O-RAN-WG6.CAD-V01.00.00
Technical Report

Cloud Architecture and Deployment Scenarios for O-RAN Virtualized RAN

Revision History

Date	Revision	Company	Description
2019.01.18	V0000.00	AT&T, Orange, Lenovo, …	Template with initial scenarios.
2019.01.29	V00.00.01	Editor (AT&T)	Updates to terminology, miscellaneous other updates
2019.02.07	V00.00.02	Editor (AT&T)	More definitions in 2.1, New Sec 4 on Overall Architecture, expansion/ updates of sec 5 Profiles, added Sec 6 OAM placeholder.
2019.03.18	V00.00.03	Editor (AT&T)	Many additions in content and section structure.
2019.04.01	V00.00.04	Editor (AT&T)	Some restructuring and combining of early sections, and more discussion on scope and context. Addition of implementation consideration section, including performance. Added optional Fronthaul GW. Provided framework discussion in each scenario's subsection. Other updates.
2019.04.10	V00.00.05	Aricent, Red Hat, KDDI, Ciena	Updates to include comments before April 11 review. Comments from RaviKanth (Aricent), Pasi (Red Hat), Shinobu (KDDI), and Lyndon (Ciena).
2019.04.15	V00.00.06	Editor (AT&T)	Updates to include some updates from comments from April 11 review.
2019.04.24	V00.00.07	Editor (AT&T)	Updates of diagrams to address comments, additional figures on scope, and other changes to address April 11 review comments.
2019.05.01	V00.00.08	KDDI	Updates to diagrams for Scenarios A and B. Modifications per KDDI regarding C.2.
2019.05.12	V00.00.09	KDDI, Red Hat, Editor (AT&T)	Updates based on meeting discussions, subsection additions based on proposals.
2019.05.15	V00.00.10	Editor (AT&T)	Clean-up in preparation of creating a baseline document – marking of many comments as done, adding editor notes where needed, and other clarifications.
2019.05.20	V00.00.11	Editor (AT&T)	Continued clean-up in preparation of a baseline.
2019.05.29	V00.00.12	Editor (AT&T)	Continued clean-up in preparation of a baseline.
2019.06.04	V00.00.13	Wind River, China Mobile	Major additions to the Cloud requirements in section 5.4 and Appendix B by Wind River, plus updates to the Fronthaul section from China Mobile. Various additional minor updates.
2019.06.13	V00.01.00	Editor (AT&T)	This is the same as V00.00.13, but with renumbering to indicate this is the initial baseline for comment, V00.01.00
2019.06.14	V00.01.01	Wind River, AT&T	This includes updates from CRs discussed and agreed to on the June 13 call: • Wind River contributions on adding a figure for NUMA illustration and a major enhancement of Sec 9.1 on cache • AT&T contribution to add material on centralization of O-DU/O-CU resources, to Sections 5.1 and 6.2 • Update of figures to address Open Fronthaul comments (discussed June 6)

2019.07.05	V00.01.02	Editor (AT&T), based on meeting discussion	Updates to address several CRs:
			• Multiple editorial items:
			  ○ Draft text to address 5G/4G scope in Sec 1.2 – further discussion via separate CR
			  ○ Statement in 5.2 about performance to focus on delay
			  ○ Statement in 5.7 about transport
			  ○ 5.8; update of Figure 13 to indicate cloud locations. Added MEC text that to address MEC comment during call.
			  ○ Delay and loss table updates in 6, and statement in 5.2
			• Former 9.1 and 9.3 sections of Appendix B (on cache and storage details) will be transferred to Tong's document (Reference Design).
			• Update the O-DU pooling analysis in Section 5.1.3.

2019.07.18	V00.01.03	AT&T, Red Hat, TIM, Intel, Ericsson	Updates to address multiple CRs, through July 18: • Address NSA aspects in scope • Addition of 5.3 (Acceleration) • Removal of Scale up/down appendix, and note for future study • Update of delay figure in 5.2. • Update of Figure 4 • Replacement of Zbox concept with O-Cloud, and all related updates.
2019.08.02	V00.01.04	AT&T, Wind River, Red Hat	Updates to address multiple CRs, discussed on Aug 1: • Update Section 5.6, merge in sec 7, explain some fundamental operations concepts. • Update the sync section to point to work in other WGs, and say that text will wait until CAD version 2. • Update the delay section (5.2.1) • Remove notes that refer to items that will not receive contributions in version 1. Remove comments that are no longer relevant. • Remove Appendix A
2019.08.09	V00.01.05	Red Hat, TIM, DT, Editor (AT&T)	Updates to address multiple CRs and DT review comments, discussed on Aug 8. • Update 5.2.1 to address non-optimal fronthaul, and to correct some equations • Update 5.6 to add a figure showing the O1* interface • Addressed a range of comments by DT, some editorial, some more involved.
2019.08.16	V00.01.06	Ericsson, Wind River, AT&T	Updates to address multiple CRs and DT review comments, discussed on Aug 15. • Updates to address Ericsson's comments • Update to address DT's request to define vO-DU tile • Update of the Cloud Considerations section (5.4), mostly for restructuring to remove duplication, but to also add material for VMs or Containers where necessary to provide balanced coverage. • Additional updates: Many resolved and obsolete Word comments have been removed in anticipation of finalization. • References to documents that are not finalized have been removed.
2019.08.23	V00.01.07	AT&T	Updates to reflect: • Updates of the O-DU pooling section based on Aug 20 discussion • Management section updates are to address comments made on Aug 15 discussion, particularly regarding the

			use of the term domain manager and its role in an ME, and the location of O1 terminations • Edits to remove references to O-RAN WGs, and make updates of the revision history. • Addition of standard O-RAN Annex ZZZ
2019.08.26	V00.01.08	Editor (AT&T)	• Clean up of references and cross references to them • Removed Word comments • Removed cardinality questions in Scenarios A (removed 6.1.1) and Scenario B
2019.08.26	V00.01.09	Editor (AT&T)	Final minor comments during Aug 27 WG6 call, in preparation for vote.
2019.10.01	V01.00.00	Editor (AT&T)	Update of Annex ZZZ, page footers, and addition of title page disclaimer.

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1. Scope

This Technical Report has been produced by the O-RAN Alliance.

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

Version 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.

1.1. Context; Relationship to Other O-RAN Work

This document introduces and examines different scenarios and use cases for O-RAN deployments of Network Functionality into Cloud Platforms and proprietary equipment. Deployment scenarios are associated with meeting customer and service requirements, while considering technological constraints and the need to create cost-effective solutions. It will also reference management considerations covered in more depth elsewhere.

Two O-RAN management documents will be referenced (see Section 5.6):

- OAM architecture specification
- OAM interface specification (O1)

The details of implementing each identified scenario will be covered in separate Scenario documents, shown in green in Figure 1.

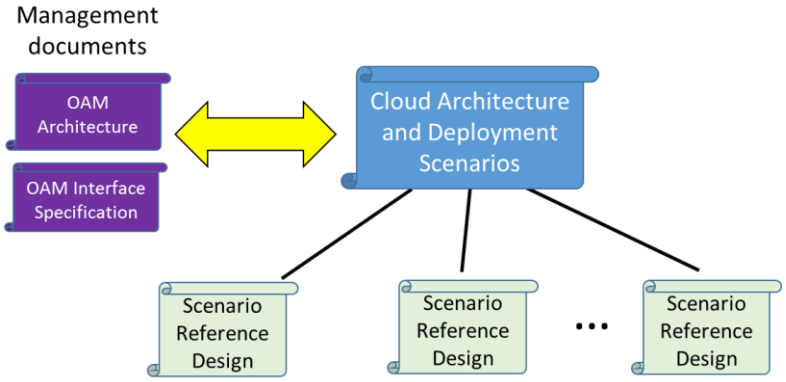


Figure 1: Relationship of this Document to Scenario Documents and O-RAN Management Documents

This document also draws on some other work from other O-RAN working groups, as well as sources from other industry bodies.

1.2. Objectives

The O-RAN Alliance seeks to improve RAN flexibility and deployment velocity, while at the same time reducing the capital and operating costs through the adoption of cloud architectures. The structure of the Orchestration and Cloudification work is shown graphically below. This document focuses on the Cloudification deployment aspects as indicated.

