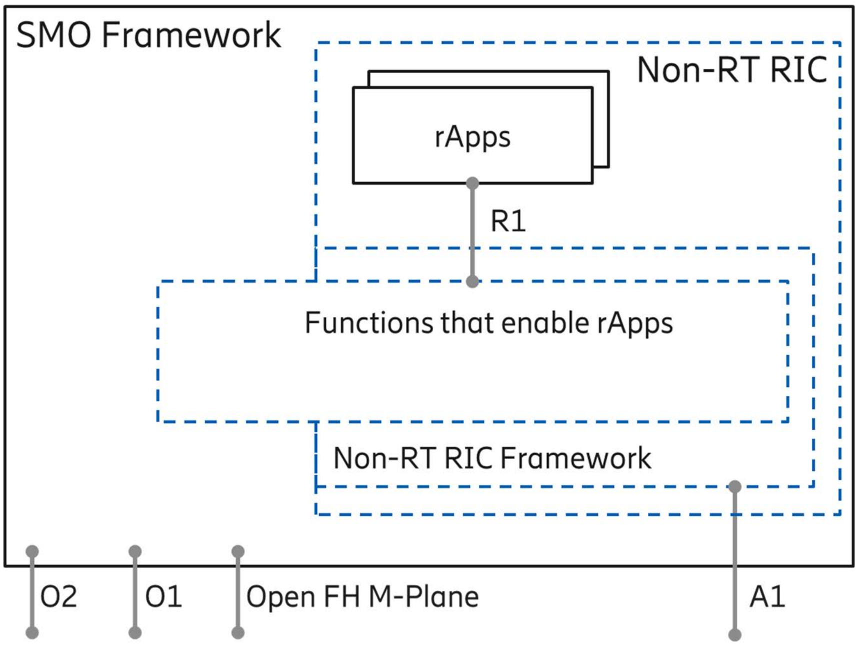


Figure 6-3-1: Exposure of SMO and Non-RT RIC Framework Services

Please refer to [25] for more details.

6.3.1.2.2 SMO support for FCAPS to O-RAN Network Functions

The SMO provides support for O-RAN network function FCAPS via the O1 Interface. The O1 Interface is defined in [30]. The O1 interface is aligned to the degree possible with the 3GPP specifications for RAN element management. In its role of supporting the FCAPs capabilities of O-RAN Network Functions, the SMO is providing support as described in ETSI TS 132 101 [3]. The following FCAPS functions defined in the O1 Specification are examples of the functionality across the O1 interface. See [30] for a fully defined list:

- Performance Management (PM).
- Configuration Management (CM).
- Fault Management (FM).
- File Management.
- Communications Surveillance (Heartbeat).
- Trace.

- Physical Network Function (PNF) Discovery.
- PNF Software Management.

The Open Fronthaul M-plane interface, as defined in [24], is specific for supporting FCAPS to the O-RU. The following FCAPS functions, as defined in [24], are examples of capabilities supported across this Open Fronthaul M-plane interface:

- "Start-up" installation.
- Software management.
- Configuration management.
- Performance management.
- Fault Management.
- File Management.

6.3.1.2.3 Non-RT RIC

Non-Real Time RAN Intelligent Controller (Non-RT RIC) is the functionality internal to the SMO in O-RAN architecture that provides the A1 interface to the Near-Real Time RIC.

The primary goal of Non-RT RIC is to support intelligent RAN optimization by providing policy-based guidance, ML model management and enrichment information to the near-RT RIC function so that the RAN can optimize, e.g. RRM under certain conditions [18]. It can also perform intelligent radio resource management function in non-real-time interval (i.e. greater than 1 second).

Non-RT RIC can use data analytics and AI/ML training/inference to determine the RAN optimization actions for which it can leverage SMO services such as data collection and provisioning services of the O-RAN nodes as well as the O1 and O2 interfaces.

The Non-RT RIC is comprised of two sub-functions:

- Non-RT RIC Framework - Functionality internal to the SMO Framework that logically terminates the A1 interface and exposes the required services to rApps through its R1 interface.
- Non-RT RIC Applications (rApps) - Modular applications that leverage the functionality exposed by the Non-RT RIC Framework to perform RAN optimization and other functions. Services exposed to rApps via the R1 interface enable rApps to obtain information and trigger actions (e.g. policies, re-configuration) through the A1, O1, O2 and Open FH M-Plane related services.

The Non-RT RIC Framework is responsible for exposing all required functionality to the rApps, whether from the Non-RT RIC Framework, or the SMO Framework.

For more information, refer to [25].

6.3.1.2.4 O-Cloud Management, Orchestration and Workflow Management

The SMO provides the capability of managing the O-Clouds as well as providing support for the orchestration of platform and application elements and workflow management. The SMO utilizes the O2 interface to the O-Cloud to provide these capabilities. The O2 interface supports the management of the cloud infrastructure and the use of the cloud resources allocated to the RAN. The O2 interface will be fully specified in the O2 interface specification by Working Group 6. The example functionalities should be supported but are not limited to the following:

- Discovery and administration of O-Cloud Resources.
- Scale-In, Scale-Out for O-Cloud.
- FCAPS (PM, CM, FM, Communication Surveillance) of O-Cloud.
- Software Management of Cloud Platform.

- Create, Delete Deployments and Associated Allocated O-Cloud Resources.
- Scale-In, Scale-Out Deployments and Allocated O-Cloud Resources.
- FCAPS (PM, FM) of Deployments and Allocated O-Cloud Resources.
- Software Management of Deployments.

6.3.2 Near-RT RIC

It is a logical function that enables near real-time control and optimization of E2 Nodes functions and resources via fine-grained data collection and actions over the E2 interface with control loops in the order of 10 ms-1s. The Near-RT RIC hosts one or more xApps that use E2 interface to collect near real-time information (e.g. on a UE basis or a Cell basis) and provide value added services. The Near-RT RIC control over the E2 Nodes is steered via the policies and the enrichment data provided via A1 from the Non-RT RIC. Based on the available data, the Near-RT RIC generates the RAN analytics information and exposes it via Y1 interface.

The RRM functional allocation between the Near-RT RIC and the E2 Node is subject to the capability of the E2 Node exposed over the E2 interface by means of the E2 Service Model [26] in order to support the use cases described in [35]. The E2 service model describes the functions in the E2 Node which may be controlled by the Near-RT RIC and the related procedures, thus defining a function-specific RRM split between the E2 Node and the Near-RT RIC. For a function exposed in the E2 Service Model [26], the near RT RIC may e.g. monitor, suspend/stop, override or control via policies the behaviour of E2 Node.

In the event of a Near-RT RIC failure, the E2 Node will be able to provide services but there may be an outage for certain value-added services that may only be provided using the Near-RT RIC.

6.3.3 O-CU-CP

The O-CU-CP terminates the NG-c, X2-c, Xn-c, F1-c and E1 interfaces as well as the RRC and PDCP (for SRB) protocols towards the UE as specified in ETSI TS 138 401 [9].

The O-CU-CP terminates E2 interface to Near-RT RIC as specified in [22].

The O-CU-CP terminates O1 interface towards the SMO as specified in [28].

The O-CU-CP terminates NG-c interface to 5GC as specified in ETSI TS 138 300 [7].

The O-CU-CP terminates X2-c interface to eNB or to en-gNB in EN-DC as specified in ETSI TS 136 420 [5] and ETSI TS 138 300 [7].

The O-CU-CP terminates Xn-c to gNB or ng-eNB as specified in ETSI TS 138 300 [7] and ETSI TS 138 420 [11].

6.3.4 O-CU-UP

The O-CU-UP terminates the NG-u, X2-u, S1-u, Xn-u, F1-u and E1 interfaces as well as the PDCP and SDAP protocols towards the UE as specified in ETSI TS 138 401 [9].

