O-RAN Architecture Description

Revision History

Date	Revision	Editor(s)	Description
2019.09.06	00.01	Haseeb Akhtar (Ericsson)	First draft of O-RAN Architecture Description Document.
2019.10.12	00.02	Haseeb Akhtar (Ericsson)	• Added the contact names of sponsoring organizations. • Figure – 2 to show the UEs clustered together. • Added a description of Non-RT RIC (Section 4.3.1).
2019.10.14	00.03	Haseeb Akhtar (Ericsson)	• Added DT as one of the co-sponsors. • Revised the description of Non-RT RIC (Section 4.3.1). • Added a description of Near-RT RIC (Section 4.3.2). • Updated the versioning format as per O-RAN guidance.
2019.10.16	00.04	Haseeb Akhtar (Ericsson)	• Revised the description of Non-RT RIC (Section 4.3.1). • Minor editorial corrections.
2019.10.17	00.05	Cagatay Buyukkoc (AT&T)	• Added Orange as one of the co-sponsors.
2020.01.16	01.00	Paul Smith (AT&T) Jinri Huang (CMCC) Chai Li (CMCC) Haseeb Akhtar (Ericsson)	• Added the CR for v1.0 work items of Architecture Description (PA19).

Contents

Chapter 1. Introductory Material

1.1 Scope

This Technical Specification has been produced by the 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. Should the O-RAN Alliance 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 present document defines the O-RAN architecture and 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.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 23.501: "System Architecture for the 5G System (5GS); Stage 2".

[3] 3GPP TS 32.101: "Technical Specification Group Services and System Aspects; Telecommunication management; Principles and high level requirements (Release 15)".

[4] 3GPP TS 36.401: " Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Architecture Description".

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

[6] 3GPP TS 38.300 NR; "NR and NG-RAN Overall Description; Stage 2".

[7] 3GPP TS 38.401: "NG-RAN; Architecture description".

[8] 3GPP TS 38.420: "NG-RAN; Xn general aspects and principles".

[9] 3GPP TS 38.460: "NG-RAN; E1 general aspects and principles".

[10] 3GPP TS 38.470: "NG-RAN; F1 general aspects and principles".

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

[12] O-RAN-WG1.OAM-Architecture-v02.00: "O-RAN WG1 Operations and Maintenance Architecture v02.00".

[13] O-RAN-WG1.O1-Interface-v02.00: "O-RAN Operations and Maintenance Interface Specification".

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

[15] ORAN-WG3.E2GAP.0-v0.1: “O-RAN Working Group 3; Near-Real-time RAN Intelligent Controller Architecture & E2 General Aspects and Principles”.

[16] ORAN-WG4.MP.0-v02.00.00: “O-RAN Alliance Working Group 4; Management Plane Specification”.

[17] ORAN-WG4.CUS.0-v02.00: “O-RAN Fronthaul Working Group; Control, User and Synchronization Plane Specification”.

[18] O-RAN-WG6.CAD-V00.01.09: “Cloud Architecture and Deployment Scenarios for O-RAN Virtualized RAN”.

[19] ORAN-WG2.Use Case Requirements v01.00: “O-RAN Working Group 2 (Non-RT RIC & A1 interface)”.

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].

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 as defined in [15],
- for E-UTRA access: O-eNB.

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 workflow including model training, inference and updates.

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

NMS: a Network Management System for the O-RU as specified in [16] to support Open Fronthaul M-Plane. This NMS is an optional part of the SMO as defined in [12].

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 (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.

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-eNB: an eNB [4] or ng-eNB [6] that supports E2 interface.

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 entity as specified in [12] 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 management entities and the O-Cloud for supporting O-RAN virtual network functions.

SMO a Service Management and Orchestration system as described in [13].

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 [15].

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].