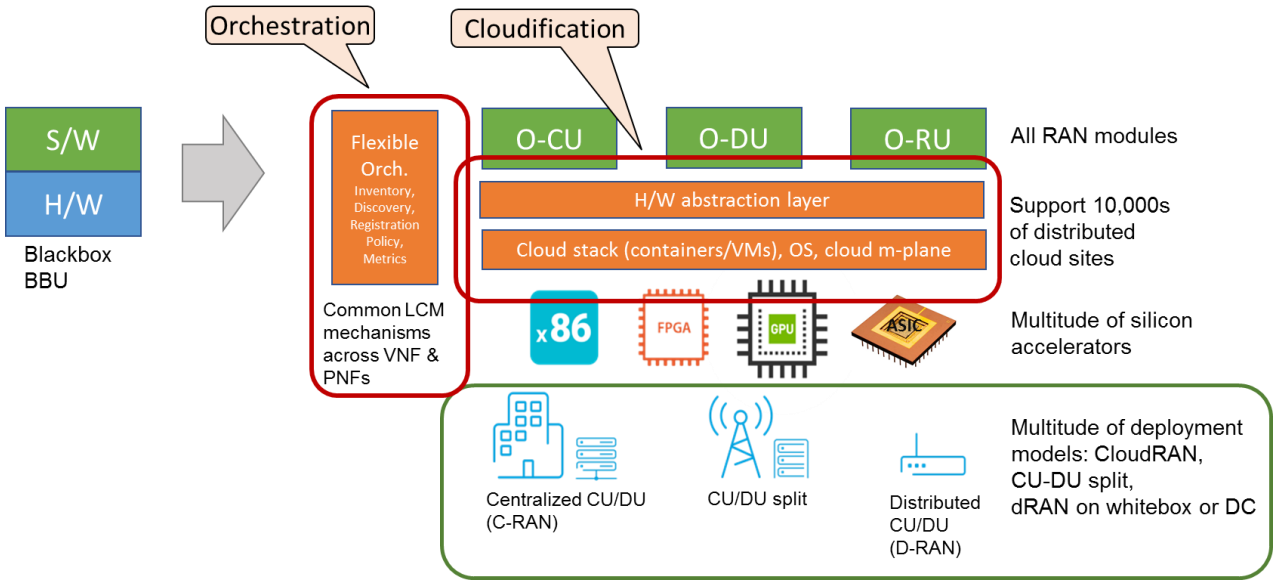


Figure 2: Major Components Related to the Orchestration and Cloudification Effort

A key principle is the decoupling of RAN hardware and software for all components including near-RT RIC, O-CU (O-CU-CP and O-CU-UP), O-DU, and O-RU, and the deployment of software components on commodity server architectures supplemented with programmable accelerators where necessary.

Key characteristics of cloud architectures which we will reference in this document are:

a) Decoupling of hardware from software. This aims to improve flexibility and choice for operators by decoupling selection and deployment of hardware infrastructure from software selection,

b) Standardization of hardware specifications across software implementations, to simplify physical deployment and maintenance. This aims to promote the availability of a multitude of *software* implementation choices for a given hardware configuration.

c) Sharing of hardware. This aims to promote the availability of a multitude of *hardware* implementation choices for a given software implementation.

d) Flexible instantiation and lifecycle management through orchestration automation. This aims to reduce deployment and ongoing maintenance costs by promoting simplification and automation throughout the hardware and software lifecycle through common chassis specifications and standardized orchestration interfaces.

This document will define various deployment scenarios that can be supported by the O-RAN specifications and are of either current or relatively near-term interest. Each scenario is identified by a specific grouping of functionality at different key locations (Cell Site, Edge Cloud, and Regional Cloud, which will be defined shortly), and an identification of whether functionality at a given location is provided by a proprietary solution with software coupled with hardware, or by a cloud architecture that meets the above requirements.

The scope of this work clearly includes supporting all 5G technologies, i.e. E-UTRA and NR with both EPC-based Non-Standalone (NSA) and 5GC architectures. This implies that cloud/orchestration aspects of NSA (E-UTRA) are also supported. However, Version 1 primarily addresses 5G SA deployments.

This technical report examines the constraints that drive a specific solution, and discuss the hierarchical properties of each solution, including a rough scale of the size of each cloud and a sense of the number of sub clouds expected to be served by a higher cloud. Figure 3 shows as example of how multiple cell sites feed into a smaller number of Edge Clouds, and how in turn multiple Edge Clouds feed into a Regional Cloud. For a given scenario, the Logical Functions are distributed in a certain way among each type of cloud, and the "cardinality" of the different functions will be discussed.

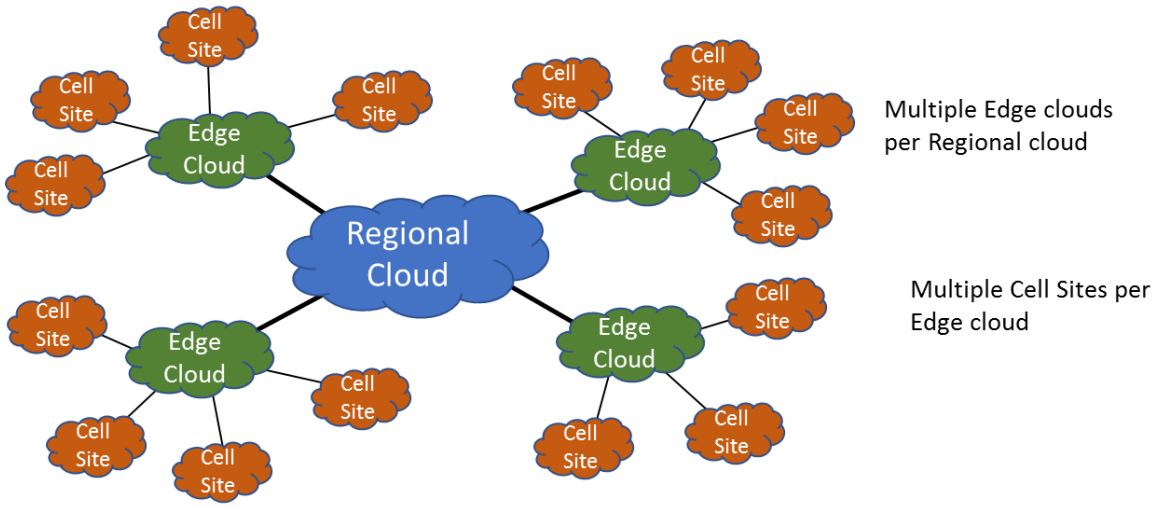


Figure 3: Different Clouds/ Sites

This has implications on the processing power needed in each type of cloud, as well as implications on the environmental requirements. This document will also discuss considerations of hardware chassis and components that are reasonable in each scenario, and the implications of managing such a cloud.

Additional major areas for this document are listed below:

- Mapping of logical functions to physical elements and locations, and implications of that mapping.
- High-level assessment of critical performance requirements, and how that influences architecture.
- Processor and accelerator options (e.g., x86, FPGA, GPU). In order to determine whether a Network Function is a candidate for openness, there needs to be the possibility to have multiple suppliers of software for given hardware, and multiple sources of required chip/accelerators.
  - The Hardware Abstraction Layer, aka "Acceleration Abstraction Layer" needs to be addressed in light of various hardware options that could be used.
- Cloud infrastructure makeup. This includes considerations such as:
  - Deployments are allowed to use VMs, Containers in VMs, or just Containers.
  - Multiple Operating Systems are expected to be supported; e.g., open source Ubuntu, CentOS Linux, or Yocto Linux-based distributions, or selected proprietary OSs.
- Management of a cloudified RAN introduces some new management considerations, because the mapping between Network Functionality and cloud platforms can be done in multiple ways, depending on the scenario that is chosen. Thus, management of aspects that are related to platform aspects rather than RAN functional aspects need to be designed with flexibility in mind from the start. For example, logging of physical functions, scale out actions, and survivability considerations are affected.
  - These management considerations are introduced in this document, but management documents will address the solutions.
- The transport layer will be discussed, but only to the extent that it affects the architecture and design of the network. For example, the chosen L1 technology may affect the performance of transport. As another example, the use of a Fronthaul Gateway will affect economics as well as the placement options of certain Network Functions. And of course, the existence of L2 switches in a cloud platform deployment will be required for efficient use of server resources.

Additional areas could be considered in the future.

2. References

The following documents contain provisions which, through reference in this text, constitute provisions of this report.

[1] 3GPP TS 38.470, *NG-RAN; F1 general aspects and principles (Release 15)*, July 2019.

[2] 3GPP TR 21.905: *Vocabulary for 3GPP Specifications*.

[3] eCPRI Interface Specification V1.2 (2018-06-25): *Common Public Radio Interface: eCPRI Interface Specification*

[4] eCPRI Transport Network V1.2 (2018-06-25) Requirements Specification: *Common Public Radio Interface: Requirements for the eCPRI Transport Network*

[5] IEEE Std 802.1CM-2018 - *Time-Sensitive Networking for Fronthaul*

[6] ITU-T Technical Report, *GSTR-TN5G - Transport network support of IMT-2020/5G*, October 2018.

[7] *O-RAN Fronthaul Control, User and Synchronization Plane Specification*, Technical Specification O-RAN-WG4.CUS.0-v02.00, August 2019. See https://www.o-ran.org/specifications.

[8] *O-RAN Operations and Maintenance Architecture – v01.00*, O-RAN Alliance Technical Specification, August 2019. See https://www.o-ran.org/specifications.

[9] *O-RAN Operations and Maintenance Interface Specification – v1.0*, O-RAN Alliance Technical Specification, August 2019. See https://www.o-ran.org/specifications .

3. Definitions and Abbreviations

3.1. Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [2] 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 [2].

Cell Site	This refers to the location of Radio Units (RUs); e.g., placed on same structure as the Radio Unit or at the base. The Cell Site in general will support multiple sectors and hence multiple O-RUs.
Edge Cloud	This is a location that supports virtualized RAN functions for multiple Cell Sites, and provides centralization of functions for those sites and associated economies of scale. An Edge Cloud might serve a large physical area or a relatively small one close to its cell sites, depending on the Operator's use case. However, the sites served by the Edge Cloud must be near enough to the O-RUs to meet the delay requirements of the O-DU functions.
F1 Interface	The open interface between O-CU and O-DU in this document is the same as that defined by the CU and DU split in 3GPP TS 38.473. It consists of an F1-u part and an F1-c part.
Managed Element	Term used in OAM to refer to a single entity managed as a whole by the Network Management System (NMS). The Managed Element may contain multiple Managed or Network Functions and be physically deployed over one or more cloud platforms depending on the requirements of the Managed Functions.
Managed Function	Term used in OAM to refer to a distinct *logical* function that is managed. Examples include near-RT RIC, O-CU-CP, O-CU-UP, O-DU, and O-RU. *From the OAM Framework document:* 3GPP TS 28.622 states that a Managed Function (MF) can represent a telecommunication function either realized by software running on dedicated hardware or realized by software running on NFVI. Each managed function instance communicates with a manager (directly or indirectly) over one or more management interfaces exposed via its containing managed element instance.
Network Function	The near-RT RIC, O-CU-CP, O-CU-UP, O-DU, and O-RU *logical* functions that can be provided either by virtualized or non-virtualized methods.
Regional Cloud	This is a location that supports virtualized RAN functions for many Cell Sites in multiple Edge Clouds, and provides high centralization of functionality.