The O-CU-UP terminates E2 interface to Near-RT RIC as specified in [22].

The O-CU-UP terminates O1 interface towards the SMO as specified in [28].

The O-CU-UP terminates NG-u interface to 5GC as specified in ETSI TS 138 300 [7].

The O-CU-UP terminates X2-u interface to eNB or to en-gNB in EN-DC as specified in ETSI TS 136 420 [5] and ETSI TS 138 300 [7].

The O-CU-UP terminates Xn-u to gNB or ng-eNB as specified in ETSI TS 138 300 [7] and ETSI TS 138 420 [11].

6.3.5 O-DU

The O-DU terminates the E2 and the F1 interface (according to the principles described in Clause 6.4.9), and the Open Fronthaul interface (also known as LLS interface [19]) as well as the RLC, MAC and High-PHY functions of the radio interface towards the UE.

The O-DU terminates the O1 interface towards the SMO as specified in [28].

The O-DU terminates the Open Fronthaul M-Plane interface, towards the O-RU, to support O-RU management either in hierarchical model or hybrid model, as specified in [24].

The O-DU may support CTI to a TN to control UL bandwidth allocation to TUs for UL LLS traffic on shared point-to-multipoint transport network (TN is a PON OLT or DOCSIS CMTS, TU is a PON ONU or DOCSIS Cable Modem). The CTI is specified in [20] and [21]. An informative overview of the CTI is shown in Annex A.

6.3.6 O-RU

The O-RU terminates the Open Fronthaul interface (also known as LLS interface [19]) as well as Low-PHY functions of the radio interface towards the UE. This is a physical node.

The O-RU terminates the Open Fronthaul M-Plane interface towards the O-DU and SMO as specified in [24].

6.3.7 O-eNB

The O-eNB terminates:

- the S1, X2 and E2 interfaces as well as the RRC, PDCP, RLC, MAC and PHY layers of the LTE-Uu radio interface towards the UE in case O-eNB is an eNB as defined in ETSI TS 136 401 [4].
- the NG, Xn and E2 interfaces as well as the RRC, SDAP, NR PDCP, RLC, MAC and PHY layers of the LTE-Uu radio interface towards the UE in case O-eNB is an ng-eNB as defined in ETSI TS 138 300 [7].

The O-eNB supports O-DU and O-RU functions with an Open Fronthaul interface between them as specified in [19] and [24].

6.3.8 O-Cloud

O-Cloud is a cloud computing platform comprising a collection of physical infrastructure nodes that meet O-RAN requirements to host the relevant O-RAN functions (i.e. Near-RT RIC, O-CU-CP, O-CU-UP and O-DU), the supporting software components (such as Operating System, Virtual Machine Monitor, Container Runtime, etc.) and the appropriate management and orchestration functions which satisfies the following criteria:

- Exports the O-RAN O2 interface for cloud and workload management to provide functions such as infrastructure discovery, registration, software lifecycle management, workload lifecycle management, fault management, performance management, and configuration management.
- Exports O-RAN Accelerator Abstraction Layer (AAL) API towards the hosted O-RAN workloads for hardware accelerator management.
- Exports O-Cloud Notification interface towards the hosted O-RAN workloads in order to notify the workloads of critical notifications (e.g. PTP synchronization states).
- Satisfies one or more of the deployment scenarios and their associated requirements as outlined in the O-RAN Cloud Architecture and Deployment Scenarios specification [17] and subsequent detailed scenario specifications published by O-RAN.
- The virtualization of the O-RU is for future study.

6.4 Relevant Interfaces in O-RAN Architecture

6.4.1 Introduction to Relevant Interfaces in O-RAN Architecture

The following interfaces are defined and maintained by O-RAN:

- A1 interface.
- O1 interface.
- O2 interface.
- E2 interface.
- Y1 interface.
- O-Cloud Notification interface.
- Open Fronthaul interface.

The following interfaces are defined and maintained by 3GPP, but seen also as part of the O-RAN architecture:

- E1 interface.
- F1-c interface.
- F1-u interface.
- NG-c interface.
- NG-u interface.
- X2-c interface.
- X2-u interface.
- Xn-c interface.
- Xn-u interface.
- Uu interface.

Following sections describe the termination points of O-RAN defined interfaces and 3GPP interfaces adopted by O-RAN.

6.4.2 A1 Interface

A1 interface is between Non-RT-RIC and the Near-RT RIC functions [18].

A1 is the interface between the Non-RT RIC function in SMO and the Near-RT RIC function. A1 interface supports three types of services as defined in [18]:

- Policy Management Service.
- Enrichment Information Service.
- ML Model Management Service.

A1 policies have the following characteristics compared to persistent configuration [18] and [35]. A1 policies:

- are not critical to traffic;
- have temporary validity;

- may handle individual UE or dynamically defined groups of UEs;
- act within and take precedence over the configuration;
- are non-persistent, i.e. do not survive a restart of the near-RT RIC.

6.4.3 O1 Interface

The O1 interface is between O-RAN Managed Element and the management entity as defined in [28] and [30].

6.4.4 O2 Interface

The O2 interface is between the SMO and O-Cloud as introduced in [17].

6.4.5 E2 Interface

E2 is a logical interface connecting the near-RT RIC with an E2 Node as defined in [22]:

- An E2 Node is connected to only one near-RT RIC.
- A near-RT RIC can be connected to multiple E2 Nodes.

The protocols over E2 interface are based exclusively on Control Plane protocols. The E2 functions are grouped into the following categories:

- Near-RT RIC Services (REPORT, INSERT, CONTROL and POLICY, as described in [22]).
- Near-RT RIC support functions, which include, e.g. E2 Interface Management (E2 Setup, E2 Reset, Reporting of General Error Situations, etc.) and Near-RT RIC Service Update (capability exchange related to the list of E2 Node functions exposed over E2, etc.).

6.4.6 O-Cloud Notification Interface

The O-Cloud Notification interface allows event consumer such as an O-DU deployed on O-Cloud to subscribe to events/status from the O-Cloud. The cloud infrastructure will provide event producer to enable cloud workloads to receive events/status that might be known only to the infrastructure.

6.4.7 Open Fronthaul Interface

The Open FH (Fronthaul) Interface is between O-DU and O-RU functions [19] and [24]. The Open FH Interface includes the CUS (Control User Synchronization) Plane and M (Management) Plane. In hybrid mode, the Open FH M-Plane interface connects the O-RU to the SMO for FCAPS functionality.

6.4.8 E1 Interface

The E1 interface, as defined by 3GPP, is between the gNB-CU-CP and gNB-CU-UP logical nodes ETSI TS 138 401 [9] and ETSI TS 138 460 [13]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted between the O-CU-CP and the O-CU-UP functions.

6.4.9 F1-c Interface

The F1-c interface, as defined by 3GPP, is between the gNB-CU-CP and gNB-DU logical nodes ETSI TS 138 401 [9] and ETSI TS 138 470 [15]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted between the O-CU-CP and the O-DU functions, as well as for the definition of interoperability profile specifications.

6.4.10 F1-u Interface

The F1-u interface, as defined by 3GPP, is between the gNB-CU-UP and gNB-DU logical nodes ETSI TS 138 401 [9] and ETSI 138 470 [15]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted between the O-CU-UP and the O-DU functions, as well as for the definition of interoperability profile specifications.

6.4.11 NG-c Interface

The NG-c interface, as defined by 3GPP, is between the gNB-CU-CP and the AMF in the 5GC ETSI TS 138 300 [7]. It is also referred as N2 in [7]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted between the O-CU-CP and the 5GC.