3GPP	3rd Generation Partnership Project
5GC	5G Core
AAL	Accelerator Abstraction Layer
API	Application Programing Interface
AI	Artificial Intelligence
AMF	Access and Mobility Functions
CM	Configuration Management
eNB	evolved Node B
EN-DC	E-UTRA-NR Dual Connectivity
FCAPS	Fault, Configuration, Accounting, Performance, Security
FM	Fault Management
gNB	next generation Node B
gNB-CU	gNB Central Unit
gNB-DU	gNB Distributed Unit
LTE	Long Term Evolution
MAC	Media Access Control
ML	Machine Learning
Near-RT RIC	O-RAN near real time RAN Intelligent Controller
NFV	Network Function Virtualization
NG-RAN	Next Generation RAN
NMS	Network Management System
Non-RT RIC	O-RAN non-real time RAN Intelligent Controller
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
PDCP	Packet Data Convergence Protocol
PHY	PHYsical layer
PM	Performance Management
PNF	Physical Network Function

RAN	Radio Access Network
RLC	Radio Link Control
RRM	Radio Resource Management
SDAP	Service Data Adaptation Protocol
SMO	Service Management and Orchestration
VNF	Virtualized Network Function

Chapter 2. O-RAN Overview

2.1 Scope and Objectives

O-RAN activities are guided by the following objectives [11]:

- 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.

Chapter 3. General O-RAN Architecture Principles

This section 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.

Chapter 4. O-RAN Architecture

4.1 Overall Architecture of O-RAN

Figure 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. Figure 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 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 model, as specified in [16]. It is an optional interface to the SMO that is included for backward compatibility purposes as per [16]. It is intended for management of the O-RU in hybrid mode only. The management architecture of the flat mode [12] and its relation to O1 interface for the O-RU is a subject for future study. The O-RU termination of the O1 interface towards the SMO as specified in [12] is under study.

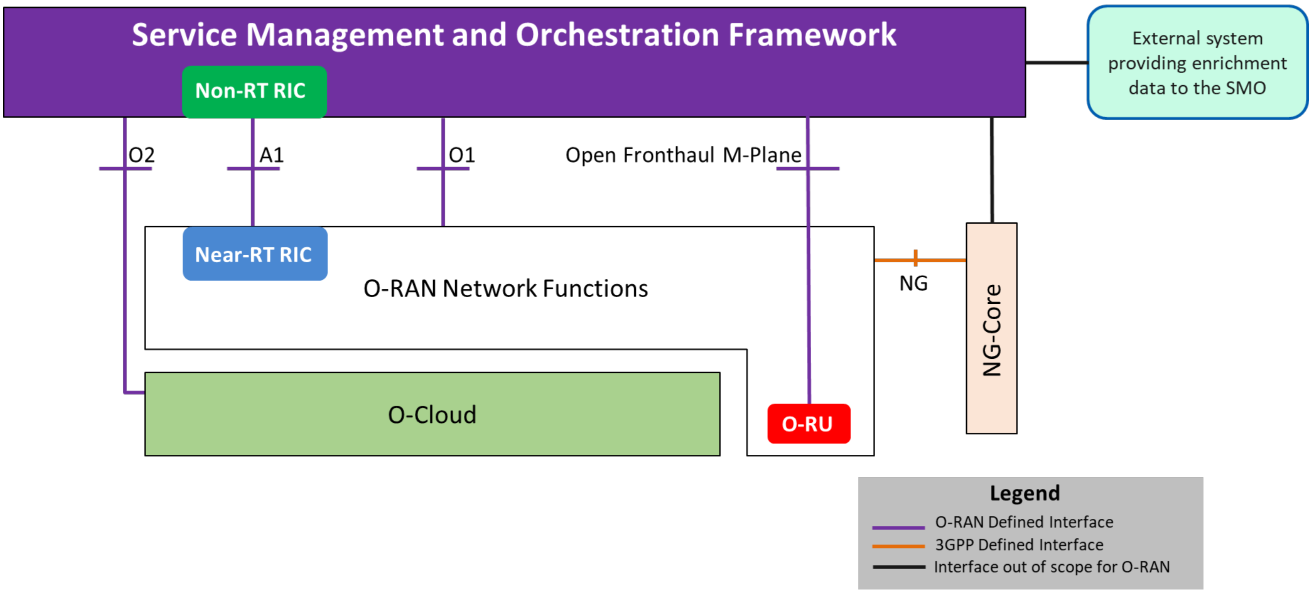

Figure 1: High Level Architecture of O-RAN

Within the logical architecture of O-RAN, as shown in Figure 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.

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 for future study.

As shown in this figure, the O-RU terminates the Open Fronthaul M-Plane interface towards the O-DU and SMO as specified in [16]. As stated earlier, O-RU's termination of the Open Fronthaul M-plane interface to the SMO is optional for the SMO.