O-Cloud	An O-RAN compliant cloud platform that is based on a server compute style architecture, and uses hardware accelerator add-ons where needed and a software stack that is decoupled from the hardware. It supports O-RAN-specified management interfaces.

3.2. Abbreviations

For the purposes of this document, the abbreviations given in 3GPP TR 21.905 [2] 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 [2].

3GPP	Third Generation Partnership Project
5G	Fifth-Generation Mobile Communications
API	Application Programming Interface
ASIC	Application-Specific Integrated Circuit
BBU	BaseBand Unit
BS	Base Station
CI	Cloud Infrastructure
CoMP	Co-Ordinated Multi-Point transmission/reception
CNF	Cloud-Native Network Function
CNI	Container Networking Interface
CPU	Central Processing Unit
CR	Cell Radius
CU	Centralized Unit as defined by 3GPP
DFT	Discrete Fourier Transform
DL	Downlink
DPDK	Data Plan Development Kit
DU	Distributed Unit as defined by 3GPP
eMBB	enhanced Mobile BroadBand
EPC	Evolved Packet Core
E-UTRA	Evolved UMTS Terrestrial Radio Access
FCAPS	Fault Configuration Accounting Performance Security
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FH	Fronthaul
FH GW	Fronthaul Gateway
FPGA	Field Programmable Gate Array
GPP	General Purpose Processor
GPU	Graphics Processing Unit
HARQ	Hybrid Automatic Repeat reQuest
HW	Hardware
IEEE	Institute of Electrical and Electronics Engineers
IM	Information Modelling, or Information Model
IRQ	Interrupt ReQuest
ISA	Instruction Set Architecture
ISD	Inter-Site Distance
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LCM	Life Cycle Management
LDPC	Low-Density Parity-Check
LTE	Long Term Evolution
LVM	Logic Volume Manager
MEC	Mobile Edge Computing
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
NF	Network Function
NFD	Node Feature Discovery
NFVI	Network Function Virtualization Infrastructure
NIC	Network Interface Card
NMS	Network Management System
NR	New Radio
NSA	Non-Standalone

NUMA	Non-Uniform Memory Access
NVMe	Non-Volatile Memory Express
O-Cloud	O-RAN Cloud Platform
OCP	Open Compute Project
O-CU	O-RAN Central Unit
O-CU-CP	O-CU Control Plane
O-CU-UP	O-CU User Plane
O-DU	O-RAN Distributed Unit (uses Lower-level Split)
O-RU	O-RAN Radio Unit
OTII	Open Telecom IT Infrastructure
OWD	One-Way Delay
PCI	Peripheral Component Interconnect
PNF	Physical Network Function
PoE	Power over Ethernet
PoP	Point of Presence
PTP	Precision Time Protocol
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RIC	RAN Intelligent Controller
RT	Real Time
RTT	Round Trip Time
RU	Radio Unit
SA	Standalone
SFC	Service Function Chaining
SMO	Service Management and Orchestration
SMP	Symmetric MultiProcessing
SoC	System on Chip
SR-IOV	Single Root Input/ Output Virtualization
SW	Software
TCO	Total Cost of Ownership
TNE	Transport Network Element
TR	Technical Report
TRP	Transmission Reception Point
TS	Technical Specification
Tx	Transmitter
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UP	User Plane
UPF	User Plane Function
URLLC	Ultra-Reliable Low-Latency Communications
vCPU	virtual CPU
VIM	Virtualized Infrastructure Manager
VNF	Virtualized Network Function
vO-CU	Virtualized O-RAN Central Unit
vO-CU-CP	Virtualized O-CU Control Plane
vO-CU-UP	Virtualized O-CU User Plane
vO-DU	Virtualized O-RAN Distributed Unit

4. Overall Architecture

This section addresses the overall architecture in terms of the Network Functions and infrastructure (PNFs, servers, and clouds) that are in scope.

4.1. RAN Component Definitions

This section reviews key RAN component definitions in O-RAN.

- The O-DU/ O-RU split is defined as using Option 7-2x. See [7].

- The O-CU/ O-DU split is defined as using the CU/ DU split F1 as defined in 3GPP TS 38.470 [1].

This document assumes these two splits.

Below is a depiction of RAN functionality (inside the gray dashed line), structured to be consistent with the discussion in this document. For example, note that the Platform is shown at the bottom, and a given function could be supported by a proprietary platform or by an O-Cloud, depending on the deployment scenario. The dashed line in the figure indicates a case in which the O-RU is implemented in a proprietary way, and the other functions are supported by an O-Cloud.

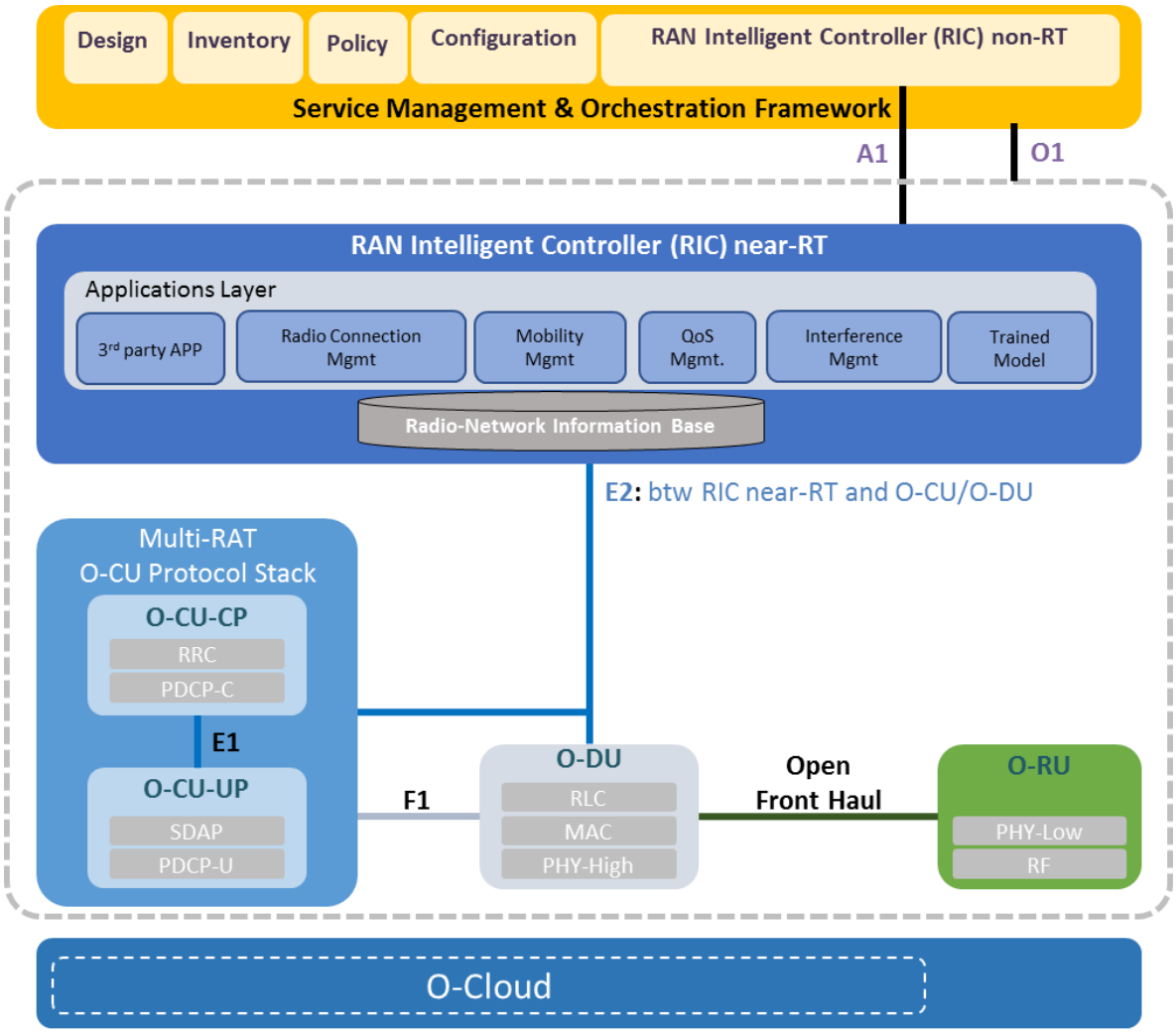


Figure 4: Architecture Overview

4.2. Degree of Openness

In theory, every architecture component could be open in every sense imaginable, but in practice it is likely that different components will have varying degrees of openness due to economic and other implementation considerations. Some factors are significantly affected by the deployment scenario; for example, what might be viable in an indoor deployment might not be viable in an outdoor deployment.

Increasing degrees of openness for a Physical Network Function (PNF) or cloud supporting RAN function(s) are:

A. Interfaces among Network Functions are open; e.g., E2, F1, and Open Fronthaul are used. Therefore, Network Functions in different PNFs/clouds from different vendors can interconnect.