6.4.12 NG-u Interface

The NG-u interface, as defined by 3GPP, is between the gNB-CU-UP and the UPF in the 5GC ETSI TS 138 300 [7]. It is also referred as N3 in [7]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted between the O-CU-UP and the 5GC.

6.4.13 X2-c Interface

The X2-c interface is defined in 3GPP for transmitting control plane information between eNBs or between eNB and en-gNB in EN-DC as specified in ETSI TS 136 420 [5] and ETSI TS 138 300 [7]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted for the definition of interoperability profile specifications.

6.4.14 X2-u Interface

The X2-u interface is defined in 3GPP for transmitting user plane information between eNBs or between eNB and en-gNB in EN-DC as specified in ETSI TS 136 420 [5] and ETSI TS 138 300 [7]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted for the definition of interoperability profile specifications.

6.4.15 Xn-c Interface

The Xn-c interface is defined in 3GPP for transmitting control plane information between gNBs, ng-eNBs or between ng-eNB and gNB as specified in ETSI TS 138 300 [7] and ETSI TS 138 420 [11]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted for the definition of interoperability profile specifications.

6.4.16 Xn-u Interface

The Xn-u interface is defined in 3GPP for transmitting user plane information between gNBs, ng-eNBs or between ng-eNB and gNB as specified in ETSI TS 138 300 [7] and ETSI TS 138 420 [11]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted for the definition of interoperability profile specifications.

6.4.17 Uu Interface

The UE to e/gNB interface in 3GPP is denoted as the Uu interface. The Uu is a complete protocol stack from L1 to L3 and as such, seen as a whole, it terminates in the NG-RAN. If the NG-RAN is decomposed, different protocols terminate at different reference points and none of them has been defined by O-RAN. Since the Uu messages still flow from the UE to the intended e/gNB managed function, it is not shown in the O-RAN architecture as a separate interface to a specific managed function. For more information on the Uu interface between the UE and the NG-RAN, refer to Clauses 5.2 and 5.3 of ETSI TS 138 401 [9].

6.4.18 CTI (Cooperative Transport Interface)

Interface between the O-DU and TN to dynamically control bandwidth allocations to TUs when using a shared point-to-multipoint transport network. The CTI is specified in [20] and [21].

6.4.19 Y1 Interface

Y1 interface allows the Y1 consumers to subscribe or request the RAN analytics information provided by Near-RT RIC.

6.5 UE Associated Identifiers Used in O-RAN

As described earlier (Clauses 6.3.1.2.3 and 6.3.2), the Non-RT RIC and Near-RT RIC enable intelligent RAN optimization via A1, O1 and E2 interfaces respectively.

To support intelligent RAN optimization, the Non-RT RIC with rApps and Near-RT RIC with xApps utilize the knowledge of different UE associated events reported by the O-RAN functions over E2 and O1 interfaces. Both the Non-RT RIC and Near-RT RIC may need to correlate different UE associated events reported by the O-RAN functions for the same UE. In order to facilitate this correlation task, the reporting O-RAN function includes a set of UE associated identifiers with any report containing UE specific information.

Table 6.5-1 below shows the set of UE associated identifiers to be reported by any O-RAN function over O1 and E2 interfaces for any UE associated information.

Table 6.5-1: UE Associate Identifiers Used in O-RAN

UE associated identifier	Reference Specification	Comments
AMF UE NGAP ID	ETSI TS 138 413 [10]	Reported by O-CU-CP and O-eNB for UEs connected to 5GC.
GUAMI	ETSI TS 138 413 [10]	Reported by O-CU-CP and O-eNB for UEs connected to 5GC.
MME UE S1AP ID	ETSI TS 138 413 [10]	Reported by O-eNB for UEs connected to EPC.
GUMMEI	ETSI TS 138 413 [10]	Reported by O-eNB for UEs connected to EPC.
gNB-CU UE F1AP ID	ETSI TS 138 473 [16]	Reported by O-CU-CP and O-DU.
gNB-CU-CP UE E1AP ID	ETSI TS 138 463 [14]	Reported by O-CU-CP and O-CU-UP.
RAN UE ID	ETSI TS 138 473 [16] ETSI TS 138 463 [14]	Reported by O-CU-CP, O-CU-UP and O-DU when available/allocated.
M-NG-RAN node UE XnAP ID	ETSI TS 138 423 [12]	Identifier reported when the UE operates in DC with 5GC. Reported by O-CU-CP and O-eNB.
Global NG-RAN Node ID	ETSI TS 138 423 [12]	Identifier reported when the UE operates in DC with 5GC. Identifies the peer gNB/ng-eNB and is reported in conjunction with the M-NG-RAN node UE XnAP ID to ensure that the UE can be uniquely identified over Xn interface. Reported by O-eNB and O-CU-CP.
MeNB UE X2AP ID	ETSI TS 136 423 [6]	Identifier reported when the UE operate in DC with EPC. Reported by O-CU-CP and O-eNB.
Global eNB ID	ETSI TS 136 423 [6]	Identifier reported when the UE operate in DC with EPC. Identifies the peer eNB and is reported in conjunction with the MeNB UE X2AP ID to ensure that the UE can be uniquely identified over X2 interface. Reported by O-CU-CP and O-eNB.
C-RNTI	ETSI TS 138 331 [8]	Optionally reported by O-CU-CP, O-DU and O-eNB.

Additionally, the Non-RT RIC and Near-RT RIC may initiate messages towards the O-RAN functions which are associated with specific UEs. In such cases, the Non-RT RIC and Near RT RIC may include one or more of the UE associated identifiers specified in Table 6.5-1 above with any UE associated messages over A1 and E2 interface for identification of the UE in the O-RAN functions.

6.6 O-RAN Security Architecture

6.6.1 Introduction to O-RAN Security Architecture

The goal of the O-RAN ALLIANCE is to achieve a secure, open, and interoperable RAN. Building upon security advancements from the 3GPP and IETF standards development organizations, the O-RAN ALLIANCE is specifying an O-RAN security architecture that enables 5G CSP (Communication Service Providers) to deploy and operate O-RAN with the same level of confidence as a 3GPP-specified RAN. The O-RAN ALLIANCE is strengthening O-RAN's security posture by mitigating risk across its attack surface while pursuing the goals of a ZTA (Zero-Trust Architecture). This clause further explains O-RAN's inherent security benefits, threats, attack surface, and security controls to mitigate risk.

6.6.2 O-RAN Security Benefits

O-RAN's openness and disaggregated architecture provide the following inherent security benefits:

- Open-source software enables transparency and common control.
- Open interfaces ensure use of and interoperability of secure protocols and security features.
- Disaggregation enables supply chain security through diversity.
- Increased visibility enables enhanced intelligence leveraging AI and ML.

6.6.3 O-RAN Threat Analysis

6.6.3.1 Introduction to O-RAN Threat Analysis

The foundation of security is the threat analysis, which includes identification of threats, attack surface, assets, and stakeholders. The O-RAN Architecture includes new interfaces and functions, expanding the attack surface to introduce new security risks. O-RAN also shares common security risks with virtualized software in cloud-based deployments. O-RAN threats and attack surface are provided below.

6.6.3.2 O-RAN Threats

Threats against the O-RAN system can be grouped into four categories:

- **Architectural threats**, including functions, interfaces, and protocols.
- **Cloud threats**, including cloud hardware and software infrastructure.
- **Supply chain threats**, including use of open-source software.
- **Physical threats,** which is considered outside the scope of O-RAN.

6.6.3.3 O-RAN Attack Surface

O-RAN's attack surface is divided into six main groups:

- **Additional functions**: SMO, Non-RT RIC (including rApps), and Near-RT RIC (including xApps).
- **Additional open interfaces**: A1, E2, O1, O2, and Open FH (7-2x).
- **Modified architecture**: Lower Layer Split with Open FH (7-2x).
- **Trust Chain**: Decoupling of hardware and software along with use of third-party xApps and rApps.
- **Containerization and Virtualization**: Container and cloud security risks.
- **Open-source software**: Exposure to zero-day vulnerabilities and public exploits.