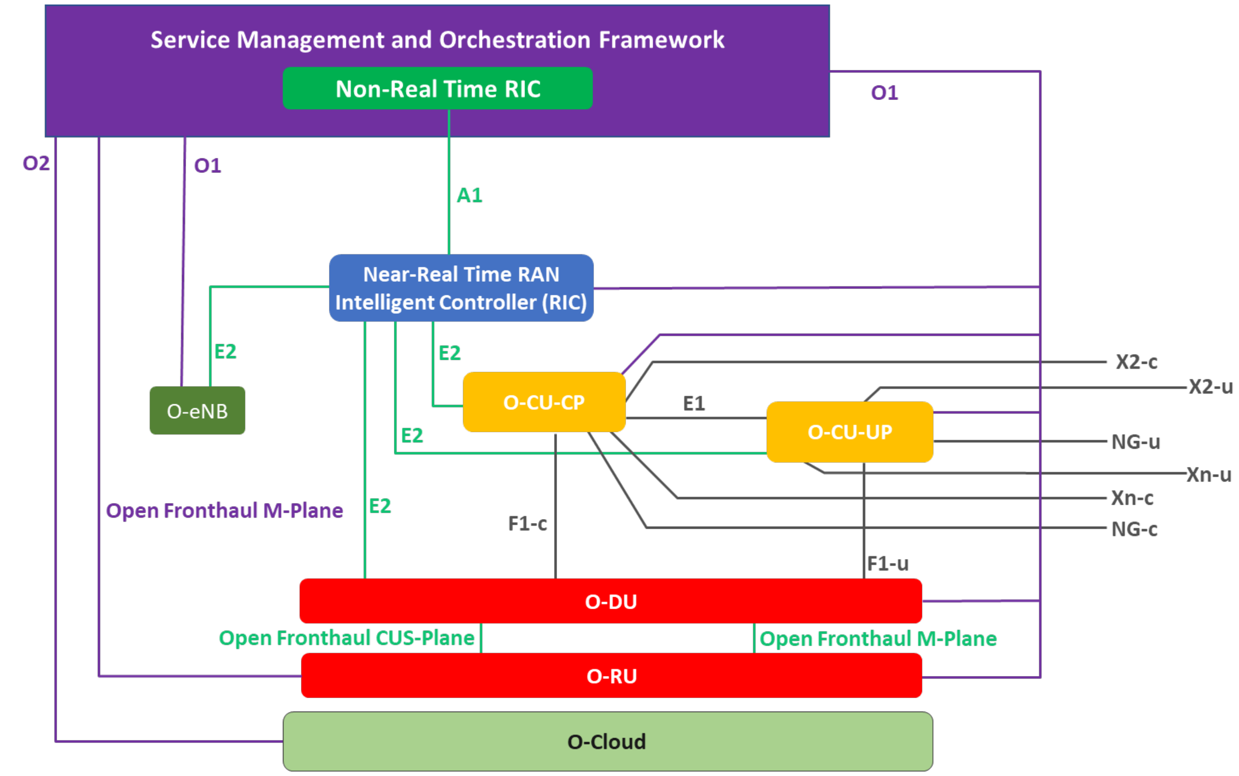

Figure 2: Logical Architecture of O-RAN

The following figure shows the Uu interface between UE and O-RAN components as well as between UE and O-eNB. Please refer to Section 4.4.15 for more details.