B. In addition to having open connections as described above, the chassis of servers in a cloud are open and can accept blades/sleds from multiple vendors. However, the blades/sleds have RAN software that *is not* decoupled from the hardware.

C. In addition to having open connections and an open chassis, a specific blade/sled uses software that *is* decoupled from the hardware. In this scenario, the software could be from one supplier, the blade/sled could be from another, and the chassis could be from another.

Categories A and B have PNFs/clouds with proprietary internal designs. Category C is an open solution that we are calling an O-Cloud, and is subject to the cloudification discussion and requirements.

In this document, the degree of openness for each PNF/cloud can vary by scenario. The question of which Network Functions should be split vs. combined, and the degree of openness in each one, is addressed in the discussion of scenarios.

4.3. Decoupling of Hardware and Software

There are three layers that we must consider when we discuss decoupling of hardware and software:

- The hardware layer, shown at the bottom in Figure 5. (In the case of a VM deployment, this maps basically to the ETSI "NFVI HW" layer.)
- A middle layer that includes Cloud Stack functions as well as hardware abstraction functions. (In the case of a VM deployment, these seem to map to the ETSI "NFVI SW" + VIM.)
- A top layer that supports the virtual RAN functions.

Each layer can come from a different supplier. The first aspect of decoupling has to do with ensuring that a Cloud Stack can work on multiple suppliers' hardware; i.e., it does not require vendor-specific hardware.

The second aspect of decoupling has to do with ensuring that a Cloud Platform can support RAN virtualized functions from multiple RAN software suppliers. If this is possible, then we say that the Cloud Platform (which includes the hardware that it runs on) is an O-RAN Cloud Platform, or "O-Cloud". See Figure 5 below.

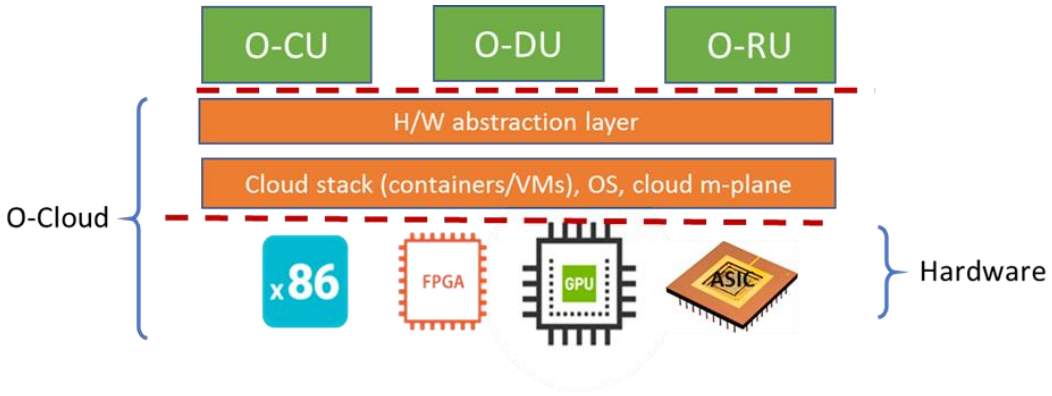


Figure 5: Decoupling, and Illustration of the O-Cloud Concept

The general definition of the O-Cloud Cloud Platform includes the following characteristics:

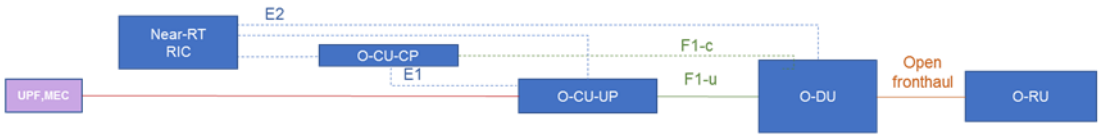
1. The Cloud Platform is a set of hardware and software components that provide cloud computing capabilities to execute RAN network functions.
2. The Cloud Platform hardware includes compute, networking and storage components, and may also include various acceleration technologies required by the RAN network functions to meet their performance objectives.
3. The Cloud Platform software exposes open and well-defined APIs that enable the management of the entire life cycle for network functions.
4. The Cloud Platform software is decoupled from the Cloud Platform hardware (i.e., it can typically be sourced from different vendors).

The scope of this document includes listing specific requirements of the Cloud Platform to support execution of the various O-RAN Network Functions.

An example of a Cloud Platform is an OpenStack and/or a Kubernetes deployment on a set of COTS servers (including FPGA and GPU cards), interconnected by a spine/leaf networking fabric.

There is an important interplay between specific virtualized RAN functions and the hardware that is needed to meet performance requirements and to support the functionality *economically*. Therefore, a hardware/ cloud platform combination that can support, say, a vO-CU function might not be appropriate to adequately support a vO-DU function. When RAN functions are combined in different ways in each specific deployment scenario, these aspects must be considered.

Below is a high-level conceptual example of how different accelerators, along with their associated cloud capabilities, can be required for different RAN functions. Although we do not specify any particular hardware requirement or cloud capability here, we can note some general themes. For example, any RAN function that involves real-time movement of user traffic will require the cloud platform to control for delay and jitter, which may in turn require features such as real-time OSs, avoidance of frequent interrupts, CPU pinning, etc.



Cloud/ HW features	Near-RT RIC	O-CU-CP	O-CU-UP	O-DU	O-RU
Standard Cloud Infrastructure (CI) & General Purpose CPU	✓	✓			
CI + high speed UP support. Acceleration optional			✓		
CI + high speed UP, acceleration for O-DU				✓	
CI + high speed UP, acceleration for O-RU					✓

Figure 6: Relationship Between RAN Functions and Demands on Cloud Infrastructure and Hardware

Please note that any cloud that has features required for a given function (e.g., for O-DU) can also support functions that do not require such features. For example, a cloud that can support O-DU can also support functions such as O-CU-CP.

5. Deployment Scenarios: Common Considerations

In any implementation of logical network functionality, decisions need to be made regarding which logical functions are mapped to which Cloud Platforms, and therefore which functions are to be co-located with other logical functions. In this document we do not prescribe one specific implementation, but we do understand that in order to establish agreements and requirements, the manner in which the Network Functions are mapped to the same or different Cloud Platforms must be considered.

We refer to each specific mapping as a "deployment scenario". In this section, we examine the deployment scenarios that are receiving the most consideration. Then we will select the one or ones that should be the focus of initial scenario reference design efforts.

5.1. Mapping Logical Functionality to Physical Implementations

There are many aspects that need to be considered when deciding to implement logical functions in distinct O-Clouds. Some aspects have to do with fundamental technical constraints and economic considerations, while others have to do with the nature of the services that are being offered.

5.1.1. Technical Constraints that Affect Hardware Implementations

Below are some factors that will affect the cost of implementations, and can drive a carrier to require separation of or combining of different logical functions.

- **Environment:** Equipment may be deployed in indoor controlled environments (e.g., Central Offices), semi-controlled environments (e.g., cabinets with fans and heaters), and exposed environments (e.g., Radio Units on

a tower). In general, the less controlled the environment, the more difficult and expensive the equipment will be. The required temperature range is a key design factor, and can drive higher power requirements.

- **Dimensions:** The physical dimensions can also drive deployment constraints – e.g., the need to fit into a tight cabinet, or to be placed safely on a tower or pole.
- **Transport technology:** The transport technology used for Fronthaul, Midhaul, and Backhaul is often fiber, which has an extremely low and acceptable loss rate. However, there are options other than fiber, in particular wireless/ microwave, where the potential for data loss must be considered. This will be discussed further in the next section.
- **Acceleration Hardware:** The need for acceleration hardware can be driven by the need to meet basic performance requirements, but can also be tied to some of the above considerations. For example, a hardware acceleration chip (COTS or proprietary) can result in lower power use, less generated heat, and smaller physical dimensions than if acceleration is not used. On the other hand, some types of hardware acceleration chips might not be "hardened" (i.e., they might only operate properly in a restricted environment), and could require a more controlled environment such as in a central office.

  The acceleration hardware most often referred to includes:

  - Field Programmable Gate Arrays (FPGAs)
  - Graphical Processing Units (GPUs)
  - System on Chip (SoC)
- **Standardized Hardware:** Use of standardized hardware designs and standardized form factors can have advantages such as helping to reduce operations complexity, e.g., when an operator makes periodic technology upgrades of selected components. An example would be to use an Open Compute Project (OCP) or Open Telecom IT Infrastructure (OTII) –based design.

5.1.2. Service Requirements that Affect Implementation Design

RANs can serve a wide range of services and customer requirements, and each market can drive some unique requirements. Some examples are below.

- **Indoor or outdoor deployment:** Indoor deployments (e.g., in a public venue like a sports stadium, train station, shopping mall, etc.) often enjoy a controlled environment for all elements, including the Radio Units. This can improve the economics of some indoor deployment scenarios. The distance between Network Functions tends to be much lower, and the devices that support O-RU functionality may be much easier and cheaper to install and maintain. This can affect the density of certain deployments, and the frequency that certain scenarios are deployed.
- **Bands supported, and Macro cell vs. Small cell:** The choice of bands (e.g., Sub-6 GHz vs. mmWave) might be driven by whether the target customers are mobile vs. fixed, and whether a clear line of sight to the customer is available or is needed. The bands to be supported will of course affect O-RU design. In addition, because mmWave carriers can support much higher channel width (e.g., 400 MHz vs. 20 MHz), mmWave deployments can require a great deal more O-DU and O-CU processing power. And of course the operations costs of deploying Macro cells vs. Small cells differ in other ways.
- **Performance requirements of the Application / Network Slice:** Ultimately, user applications drive performance requirements, and RANs are expected to support a very wide range of applications. For example, the delay requirements to support a Connected Car application using Ultra Reliable Low Latency Communications (URLLC) will be more demanding than the delay requirements for other types of applications. In our discussion of 5G, we can start by considering requirements separately for URLLC, enhanced Mobile Broadband (eMBB), and massive Machine Type Communications (mMTC).