NOTE: The first 3 items in the list above are O-RAN specific. The last 3 items in the list are not exclusive to O-RAN.

For further information about the O-RAN's threat modelling, see the "Security Threat Modeling and Remediation Analysis" document [33].

6.6.4 O-RAN Security Protocols

O-RAN specifies configuration and cipher suites for use of the following security protocols on O-RAN interfaces: SSHv2 (Secure Shell 2.0), TLS 1.2 and 1.3, DTLS (Datagram Transport Layer Security) 1.2, IPsec (Internet Protocol Security), IEEE 802.1X, and NETCONF (Network Configuration Protocol) over Secure Transport.

Details about where these protocols are used in O-RAN Alliance working group specifications to enforce confidentiality, authenticity, integrity, and least privilege can be found in the "Security Requirements Specifications" document [32]. For further information about O-RAN security protocols see the "Security Protocols Specifications" document [31].

O-RAN has also provided requirements for SBOM (Software Bill of Materials) in [32].

6.6.5 Considerations for a Zero-Trust Architecture

O-RAN is following 3GPP security design tenets and industry best practices working toward the guiding principle of zero-trust, so that O-RAN delivers the level of security expected by 5G network operators and users. Internal and external threats should be considered in a ZTA. Traditionally, the RAN was considered trusted, but zero-trust assumes there is no implicit trust of a user or asset based upon physical location, network location, or ownership. This increases risk for RAN security by increasing likelihood scoring, a component of risk. A ZTA, as defined in NIST 800-207 [i.3], includes support for a PKI (Public Key Infrastructure) with certificate-based mutual authentication.

7 O-RAN Information Model (IM) Principles

O-RAN shall align its Information Model (IM) with 3GPP to the extent possible. The additional O-RAN extensions to its IM and DMs (Data Models) are described in [29].

Annex A (informative): Implementation Options of O-RAN Functions and Network Elements

A.1 Shared Cell

Shared cell [19] is defined as the operation for the same cell by several O-RUs with one or multiple component carriers. It can be deployed in either FHM (Fronthaul Multiplexer) or Cascade mode as described below.

In FHM mode, the shared cell may be realized by placing an FHM function between an O-DU and several O-RUs that may have one or multiple component carriers from these O-RUs. FHM function may be modelled as an O-RU with LLS Fronthaul support (same as normal O-RU) along with the copy and combine function (additional to normal O-RU), but without radio transmission/reception capability. Figure A.1-1 below shows how each O-RU can be used for either operating in the same cell (Single Cell Scenario) or in different cells (Multiple Cells Scenario) by configuring the FHM function.

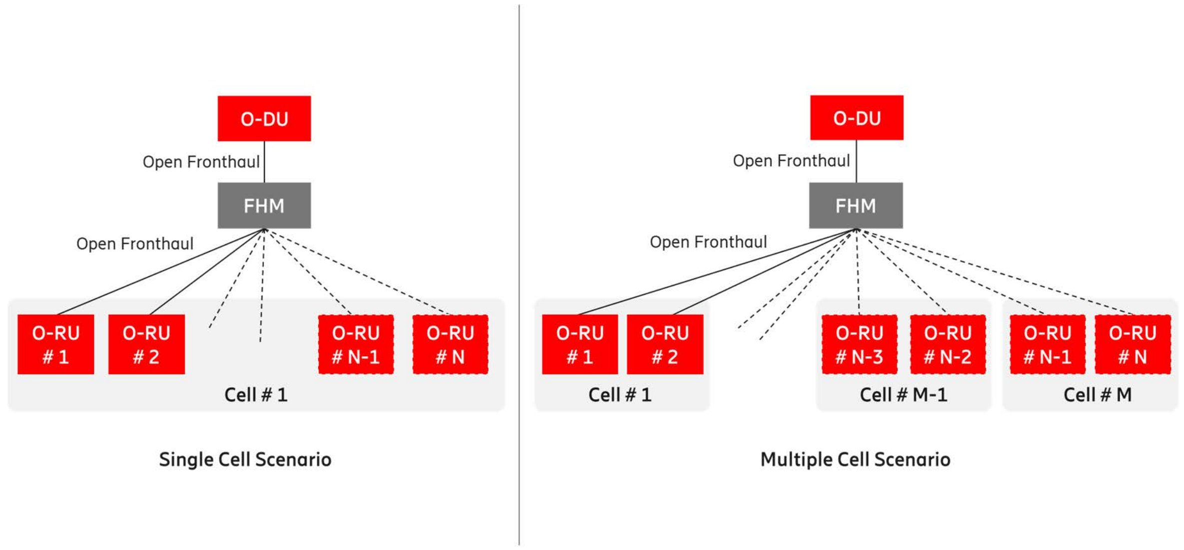


Figure A.1-1: Shared cell deployment using FHM mode

In Cascade mode, the shared cell is realized by several O-RUs cascaded in chain. In this case, one or more O-RUs are inserted between the O-DU and the O-RU. The O-RUs in the cascaded chain except for the last O-RU support Copy and Combine function. Figure A.1-2 below shows an implementation of Cascade mode shared cell.

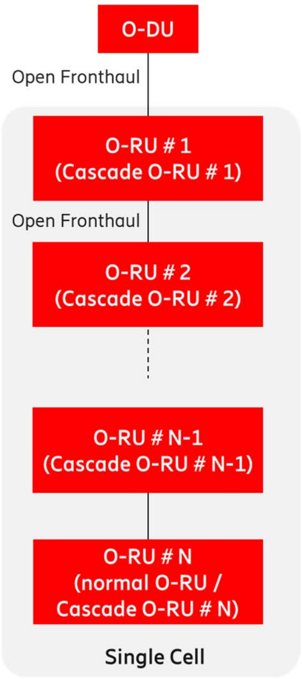


Figure A.1-2: Shared cell deployment using Cascade mode

The Cascade mode, as described above, is implemented within the O-RU.

Refer to [19] for additional information.

A.2 FHGW Function

The FHGW (Fronthaul Gateway) function may be placed between the O-DU and RU/RRU (Radio Unit / Remote Radio Unit) with the following O-RAN specified interfaces:

- The interface between O-DU and FHGW function is Open Fronthaul (Option 7-2x).
- The interface between FHGW function and RU/RRU is subject to reference implementation developed by any relevant O-RAN WG (e.g. WG7) as described in [23].
- The interface between FHGW function and RU/RRU does not support Open Fronthaul (Option 7-2x).
- The FHGW function may be packaged with other functions (such as Ethernet switching) in a physical product, as considered within WG7.

Figure A.2-1 below depicts the deployment of the FHGW function using O-RAN specified interfaces.

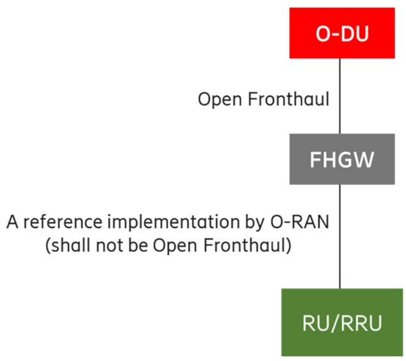


Figure A.2-1: Deployment of O-DU and RU/RRU using FHGW function

A.3 Near-RT RIC

The Near-RT RIC can control multiple E2 Nodes or can control a single E2 Node. The following figures show two implementation options of Near-RT RIC.