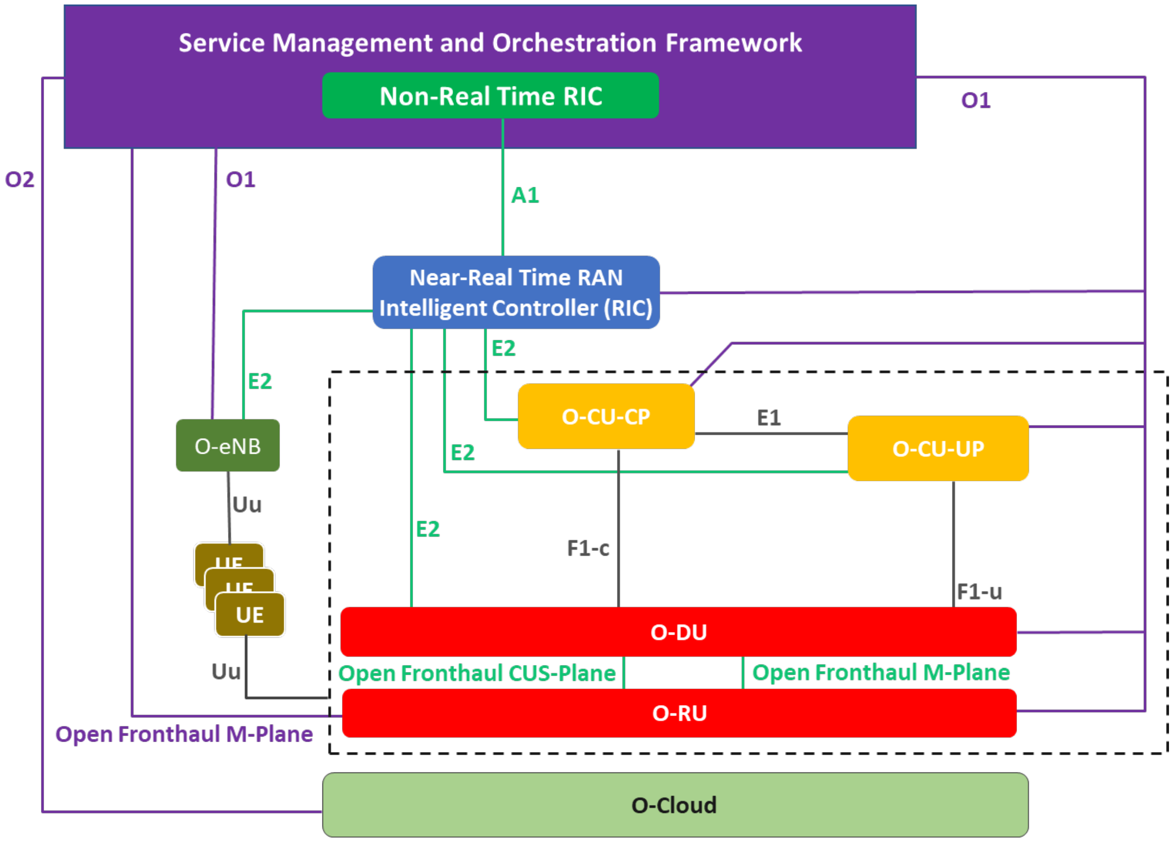

Figure 3: Uu interface for O-RAN components and O-eNB

4.2 O-RAN Control Loops

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

- O-DU Scheduler control loop
- Near-RT RIC control loop
- Non-RT RIC control loop