The consideration of performance requirements is a primary one, and is the subject of Section 5.2.

5.1.3. Rationalization of Centralizing O-DU Functionality

Almost all Scenarios to be discussed in this document involve a degree of centralization of O-DU. In this section it is assumed that O-DU resources for a set of O-RUs are centralized at the same location.

Editor's Note: While most Scenarios also centralize O-CU-CP, O-CU-UP, and RIC in one form or another, the benefits of centralizing them are not discussed in this section.

Managing O-DU in equipment at individual cell sites (via on-site BBUs today) has multiple challenges, including:

- If changes are needed at a site (e.g., adding radio carriers), then adding equipment is a coarse-grained activity – i.e., one cannot generally just add "another 1/5 of a box", if that is all that is needed. Adding the minimum increment of additional capacity might result in poor utilization and thereby prevent expansion at that site.
- Cell sites are in many separate locations, and each requires establishment and maintenance of an acceptable environment for the equipment. In turn this requires separate visits for any physical operations.
- Micro sites tend to have much lower average utilization than macro sites, but each can experience considerable peaks.
- "Planned obsolescence" occurs, due to ongoing evolution of smartphone capabilities and throughput improvements, as well as introduction of new features and services. It is common practice today to upgrade ("forklift replace") BBUs every 36-60 months.

These factors motivate the centralization of resources where possible. For the O-DU function, we can think of two types of centralization: *simple* centralization and *pooled* centralization.

If the equipment uses O-DU centralization in an Edge Cloud, at any given hour an O-RU will be using a single specific O-DU resource that is assigned to it (e.g. via Kubernetes). On a broad time scale, traffic from any cell site can be rehomed, without any physical work, to use other/additional resources that are available at that Edge Cloud location. This would likely be done infrequently; e.g., about as often as cell sites are expanded.

Centralization can have some additional benefits, such as only having to maintain a single large controlled environment for many cell sites rather than creating and maintaining many distributed locations that might be less controlled (e.g., outside cabinets or huts). Capacity can be added at the central site and assigned to cell sites as needed. Note that *simple* centralization still assigns each O-RU to a single O-DU resource[1], as shown below, and that traffic from one O-RU is not split into subsets that could be assigned to different O-DUs. Also note that a Fronthaul (FH) Gateway (GW) may exist between the cell site and the centralized resources, not only to improve economics but also to enable traffic re-routing when desired.

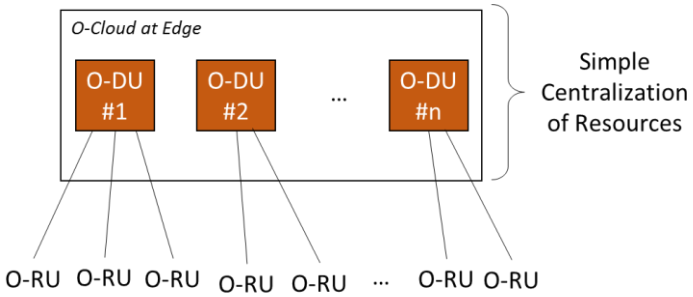


Figure 7: Simple Centralization of O-DU Resources

By comparison, with *pooled* centralization, traffic from an O-RU (or subsets of the O-RU's traffic) can be assigned more dynamically to any of several shared O-DU resources. So if one cell site is mostly idle and another experiences high traffic demand, the traffic can be routed to the appropriate O-DU resources in the shared pool. The total resources of this shared pool can be smaller than resources of distributed locations, because the peak of the sum of the traffic will be markedly lower than the sum of the individual cell site traffic peaks.

[1] In this figure, each O-DU block can be thought of as a unit of server resources that includes a hardware accelerator, a GPP, memory and any other associated hardware.

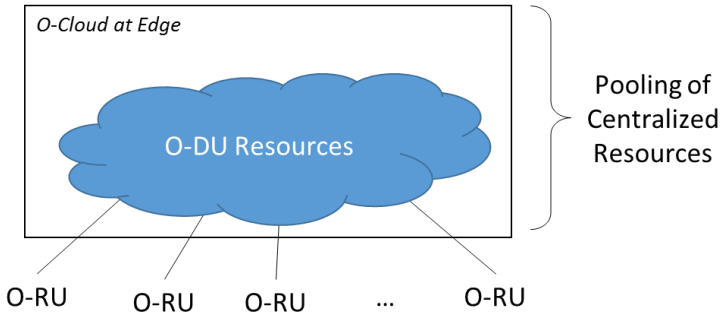


Figure 8: Pooling of Centralized O-DU Resources

We note that being able to share O-DU resources somewhat dynamically is expected to be a solvable problem, although we understand that it is by no means a trivial problem. There are management considerations, among others. There may be incremental steps toward true shared pooling, where rehoming of O-RUs to different O-DUs can be performed more dynamically, based on traffic conditions.

It is noted that O-DU centralization benefits the most dense networks where several cell sites are within the O-RU to O-DU latency limits. Sparsely populated areas most probably will be addressed by vO-CU centralization only.

Figure 9 shows the results of an analysis of a simulated greenfield deployment as an attempt to visualize the relative merit of simple centralization of O-DU ("oDU") vs. pooled centralization of O-DU ("poDU") vs. legacy DU ("BBU"), plotted against the realizable Cell Site pool size.

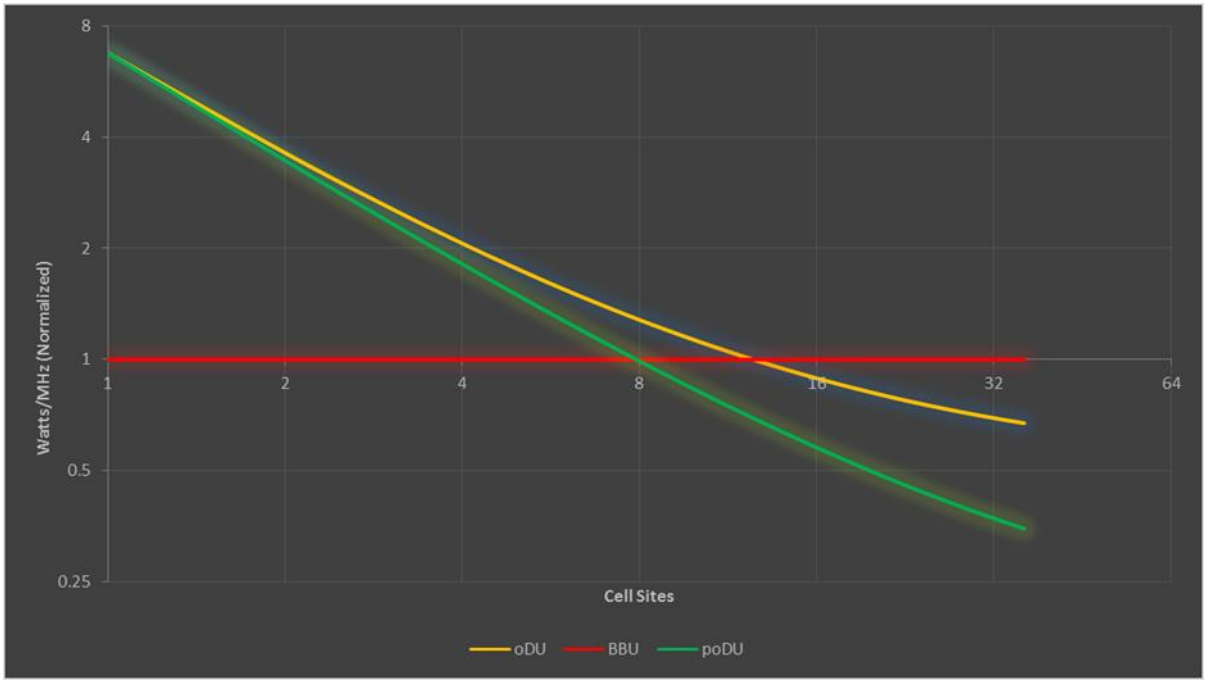


Figure 9: Comparison of Merit of Centralization Options vs. Number of Cell Sites in a Pool

An often-used measure is related to the power required to support a given number of carrier MHz. The lower the power used per carrier, the more efficient is the implementation. In Figure 9, the values of each curve are normalized to the metric of Watts/MHz for distributed legacy BBUs, normalized to equal 1. Please note that in this diagram, a lower value is better. The following assumptions apply to the figure:

- A legacy BBU processes X MHz (for carriers) and consumes Y watts. For example, a specific BBU might process 1600 MHz and consume 160 watts.
- N legacy BBUs will process N x X MHz and consume N x Y watts and have a merit figure of 1, per normalization. If a given site requires less than X MHz, it will still be necessary to deploy an X MHz BBU. For example, we may need only 480 MHz but still deploy a 1600 MHz BBU.