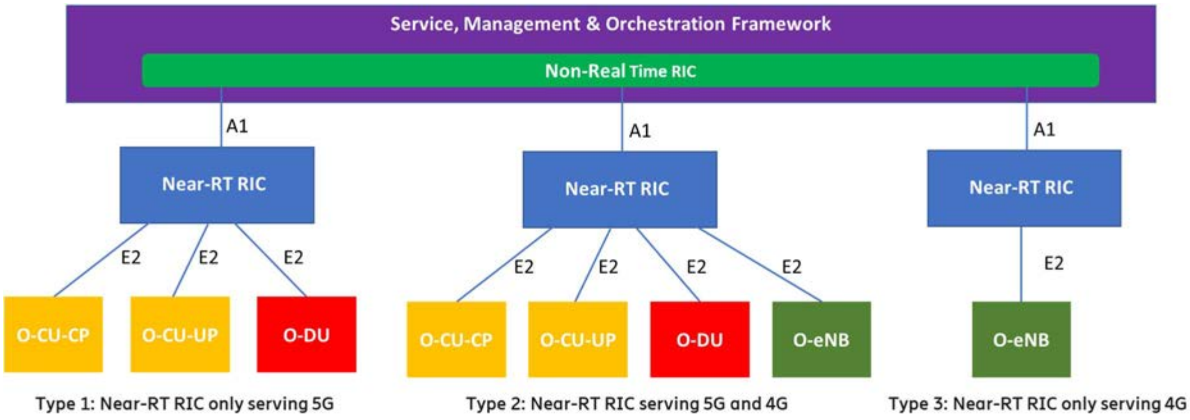


Figure A.3-1: Centralized Near-RT RIC Serving 4G and 5G Simultaneously

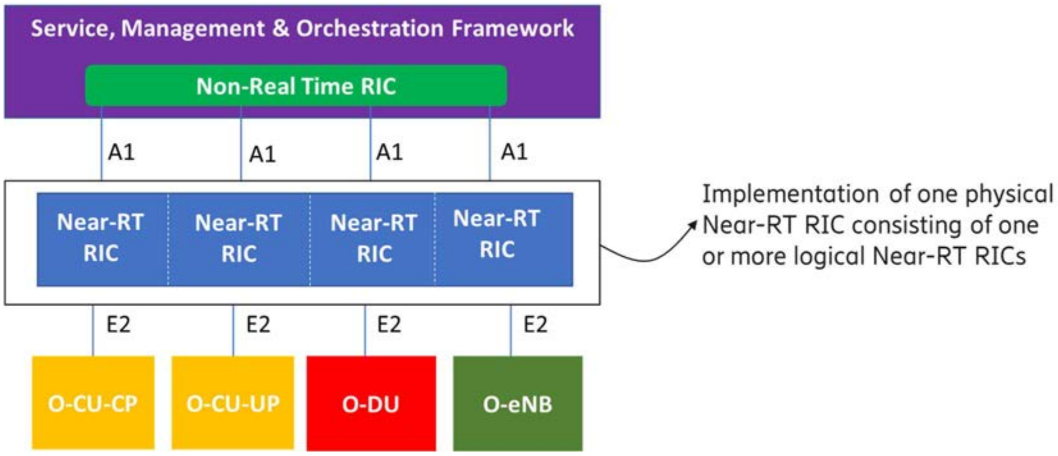


Figure A.3-2: Distributed Near-RT RIC

A.4 Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU

Although the O-RAN architecture specify the O-RAN nodes Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU as separate entities, it is possible in the implementation to bundle some or all of these O-RAN nodes, and thus collapsing some of the internal interfaces such as F1-c, F1-u, E1 and E2. At least the following implementation options are possible:

- Disaggregated network functions as per O-RAN architecture.
- Bundle the O-CU-CP and O-CU-UP.
- Bundle the O-CU-CP, O-CU-UP and O-DU.
- Bundle the Near-RT RIC, O-CU-CP and O-CU-UP.
- Bundle the O-CU-CP, O-CU-UP, O-DU and O-RU.
- Bundle the O-DU and O-RU.
- Bundle the Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU.

Bundling of O-RAN nodes is supported by the O-RAN specified interfaces O1 and E2. For the O1 interface, the bundled functions will be managed as separate Managed Functions belonging to a single Managed Element as specified in [28]. For the E2 interface the bundled functions can be exposed as part of the E2 Service Model towards the Near-RT RIC (see Annex A in [22]).

NOTE 1: In the implementation options where the Near-RT RIC function is bundled with other O-RAN functions it may only control E2 Nodes of the same RAT (Radio Access Technology) type (e.g. a bundled near-RT RIC and O-CU-CP may only control E2 Nodes O-CU-UP and O-DU) which are not bundled with Near-RT RIC.

NOTE 2: Bundling multiple instances of the same type of O-RAN function is supported.

See the figures below (i.e. Figure A.4-1 through Figure A.4-7).