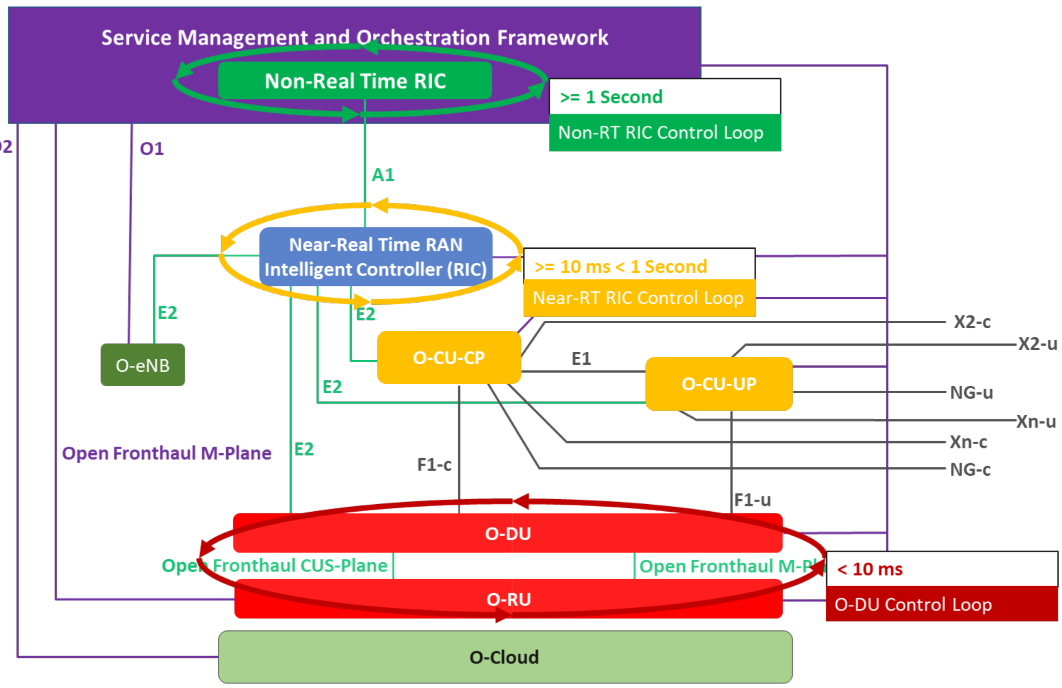

Figure 4: O-RAN Control Loops

As shown in Figure 4 above, the control loops are defined based on the controlling entity, it should however be noted that other O-RAN nodes and functions are involved in the control loop for when it comes to providing data to the controlling entity as well as executing actions triggered by the controlling entity.

The control loops run in parallel of each other and depending on the use case may or may not have any interaction with each other. The use cases for the Non-RT RIC and Near-RT RIC control loops are fully defined by O-RAN, while for the O-DU scheduler control loop, responsible for radio scheduling, HARQ, beamforming etc., only the relevant interactions with other O-RAN nodes or functions are defined.

Although the timing of these control loops is use case dependent, it is expected that typical execution time for use cases in the Non-RT RIC control loop is 1 second or more, use cases in the Near-RT RIC control loop have a use case execution time of 10 ms to 1 second and the O-DU scheduler loop operates below 10 ms.

4.3 Description of O-RAN Functions

4.3.1 Service Management and Orchestration (SMO)

This section describes the functionality provided by the SMO in O-RAN. The SMO is a consolidation of a wide variety of management services and provides many network management like functionalities. In a Service Provider's Network, the SMO may provide management services that go well beyond RAN management and can include things such as: Core Management, Transport Management, End to End Slice Management etc. The SMO discussion 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
- Optionally, and only 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

4.3.1.1 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 [13]. 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 [3]. The following FCAPS functions defined in the O1 Specification are examples of the functionality across the O1 interface. See [13] 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 [16], is specific for supporting FCAPS to the O-RU. NMS in [16], which is optionally part of the SMO, supports FCAPS functions to the O-RU through the Open Fronthaul M-plane interface. The following FCAPS functions, as defined in [16], are examples of capabilities supported across this Open Fronthaul M-plane interface.

- “Start-up” installation
- SW management
- Configuration management
- Performance management
- Fault Management
- File Management

4.3.1.2 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 [14]. 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.

4.3.1.3 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

4.3.2 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.

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 [15], in order to support the use cases described in [19]. 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 [15], the near RT RIC may e.g. monitor, suspend/stop, override or control via policies the behavior 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.

4.3.3 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 [7].

The O-CU-CP terminates E2 interface to Near-RT RIC as specified in [15].

The O-CU-CP terminates O1 interface towards the SMO as specified in [12].

The O-CU-CP terminates NG-c interface to 5GC as specified in [6].

The O-CU-CP terminates X2-c interface to eNB or to en-gNB in EN-DC as specified in [5] [6].

The O-CU-CP terminates Xn-c to gNB or ng-eNB as specified in [6] [8].

4.3.4 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 [7].

The O-CU-UP terminates E2 interface to Near-RT RIC as specified in [15].

The O-CU-UP terminates O1 interface towards the SMO as specified in [12].

The O-CU-UP terminates NG-u interface to 5GC as specified in [6].

The O-CU-UP terminates X2-u interface to eNB or to en-gNB in EN-DC as specified in [5] [6].

The O-CU-UP terminates Xn-u to gNB or ng-eNB as specified in [6] [8].

4.3.5 O-DU

The O-DU terminates the E2 and the F1 interface (according to the principles described in Section 4.4.7), and the Open Fronthaul Interface (also known as LLS interface [17]) 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 [12].

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 [16].

Note: This definition applies when the LLS fronthaul interface, so called split 7-2x, is being used between the O-DU and the O-RU ([17]). If other fronthaul interfaces are employed (e.g., split 8 or split 6), the definition of the O-DU and O-RU entities are for further study.