- Simple Centralization (the "oDU" line): In this case, active TRPs are statically mapped to specific VMs and vO-DU tiles[2]. Fewer vO-DU tiles are required to support the same number of TRPs, because MHz per site is not a constant.
  - Independent of resources to support active user traffic, a fixed power level is required to power Ethernet "frontplane" switches and hardware to support management and orchestration processes.
  - In a pool, processing capacity will be added over time as required.
  - Due to mobility traffic behavior, tiles will not be fully utilized, although centralization of resources will improve utilization when compared with a legacy BBU approach.
- Centralization with more dynamic pooling (the "poDU" line): In addition to active load balancing, individual traffic flows (which can last from a few hundreds of msecs to several seconds) will be routed to the least used tile, further optimizing (reducing) vO-DU tile requirements.
  - As in the simple centralization approach above, there is a fixed power level required for hardware that supports switching, management and orchestration processes.

As a final note, any form of centralization requires efficient transport between the O-RU and the O-DU resources. When O-RU functionality is distributed over a relatively large area (e.g., not concentrated in a single large building), the existence of a Fronthaul Gateway is a key enabler.

5.2. Performance Aspects

Performance requirements drive architectural and design considerations. Performance can include attributes such as delay, packet loss, transmission loss, and delay variation (aka "jitter").

Editor's Note: While all aspects are of interest, delay has the largest impact on network design and will be the focus of the current version of this document. Future versions can address other performance aspects if desired and is FFS.

5.2.1. User Plane Delay

This section discusses the framework for discussing delay of user-plane packets[3], and also general delay numbers that it can be agreed that apply across all scenarios. Details relevant to a specific Scenario will be discussed in each Scenario's subsection, as applicable. The purpose of these high-level targets is to act as a baseline for allocating the total latency budget to subsystems that are on the path of each constraint, as required for system engineering and dimensioning calculations, and to assess the impact on the function placement within the specific network site tiers.

The goal is to establish reasonable maximum delay targets, as well as to identify and document the major infrastructure as well as O-RAN NF-specific delay contributing components. For each service or element, minimum delay should be considered to be zero. The implication of this is that any of the elements can be moved towards the Cell Site (e.g. in a fully distributed Cloud RAN configuration, all of O-CU-UP, O-DU and O-RU would be distributed to Cell Site).

In real network deployments, the expectation is that, depending on the operator-specific implementation constraints such as location and fiber availability, deployment area density, etc., deployments result in anything between the fully distributed and maximally centralized configuration. Even on one operator's network, it is common that there are many different sizes of Edge Cloud instances, and combinations of Centralized and Distributed architectures in same network are also common (e.g. network operator may choose to centralize the deployments on dense Metro areas to the extent possible and distribute the configurations on suburban/rural areas with larger cell sizes / cell density that do not translate to pooling benefits from more centralized architecture). However, the maximum centralization within the constraints of latencies that can be tolerable is useful for establishing the basis for dimensioning of the maximum sizes, especially for the Edge and Regional cloud PoPs.

Figure 10 below illustrates the relationship among some key delay parameters.

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[2] A "vO-DU tile" refers to a chip or System on Chip (SoC) that provides hardware acceleration for math-intensive functionality such as that required for Digital Signal Processing. With the Option 7.2x split, acceleration of Forward Error Correction (FEC) functionality is required, and other functionality could be considered for acceleration if desired.

[3] Delay of control plane or OAM traffic is not considered in this section.

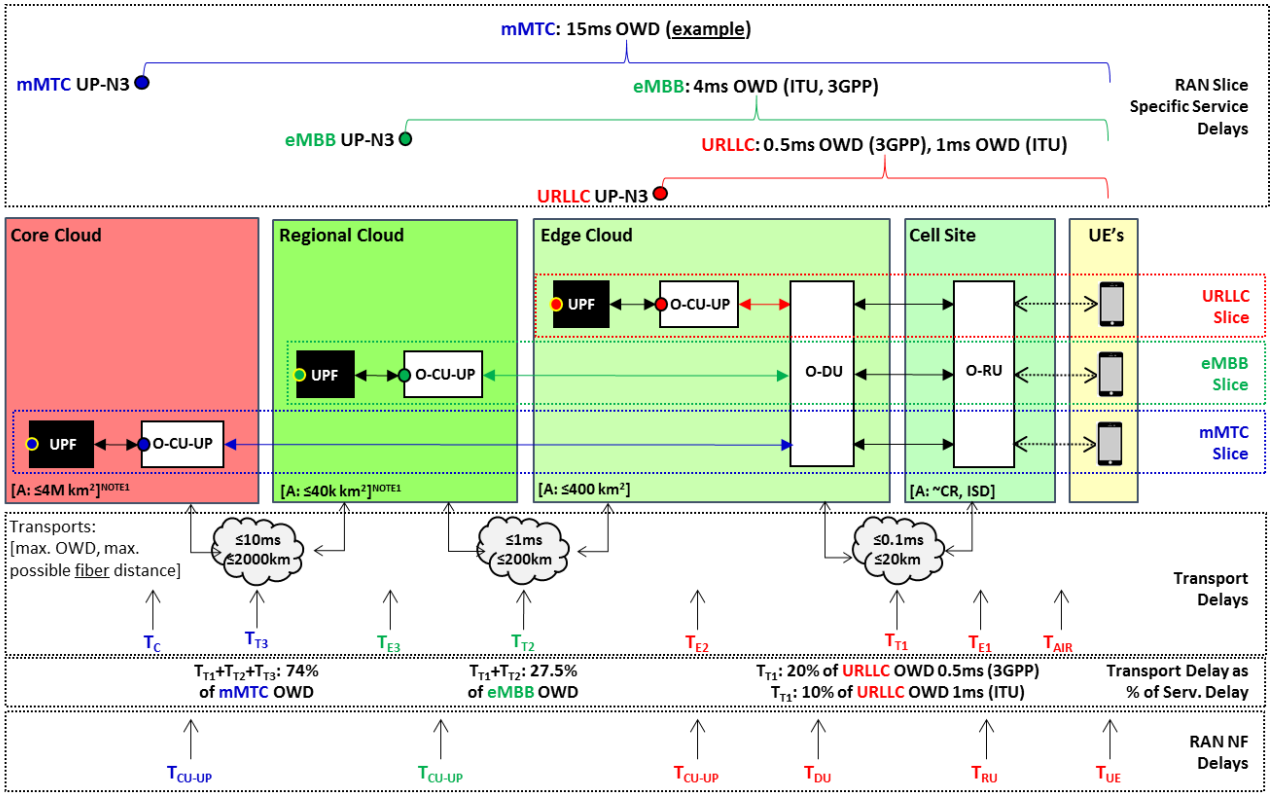

Figure 10: Major User Plane Latency Components, by 5G Service Slice and Function Placement

Please note the following:

- NOTE 1: If the T2 or/and T3 transport network(s) is/are Packet Transport Network(s), then time allocation for the transport network elements processing and queuing delays will require some portion of maximum latency allocation, and will require reduction of the maximum area accordingly.
- NOTE 2: Site Internal / fabric networks are not shown for clarity, but need some latency allocation (effectively extensions or part of transport delays; per PoP tier designations T_{E1}, T_{E2}, T_{E3} and T_C).
- NOTE 3: To maximize the potential for resource pooling benefits, minimize network function redundancy cost, and minimize the amount of hardware / power in progressively more distributed sites (towards UEs), target design should attempt to maximize the distances and therefore latencies available for transport networks within the service- and RAN-specific time constraints, especially for T_{T1}.
- NOTE 4: UPF, like EC/MEC, is outside of the scope of O-RAN, so UPF shown as a "black box" to illustrate where it needs to be placed in context of specific services to be able to take advantage of the RAN service-specific latency improvements.

Figure 10 represents User Equipment locations on the right, and network tiers towards the left, with increasing latency and increasing maximum area covered per tier towards the left. These Mobile Network Operator's (MNO's) Edge tiers are nominated as Cell Site, Edge Cloud, and Regional Cloud, with one additional tier nominated as Core Cloud in the figure.

The summary of the associated latency constraints as well as major latency contributing components as depicted in Figure 10 above is given in Table 1, below.

Table 1: Service Delay Constraints and Major Delay Contributors

RAN Service-Specific User Plane Delay Constraints			
Identifier	**Brief Description**	**Max. OWD (ms)**	**Max. RTT (ms)**
URLLC	Ultra-Reliable Low Latency Communications (3GPP)	0.5	1
URLLC	Ultra-Reliable Low Latency Communications (ITU)	1	2
eMBB	enhanced Mobile Broadband	4	8

mMTC	massive Machine Type Communications	15	30
Transport Specific Delay Components			
T_{AIR}	Transport propagation delay over air interface		
T_{E1}	Cell Site Switch/Router delay		
T_{T1}	Transport delay between Cell Site and Edge Cloud	0.1	0.2
T_{E2}	Edge Cloud Site Fabric delay		
T_{T2}	Transport delay between Edge and Regional Cloud	1	2
T_{E3}	Regional Cloud Site Fabric delay		
T_{T3}	Transport delay between Regional and Core Cloud	10	20
T_{C}	Core Cloud Site Fabric delay		
Network Function Specific Delay Components			
T_{UE}	Delay Through the UE SW and HW stack		
T_{RU}	Delay Through the O-RU User Plane		
T_{DU}	Delay Through the O-DU User Plane		
T_{CU-UP}	Delay Through the O-CU User Plane		

The transport network delays are specified as maximums, and link speeds are considered to be symmetric for all components with exception of the air interface (T_{AIR}). For the S-Plane services utilizing PTP protocol, it is a requirement that the link lengths, link speeds and forward-reverse path routing for PTP are all symmetric.