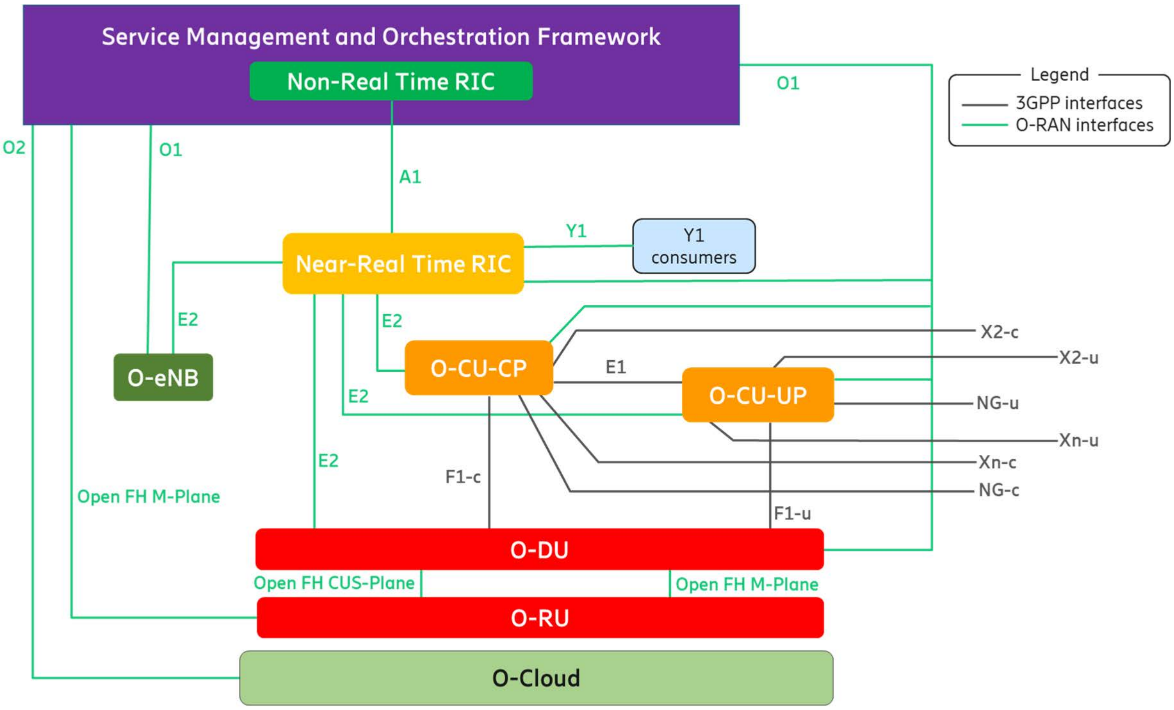


Figure A.4-1: Disaggregated Network Functions

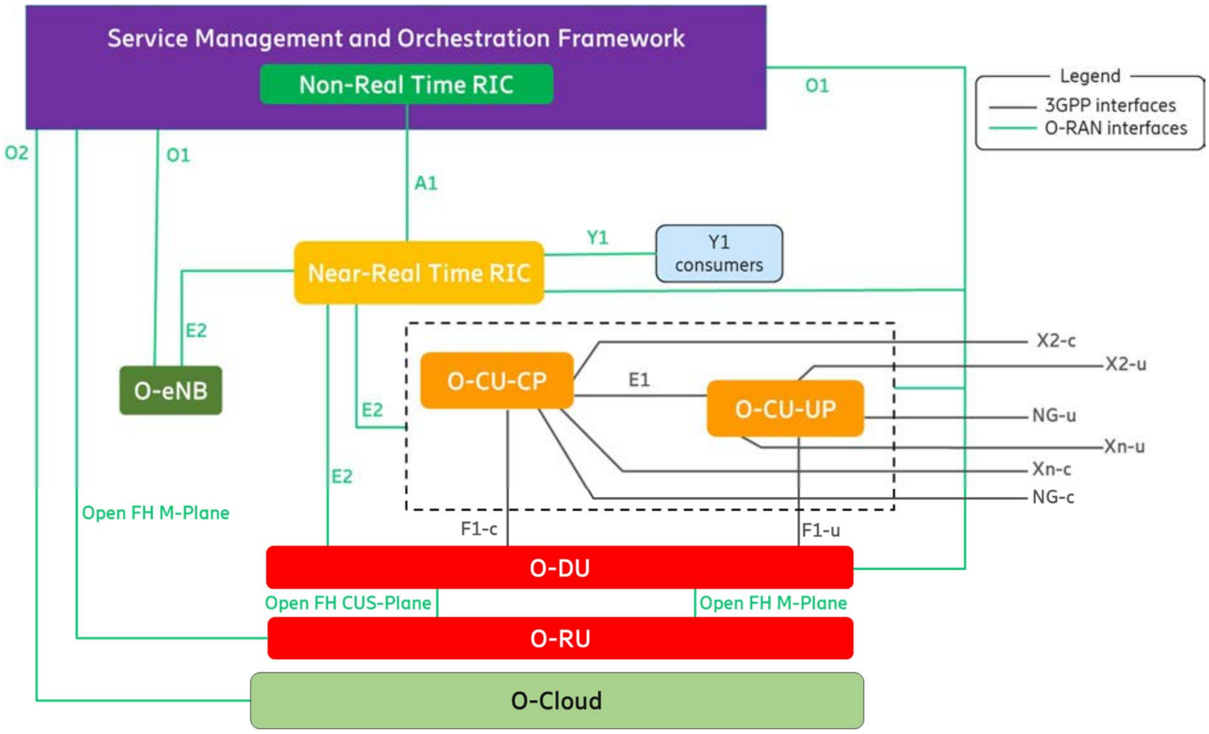


Figure A.4-2: Aggregated O-CU-CP and O-CU-UP

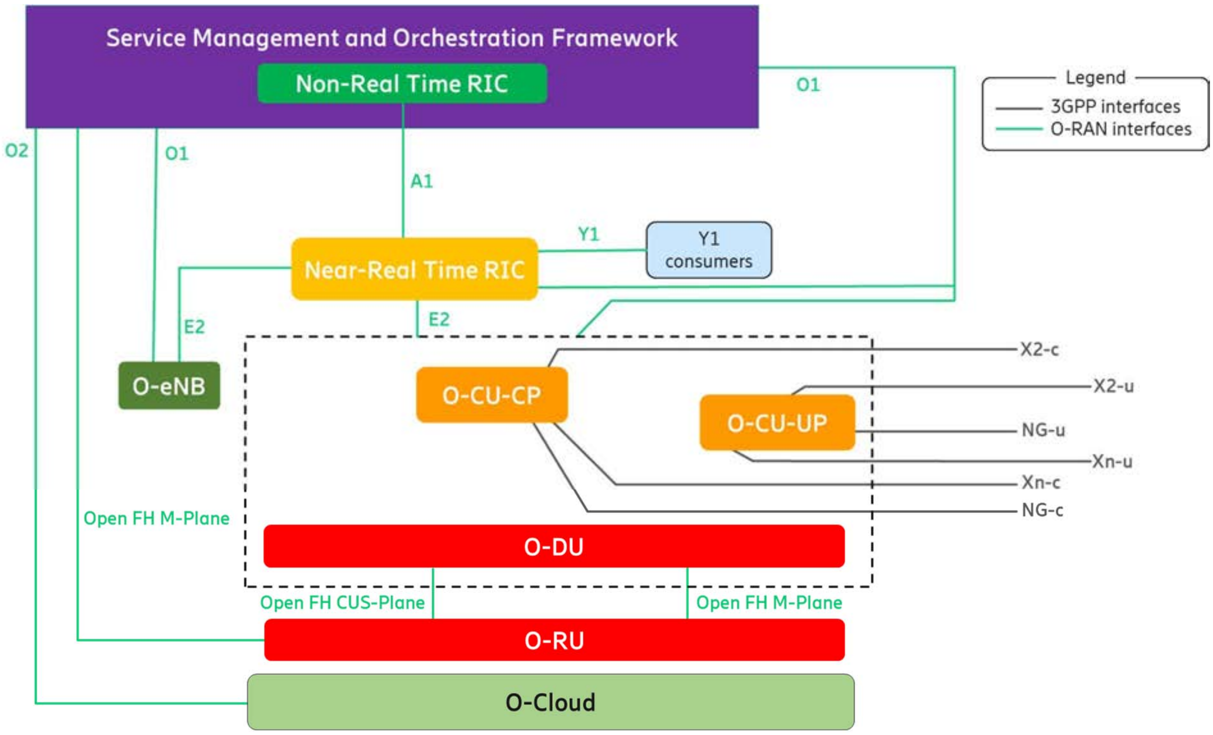


Figure A.4-3: Aggregated O-CU-CP, O-CU-UP and O-DU

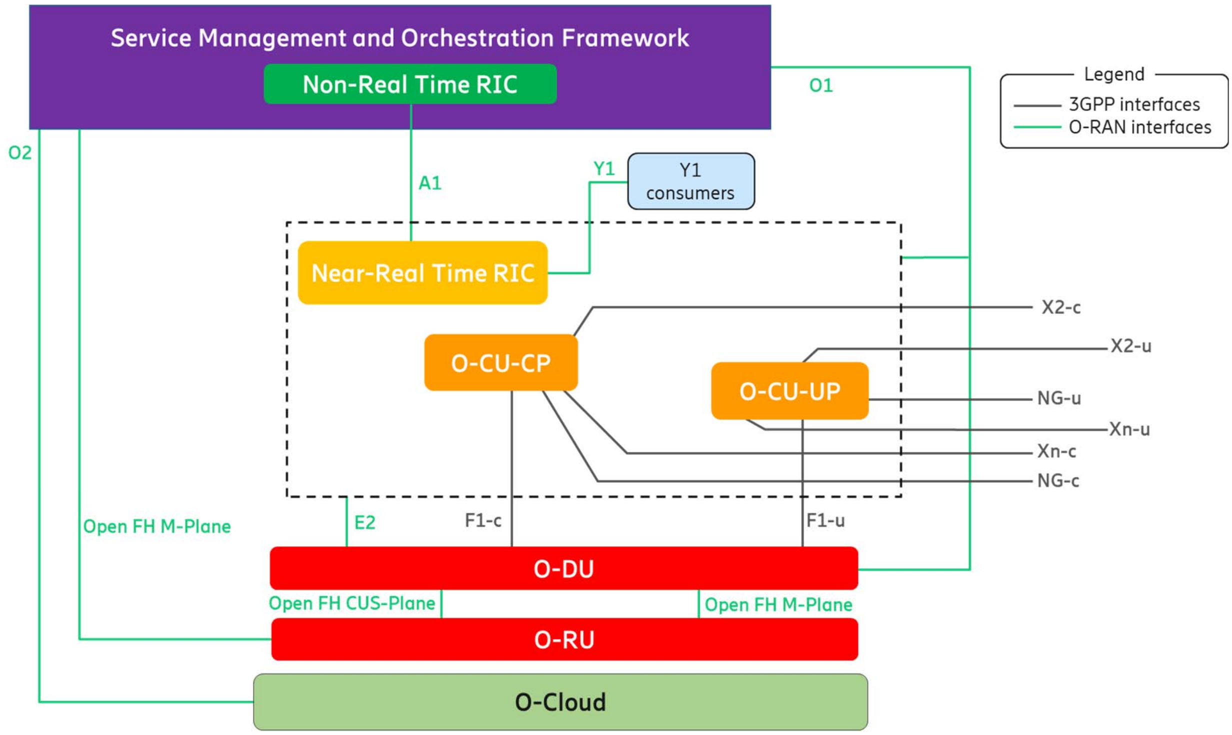


Figure A.4-4: Aggregated Near-RT RIC, O-CU-CP and O-CU-UP

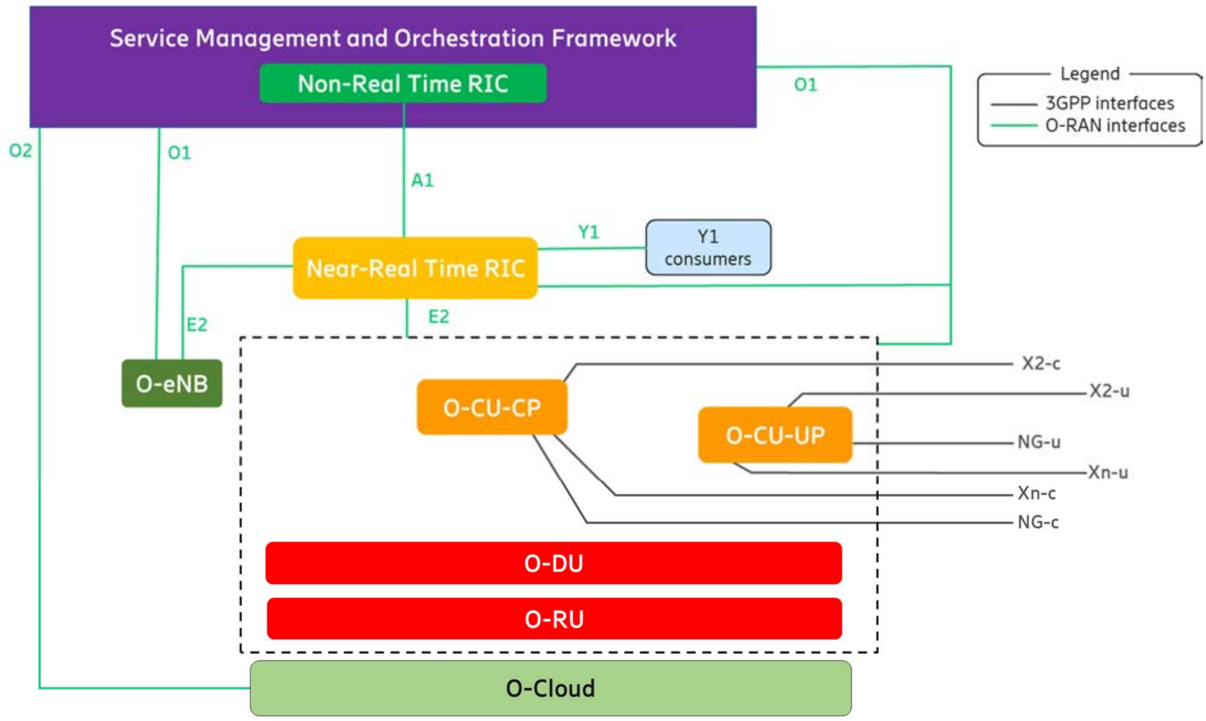


Figure A.4-5: Aggregated O-CU-CP, O-CU-UP, O-DU and O-RU

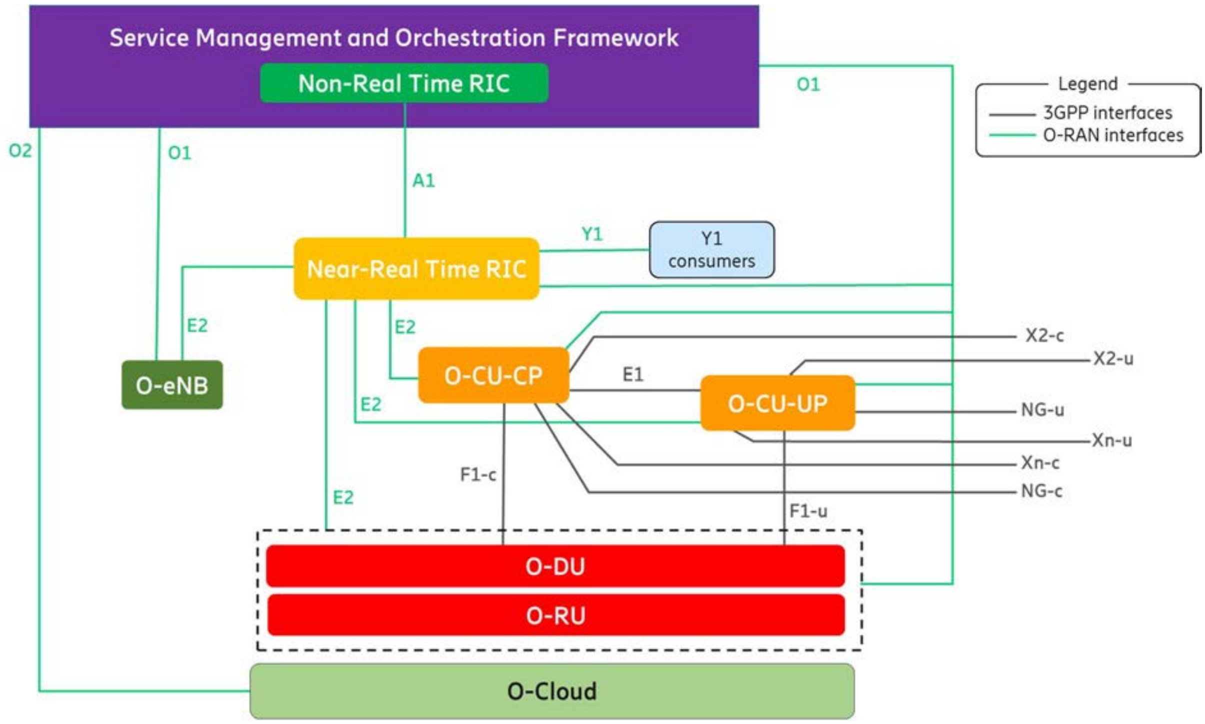


Figure A.4-6: Aggregated O-DU and O-RU

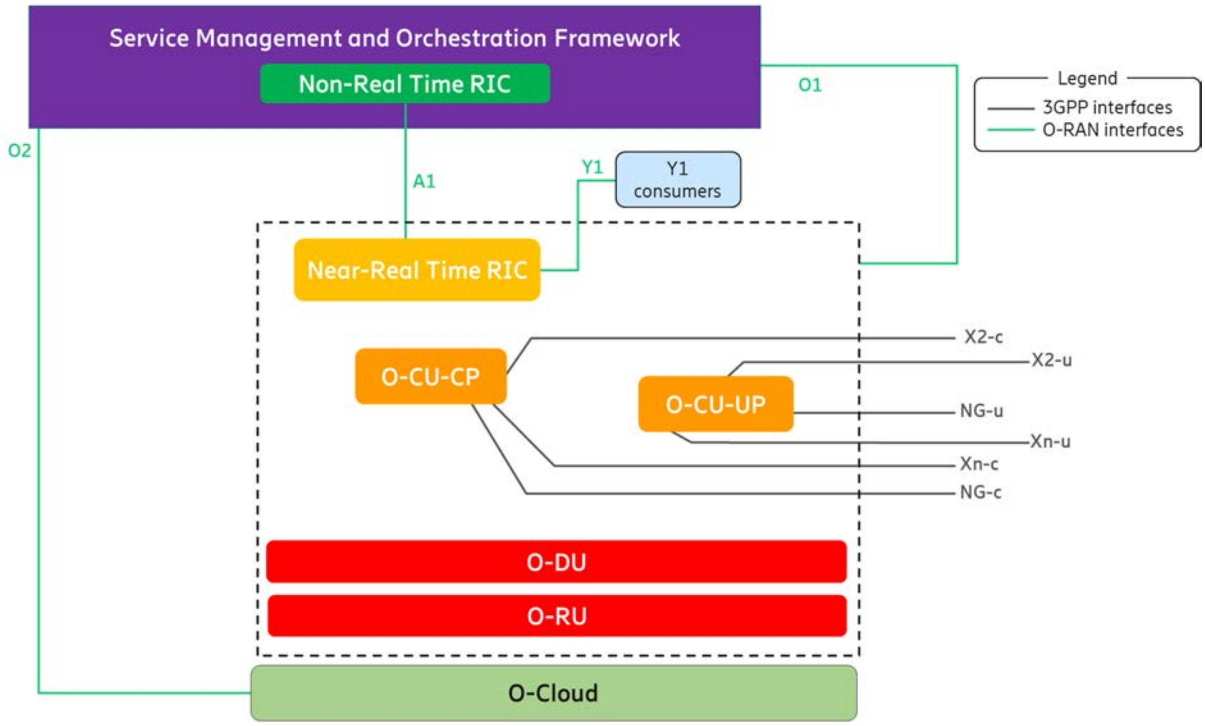
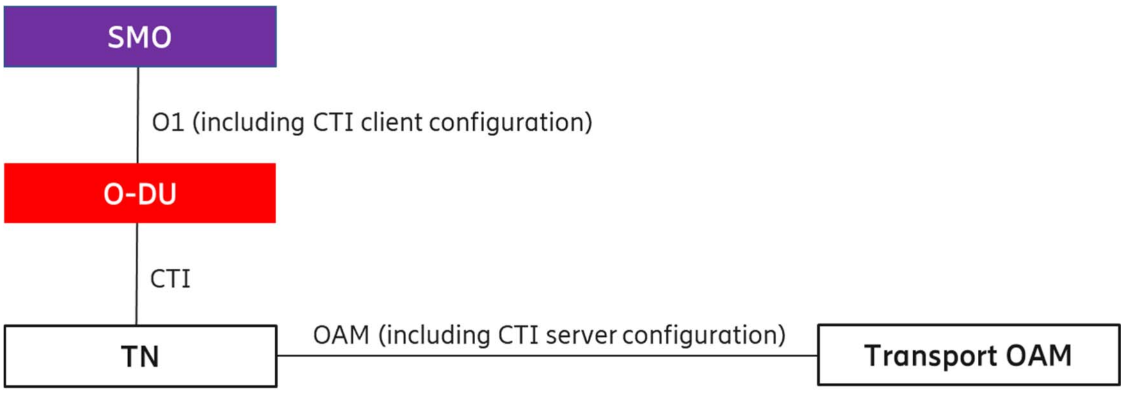


Figure A.4-7: Aggregated Near-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU

A.5 Cooperative Transport

To enhance the resource utilization and reduce the latency of UL LLS traffic when using a shared point-to-multipoint transport network requiring resource allocation (such as PON or DOCSIS), the O-RAN architecture supports a cooperative transport feature. The cooperative transport feature is based on the O-DU's knowledge of the expected uplink LLS traffic from a given O-RU which is provided to the associated (PON or DOCSIS) TN in the transport network. This enables the TN to dynamically allocate the correct bandwidth over the shared transport network to the TU that is used by the O-RU. The CTI signalling is described in [20]. To support the CTI, the O-DU is configured over the O1 interface with CTI client specific configuration as described in [21]. Note that there can be intermediate nodes between the O-DU and the TN, they will forward the CTI messages transparently but will not participate to CTI interactions.