4.3.6 O-RU

The O-RU terminates the Open Fronthaul Interface (also known as LLS interface [17]) 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 [16].

The O-RU termination of the O1 interface towards the SMO as specified in [12] is under study.

Note: This definition applies when the LLS fronthaul interface, so called split 7-2x, is being used between the O-DU and the O-RU ([17]). If other fronthaul interfaces are employed (e.g., split 8 or split 6), the definition of the O-DU and O-RU entities are for further study.

4.3.7 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 [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 [6].

The O-eNB supports O-DU and O-RU functions with an Open Fronthaul interface between them as specified in [16] and [17].

4.3.8 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.
- Satisfies one or more of the deployment scenarios and their associated requirements as outlined in the O-RAN Cloud Architecture and Deployment Scenarios specification [18] and subsequent detailed scenario specifications published by O-RAN.
- The virtualization of the O-RU is for future study.

4.4 Relevant Interfaces in O-RAN Architecture

The following interfaces are defined and maintained by O-RAN:
- A1 interface
- O1 interface
- O2 interface
- E2 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.

4.4.1 A1 Interface

A1 interface is between Non-RT-RIC and the Near-RT RIC functions [14].

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 [14]:

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

A1 policies have the following characteristics compared to persistent configuration [14]. 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.

4.4.2 O1 Interface

The O1 interface is between O-RAN Managed Element and the management entity as defined in [12].

4.4.3 O2 Interface

The O2 interface is between the SMO and O-Cloud as introduced in [18].

4.4.4 E2 Interface

E2 is a logical interface connecting the near-RT RIC with an E2 Node as defined in [15].

- 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 [15]).
- Near-RT RIC support functions, which include E2 Interface Management (E2 Setup, E2 Reset, Reporting of General Error Situations) and Near-RT RIC Service Update (i.e., capability exchange related to the list of E2 Node functions exposed over E2).

4.4.5 Open Fronthaul Interface

The Open Fronthaul Interface is between O-DU and O-RU functions [16] [17]. The Open Fronthaul Interface includes the CUS (Control User Synchronization) Plane and M (Management) Plane.

4.4.6 E1 Interface

The E1 interface, as defined by 3GPP, is between the gNB-CU-CP and gNB-CU-UP logical nodes [7] [9]. 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.

4.4.7 F1-c Interface

The F1-c interface, as defined by 3GPP, is between the gNB-CU-CP and gNB-DU logical nodes [7] [10]. 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.

4.4.8 F1-u Interface

The F1-u interface, as defined by 3GPP, is between the gNB-CU-UP and gNB-DU logical nodes [7] [10]. 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.

4.4.9 NG-c Interface

The NG-c interface, as defined by 3GPP, is between the gNB-CU-CP and the AMF in the 5GC [6]. It is also referred as N2 in [6]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted between the O-CU-CP and the 5GC.

4.4.10 NG-u Interface

The NG-u interface, as defined by 3GPP, is between the gNB-CU-UP and the UPF in the 5GC [6]. It is also referred as N3 in [6]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted between the O-CU-UP and the 5GC.

4.4.11 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 [5] [6]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted for the definition of interoperability profile specifications.

4.4.12 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 [5] [6]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted for the definition of interoperability profile specifications.

4.4.13 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 [6] [8]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted for the definition of interoperability profile specifications.

4.4.14 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 [6] [8]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted for the definition of interoperability profile specifications.

4.4.15 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, please refer to chapters 5.2 and 5.3 of [7].

Chapter 5. 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 are described in (IM specification will be published by Working Group 1).

Annex A (Informative): Implementation Options of 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.