Radios (O-RUs) are always located in the Cell Site tier, while O-DU can be located "up to" Edge Cloud tier. It is possible to move any of the user plane NF instances closer towards the cell site, as implicitly they would be inside the target maximum delay, but it is not necessarily possible to move them further away from the Cell Sites while remaining within the RAN internal and/or RAN service-specific timing constraints. A common expected deployment case is one where O-DU instances are moved towards or even to the Cell Site and O-RUs (e.g. in Distributed Cloud-RAN configurations), or in situations where the Edge Cloud needs to be located closer to the Cell Site due to fiber and/or location availability, or other constraints. While this is expected to work well from the delay constraints perspective, the centralization and pooling-related benefits will be potentially reduced or even eliminated in the context of such deployment scenarios.

The maximum transport network latency between the site hosting O-DU(s) and sites hosting associated O-RU(s) is primarily determined by the RAN internal processes time constraints (such as HARQ loop, scheduling, etc., time-sensitive operations). For the purposes of this document, we use 100us latency, which is commonly used as a target maximum latency for this transport segment in related industry specifications for user-plane, specifically "High100" on E-CPRI transport requirements [4] section 4.1.1, as well as "Fronthaul" latency requirement in ITU technical report GSTR-TN5G [6], section 7-2, and IEEE Std 802.1CM-2018 [5], section 6.3.3.1. Based on the 5us/km fiber propagation delay, this implies that in a 2D Manhattan tessellation model, which is a common simple topology model for dense urban area fiber routing, the maximum area that can be covered from a single Edge Cloud tier site hosting O-DUs is up to a 400km^2 area of Cell Sites and associated RUs. Based on the radio inter-site distances, number of bands and other radio network dimensioning specific parameters, this can be used to estimate the maximum number of Cell Sites and cell sectors that can be covered from single Edge Cloud tier location, as well as maximum number of UEs in this coverage area.

The maximum transport network latencies towards the entities located at higher tiers are constrained by the lower of F1 interface latency (max 10 ms as per GSTR-TN5G [6], section 7.2), or alternatively service-specific latency constraints, for the edge-located services that are positioned to take advantage of improved latencies. For eMBB, UE-CU latency target is 4ms one-way delay, while for the URLLC it is 0.5ms as per 3GPP (or 1ms as per ITU requirements). The placement of the O-CU-UP as well as associated UPF, to be able to provide URLLC services would have to be at most at the Edge Cloud tier to satisfy the service latency constraint. For the eMBB services with 4ms OWD target, it is possible to locate O-CU-UP and UPF on next higher latency location tier, i.e. Regional Cloud tier. Note that while not shown in the picture, Edge compute / Multi-Access Edge Compute (MEC) services for a given RAN service type are expected to be collocated with the associated UPF function to take advantage of the associated service latency reduction potential.

For the services that do not have specific low-latency targets, the associated O-CU-UP and UPF can be located on higher tier, similar to deployments in typical LTE network designs. This is designated as Core Cloud tier in the example in Figure 10 above. For eMBB services, if there are no local service instances in the Edge or Regional clouds to take advantage of the 4ms OWD enabled by eMBB service definition, but the associated services are provided from either core clouds, external networks or from other Edge Cloud / RAN instances (in case of user-to-user traffic), the associated non-constrained (i.e. over 4ms from subscriber) eMBB O-CU-UP and UPF instances can be located in Core Cloud sites without perceivable impact to the service user, as in such cases the transport and/or service-specific latencies are dominant latency components.

The intent of this section is not to micromanage the latency budget, but to rather establish a reasonable baseline for dimensioning purposes, particularly to provide basic assessment to enable sizing of the cloud tiers within the context of the service-specific constraints and transport allocations. As such, we get the following "allowances" for the aggregate unspecified elements:

- $URLLC_{3GPP}$: 0.5ms - 0.1ms (T_{T1}) = 0.4ms $\geq T_{UE} + T_{AIR} + T_{E1} + T_{RU} + 2(T_{E2}) + T_{DU} + T_{CU\text{-}UP}$
- $URLLC_{ITU}$: 1ms - 0.1ms (T_{T1}) = 0.9ms $\geq T_{UE} + T_{AIR} + T_{E1} + T_{RU} + 2(T_{E2}) + T_{DU} + T_{CU\text{-}UP}$
- eMBB: 4ms - 0.1ms (T_{T1}) - 1ms (T_{T2}) = 2.9ms $\geq T_{UE} + T_{AIR} + T_{E1} + T_{RU} + 2(T_{E2}) + T_{DU} + T_{E3} + T_{CU\text{-}UP}$
- $mMTC_{15}$: 15ms - 0.1ms (T_{T1}) - 1ms (T_{T2}) - 10ms (T_{T3}) = 3.9ms $\geq T_{UE} + T_{AIR} + T_{E1} + T_{RU} + 2(T_{E2}) + T_{DU} + T_{E3} + T_{CU\text{-}UP} + T_C$

If required, we may provide more specific allocations in later versions of the document, as we gain more implementation experience and associated test data, but at this stage it is considered to be premature to do so. It should also be noted that the URLLC specification is still work in progress at this stage in 3GPP, so likely first implementations will focus on eMBB service, which leaves 2.9ms for combined O-RAN NFs, air interface, UE and cloud fabric latencies.

It is possible that network queuing delays may be the dominant delay contributor for some service classes. However, these delay components should be understood to be in context of the most latency-sensitive services, particularly on RU-DU interfaces, and relevant to the system level dimensioning. It is expected that if we will have multiple QoS classes, then the delay and loss parameters are specified on per-class basis, but such specification is outside of scope of this section.

The delay components in this section are based on presently supported O-RAN splits, i.e. 3GPP reference split configurations 7-2 & 8 for the RU-DU split (as defined in O-RAN), and 3GPP split 2 for F1 (as defined in O-RAN) and associated transport allocations, and constraints are based on the 5G service requirements from ITU & 3GPP.

Other extensions have been approved and included in version 2.0 of the O-RAN Fronthaul specification [7], which allow for so called "non-ideal" Fronthaul. It should be noted that while they allow substantially larger delays (e.g. 10 ms FH splits have been described and implemented outside of O-RAN), they cannot be considered for all possible 5G use cases, as for example it is clearly impossible to meet the 5G service-specification requirements over such large delay values over the FH for URLLC or even 4 ms eMBB services. In addition, in specific scenarios (e.g. high-speed users), adding latency to the fronthaul interface can result in reduced performance, and lower potential benefits, e.g. in Co-Ordinated Multi-Point (CoMP) mechanisms.

5.3. Hardware Acceleration Options

Cloud platforms consist of GPP CPUs, Memory, Networking I/O, and may also provide HW accelerators to offload computational-intense functions with the aim of optimizing the performance of the VNF (e.g., O-DU, O-CU-CP, O-CU-UP, RIC). There are many different types of HW accelerators: FPGA, ASIC, GPU and many different types of acceleration functions, such as Low-Density Parity-Check (LDPC) Forward Error Correction (FEC) for O-DU, Wireless Cipher for O-CU, and Artificial Intelligence for RIC. The combination of HW accelerator and acceleration function, and indeed the option to use HW acceleration, is the vendor's choice; however all types of HW acceleration on the cloud platform should ensure the decoupling of SW from HW. The decoupling of HW and SW implies the following key objectives:

- Multiple vendors of hardware GPP CPUs and accelerators (e.g., FGPA, DSP, or GPU) can support cloud platforms (including agreed-upon abstraction layers) from multiple vendors, which in turn can support the software providing RAN functionality.
- A given hardware and cloud platform shall support RAN software (including RIC, O-CU-CP, O-CU-UP, O-DU, and possibly O-RU functionality in the future) from multiple vendors.

5.3.1. HW Acceleration Abstraction

There are different methods of abstraction that should be considered for HW acceleration on the cloud platform; these are:

- HW Accelerator Deployment model
- HW Accelerator Application APIs

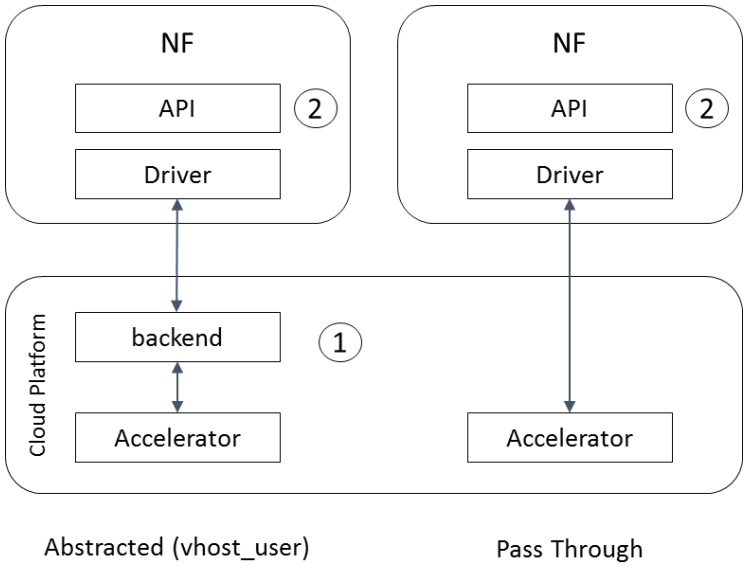

Figure 11: HW Abstraction Considerations

5.3.1.1. HW Accelerator Deployment Model

Figure 11 above presents two common HW deployment models, an abstracted implementation utilizing a vhost_user and virtIO type deployment, and a pass-through model using SR-IOV. While the abstracted model allows a full decoupling of the Network Function (NF) from the HW accelerator, this model may not suit real-time latency sensitive NFs such as the O-DU. For low-latency HW acceleration, SR-IOV pass through may be required. The SR-IOV pass through model is also supported in container environments.