A simplified architecture of the CTI is shown in Figure A.5-1 below. The SMO, O-DU and O1 interface shown in this figure are part of the O-RAN Logical Architecture (see Clauses 6.3.1, 6.3.5 and 6.4.3, respectively), whereas the TN and Transport OAM, are the components of the transport network. For detailed specification and reference architecture, see [20] and [21].



A.5-1: Simplified CTI Architecture

Annex B (informative): Change history

Date	Version	Information about changes
2020.01.16	01.00	• First version with an overall architecture of O-RAN. Describe O-RAN architecture elements and relevant interfaces.
2020.10.30	02.00	• Introduce new implementation options by bundling O-RAN logical functions. • Clarify the O-RAN position that OFH (7-2x) is the interface between O-DU and O-RU. Add a new principle that architecture may evolve as deemed appropriate by the O-RAN community.
2020.11.25	03.00	• Introduce functional architecture of Non-RT RIC with description of rApps, R1 interface, and Non-RT RIC framework. • Add implementation options of FHM and FHGW functions. • Remove the optionality of SMO to support OFH M-Plane interface towards O-RU. • Add definition of “Managed Application”. Add ‘legends’ to the architecture figures.
2021.03.18	04.00	• Enhance O-RAN control loops by making their execution times and interactions dependent on use cases. • Explain that the execution times of Non-RT and Near-RT control loops may overlap as dictated by use cases. • Designate the O1 interface between SMO and O-RU as a topic for future study. • Use two colors (i.e., green for O-RAN and black for 3GPP) for the logical interfaces in the architecture figures.