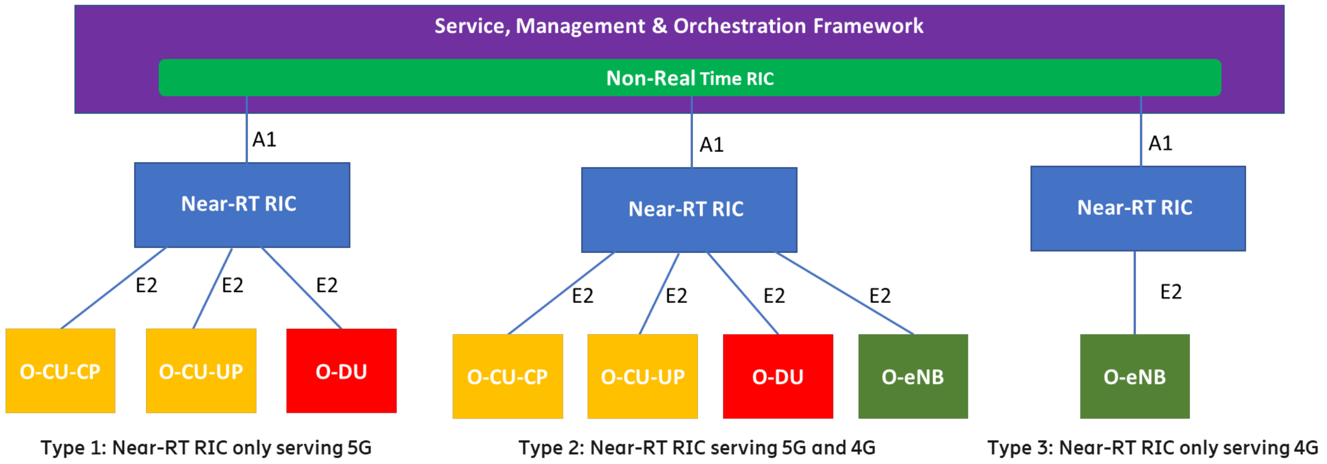

Figure 5: Centralized Near-RT RIC Serving 4G and 5G Simultaneously

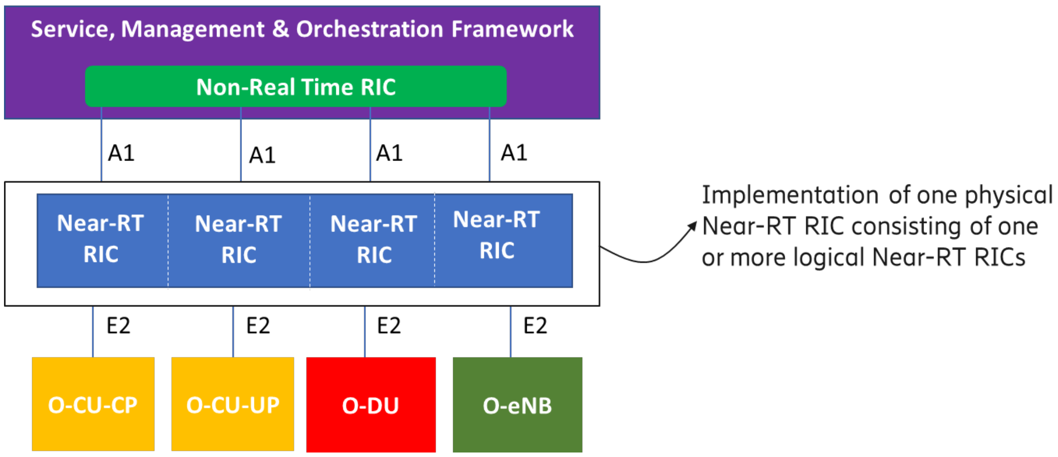

Figure 6: Distributed Near-RT RIC

Annex ZZZ : O-RAN Adopter License Agreement

BY DOWNLOADING, USING OR OTHERWISE ACCESSING ANY O-RAN SPECIFICATION, ADOPTER AGREES TO THE TERMS OF THIS AGREEMENT.

This O-RAN Adopter License Agreement (the "Agreement") is made by and between the O-RAN Alliance and the entity that downloads, uses or otherwise accesses any O-RAN Specification, including its Affiliates (the "Adopter").

This is a license agreement for entities who wish to adopt any O-RAN Specification.

Section 1: DEFINITIONS

1.1 "Affiliate" means an entity that directly or indirectly controls, is controlled by, or is under common control with another entity, so long as such control exists. For the purpose of this Section, "Control" means beneficial ownership of fifty (50%) percent or more of the voting stock or equity in an entity.

1.2 "Compliant Implementation" means any system, device, method or operation (whether implemented in hardware, software or combinations thereof) that fully conforms to a Final Specification.

1.3 "Adopter(s)" means all entities, who are not Members, Contributors or Academic Contributors, including their Affiliates, who wish to download, use or otherwise access O-RAN Specifications.