2021.07.16	05.00	• Elaborate the relationship between rApps, R1 interface, Non-RT RIC framework, and SMO framework within Non-RT RIC functional architecture. • Introduce the concept of ‘anchored’ vs. ‘non-anchored’ functionality within SMO and Non-RT RIC frameworks. • Provide a high-level view of ‘functions’ required to enable the capabilities of rApps. • Add a CTI clause and an Annex clause containing a simple CTI implementation.
2021.11.18	06.00	• Clarify how R1 interface works between rApps and O-RAN logical functions. • Extend the “OFH M-Plane” interface between SMO and O-RU. • Add ‘UE Associated Identifiers Used in O-RAN’ clause for correlating UE identities. • Introduce “O-Cloud Notification” interface between O-RAN functions and O-Cloud. • Add “O-RAN Security Architecture” clause consisting of ‘Threat Analysis’, ‘Attach Surfaces’, and ‘Security Protocols’.
2022.10.21	07.00	• Add the concept of SBA as part of the “SMO Architecture Principles” clause. • Implement changes (i.e., new legal statement in cover page, revised foot note, and deletion of annex ZZZ) to be compliant with the new IPR policy of O-RAN ALLIANCE.
2022.11.17	08.00	• Introduce new Y1 interface for exposing RAN analytics information to internal and/or external functions. • Remove all references to future work items (e.g., O1 interface between SMO and O-RU, planned security enhancements, etc.) to align with the O-RAN drafting rules. • Add C-RNTI to UE identifier so that it can be optionally reported by O-CU-CP, O-DU, and O-eNB.

History

Document history		
V8.0.0	January 2024	Publication