1.4 "Minor Update" means an update or revision to an O-RAN Specification published by O-RAN Alliance that does not add any significant new features or functionality and remains interoperable with the prior version of an O-RAN Specification. The term "O-RAN Specifications" includes Minor Updates.

1.5 "Necessary Claims" means those claims of all present and future patents and patent applications, other than design patents and design registrations, throughout the world, which (i) are owned or otherwise licensable by a Member, Contributor or Academic Contributor during the term of its Member, Contributor or Academic Contributorship; (ii) such Member, Contributor or Academic Contributor has the right to grant a license without the payment of consideration to a third party; and (iii) are necessarily infringed by a Compliant Implementation (without considering any Contributions not included in the Final Specification). A claim is necessarily infringed only when it is not possible on technical (but not commercial) grounds, taking into account normal technical practice and the state of the art generally available at the date any Final Specification was published by the O-RAN Alliance or the date the patent claim first came into existence, whichever last occurred, to make, sell, lease, otherwise dispose of, repair, use or operate a Compliant Implementation without infringing that claim. For the avoidance of doubt in exceptional cases where a Final Specification can only be implemented by technical solutions, all of which infringe patent claims, all such patent claims shall be considered Necessary Claims.

1.6 "Defensive Suspension" means for the purposes of any license grant pursuant to Section 3, Member, Contributor, Academic Contributor, Adopter, or any of their Affiliates, may have the discretion to include in their license a term allowing the licensor to suspend the license against a licensee who brings a patent infringement suit against the licensing Member, Contributor, Academic Contributor, Adopter, or any of their Affiliates.

Section 2: COPYRIGHT LICENSE

2.1 Subject to the terms and conditions of this Agreement, O-RAN Alliance hereby grants to Adopter a nonexclusive, nontransferable, irrevocable, non-sublicensable, worldwide copyright license to obtain, use and modify O-RAN Specifications, but not to further distribute such O-RAN Specification in any modified or unmodified way, solely in furtherance of implementations of an O-RAN

Specification.

2.2 Adopter shall not use O-RAN Specifications except as expressly set forth in this Agreement or in a separate written agreement with O-RAN Alliance.

Section 3: FRAND LICENSE

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

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

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

Section 4: TERM AND TERMINATION

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

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

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

Section 5: CONFIDENTIALITY

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

Section 6: INDEMNIFICATION

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

Section 7: LIMITATIONS ON LIABILITY; NO WARRANTY

EXCEPT FOR BREACH OF CONFIDENTIALITY, ADOPTER'S BREACH OF SECTION 3, AND ADOPTER'S INDEMNIFICATION OBLIGATIONS, IN NO EVENT SHALL ANY PARTY BE LIABLE TO ANY OTHER

PARTY OR THIRD PARTY FOR ANY INDIRECT, SPECIAL, INCIDENTAL, PUNITIVE OR CONSEQUENTIAL DAMAGES RESULTING FROM ITS PERFORMANCE OR NON-PERFORMANCE UNDER THIS AGREEMENT, IN EACH CASE WHETHER UNDER CONTRACT, TORT, WARRANTY, OR OTHERWISE, AND WHETHER OR NOT SUCH PARTY HAD ADVANCE NOTICE OF THE POSSIBILITY OF SUCH DAMAGES. O-RAN SPECIFICATIONS ARE PROVIDED “AS IS” WITH NO WARRANTIES OR CONDITIONS WHATSOEVER, WHETHER EXPRESS, IMPLIED, STATUTORY, OR OTHERWISE. THE O-RAN ALLIANCE AND THE MEMBERS, CONTRIBUTORS OR ACADEMIC CONTRIBUTORS EXPRESSLY DISCLAIM ANY WARRANTY OR CONDITION OF MERCHANTABILITY, SECURITY, SATISFACTORY QUALITY, NONINFRINGEMENT, FITNESS FOR ANY PARTICULAR PURPOSE, ERROR-FREE OPERATION, OR ANY WARRANTY OR CONDITION FOR O-RAN SPECIFICATIONS.

Section 8: ASSIGNMENT

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

Section 9: THIRD-PARTY BENEFICIARY RIGHTS

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

Section 10: BINDING ON AFFILIATES

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

Section 11: GENERAL

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

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

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

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

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

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