5.3.1.2. HW Accelerator Application APIs

To allow multiple NF vendors to utilize the same HW accelerator on the cloud platform, HW Accelerators must provide an open-sourced API. The API shall allow the NF to discover the HW capabilities assigned to it, and submit and retrieve acceleration requests/responses. Examples of open APIs include DPDK's CryptoDev, EthDev, EventDev, and Base Band Device (BBDEV).

5.3.2. HW Accelerator Management and Orchestration Considerations

The HW accelerators shall be capable of being managed and orchestrated. In particular, HW accelerators shall support feature discovery and life cycle management. Existing Open Source solutions may be leveraged for both VMs and containers as specified in O1*. Examples include OpenStack Nova and Cyborg. An example for container deployments is seen in Kubernetes which provides a device plugin framework for vendors to advertise their device and associated resources to the Kubelet for management.

5.4. Cloud Considerations

In this section we talk about the list of cloud platform capabilities which is expected to be provided by the cloud platform to be able to support the deployment of the scenarios which are covered by this document.

It is assumed that some or all deployment scenarios may be using VM orchestrated/managed by OpenStack and / or Container managed/orchestrated by Kubernetes, and therefore this section will cover both options.

The discussion in most sub-sections of this section is structured into (up to) three parts: (1) Common, (2) Container only, and (3) VM only.

5.4.1. Networking requirements

A Cloud Platform should have the ability to support high performance N – S and E – W networking, with high throughput and low latency.

5.4.1.1. Support for Multiple Networking Interfaces

Common: In the different scenarios, near-RT RIC, vO-CU, and vO-DU all depend on having support for multiple network interfaces. The Cloud Platform is required to support the ability to assign multiple networking interfaces to a single container or VM instance, so that the cloud platform could support successful deployment for the different scenarios.

Container-only: For example, the cloud platform can achieve this by supporting the implementation of Multus Container Networking Interface (CNI) Plugin. For more details, please see https://github.com/intel/multus-cni.

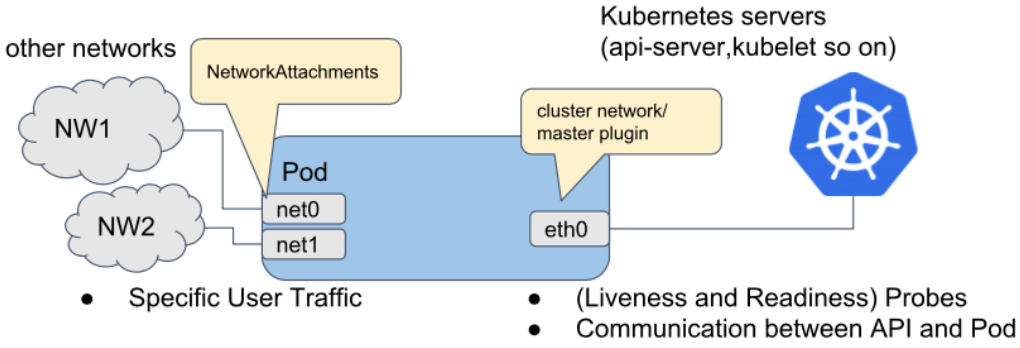

Figure 12: Illustration of the Network Interfaces Attached to a Pod, as Provisioned by Multus CNI

VM-only: OpenStack provides the Neutron component for networking. For more details, please see https://docs.openstack.org/neutron/stein/

5.4.1.2. Support for High Performance N-S Data Plane

Common: The Fronthaul connection between the O-RU/RU and vO-DU requires high performance and low latency. This means handling packets at high speed and low latency. As per the different scenarios covered in this document, multiple vO-DUs may be running on the same physical cloud platform, which will result in the need for sharing the same physical networking interface with multiple functions. Typically, the SR-IOV networking interface is used for this.

The cloud platform will need to provide support for assigning SR-IOV networking interfaces to a container or VM instance, so the instance can use the network interface (physical function or virtual function) directly without using a virtual switch.

If only one container needs to use the networking interface, the PCI pass-through network interface can provide high performance and low latency without using a virtual switch.

In general, the following two items are needed for high performance N-S data throughput:

- Support for SR-IOV; i.e., the ability to assign SR-IOV NIC interfaces to the containers/ VMs
- Support for PCI pass-through for direct access to the NIC by the container/ VM

Container-only: When containers are used, the cloud platform can achieve this by supporting the implementation of SR-IOV Network device plugin for Kubernetes. For more details, please refer to https://github.com/intel/sriov-network-device-plugin

VM-only: OpenStack provides the Neutron component for networking. For more details, please see https://docs.openstack.org/neutron/stein/admin/config-sriov.html .

5.4.1.3. Support for High-Performance E-W Data Plane

Common: High-performance E-W data plane throughput is a requirement for the implementation of the different near-RT RIC, vO-CU, and vO-DU scenarios which are covered in this document.

One of commonly used options for E-W high-performance data plane is the use of a virtual switch which provides basic communication capability for instances deployed at either the same machine or different machines. It provides L2 and L3 network functions.

To get the high performance required, one of the options is to use a Data Plan Development Kit (DPDK)-based virtual switch. Using this method, the packets will not go into Linux kernel space networking, and instead will implement userspace networking which will improve the throughput and latency. To support this, the container or VM instance will need to use DPDK to accelerate packet handling.

The cloud platform will need to provide the mechanism to support the implementation of userspace networking for container(s) / VM(s).

Container-only: As an example, the cloud platform can achieve this by supporting implementation of Userspace CNI Plugin. For more details, please refer to https://github.com/intel/userspace-cni-network-plugin.

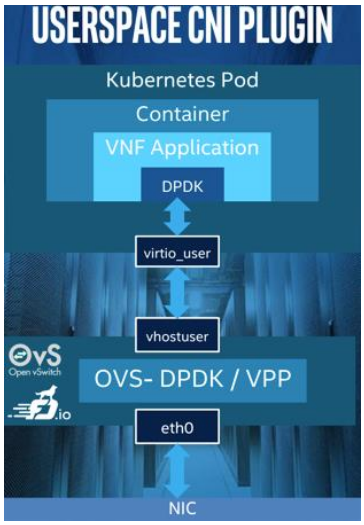

Figure 13: Illustration of the Userspace CNI Plugin

VM-only: OVS DPDK is an example of a Host userspace virtual switch and could provide high performance L2/L3 packet receive and transmit.

5.4.1.4. Support for Service Function Chaining

Common: Support for a Service Function Chaining (SFC) capability requires the ability to create a service function chain between multiple VMs or containers. In the virtualization environment, multiple instances will usually be deployed, and being able to efficiently connect the instances to provide service will be a fundamental requirement.

The ability to dynamically configure traffic flow will provide flexibility to Operators. When the service requirement or flow direction needs to be changed, the Service Function Chaining capability can be used to easily implement it instead of having to restart and reconfigure the services, networking configuration and Containers/VMs.

Container-only: An example of SFC functionality is found at: https://networkservicemesh.io/

VM only: The OpenStack Neutron SFC and OpenFlow-based SFC are examples of solutions that can implement the Service Function Chaining capability.

5.4.2. Assignment of Acceleration Resources

Common: For both container and VM solutions, specific devices such as accelerator (e.g., FPGA, GPU) may be needed. In this case, the cloud platform needs to be able to assign the specified device to container instance or VM instance.

For example, some L1 protocols require a FFT algorithm (to compute the DFT) that could be implemented in an FPGA, and the vO-DU would need the PCI Pass-Through to assign the FPGA device to the vO-DU instance so that the vO-DU instance can access and use the FPGA device.

5.4.3. Real-time / General Performance Feature Requirements

5.4.3.1. Host Linux OS

5.4.3.1.1. Support for Pre-emptive Scheduling

Support may be required to support Pre-emptive Scheduling (real time Linux uses the preempt_rt patch). Generally, without real time features, it is very difficult for an application to get deterministic response times for events, interrupts and other reasons[4]. In addition, during the housekeeping processes in Linux system, the application also cannot guarantee the running time (CPU cycle), so from the wireless application design perspective, it needs the real time feature. In addition, to support the requirements of high throughput, multiple accesses and low latency, some wireless applications need the priority-based OS environment.

5.4.3.2. Support for Node Feature Discovery

Common: Automated and dynamic placement of Cloud-Native Network Functions (CNFs) / microservices and VMs is needed, based on the hardware requirements imposed on the vO-DU, vO-CU and near-RT RIC functions. This requires the cloud platform to support the ability to discover the hardware capabilities on each node and advertise it via labels vs. nodes, and allows VNF/CNF descriptions to have hardware requirements via labels. This mechanism is also known as Node Feature Discovery (NFD).

Container-only: For example, the cloud platform can achieve this by supporting implementation of NFD for Kubernetes. For more details, please see https://github.com/kubernetes-sigs/node-feature-discovery.

VM-only: VMs can use OpenStack mechanisms. For example, the OpenStack Nova filter, host aggregates and availability zones can be used to implement the same function.

5.4.3.3. Support for CPU Affinity and Isolation

Common: The vO-DU, vO-CU and even the near-RT RIC are performance sensitive and require the ability to consume a large amount of CPU cycles to work correctly. They depend on the ability of the cloud platform to provide a mechanism to guarantee performance determinism even when there are noisy neighbors.

Container-only: This requires the cloud platform to support using affinity and isolation of cores, so high performance Kubernetes Pod cores also can be dedicated to specified tasks. For example, the cloud platform can achieve this by implementing CPU Manager for Kubernetes. For more details, please refer to https://github.com/intel/CPU-Manager-for-Kubernetes .

VM-only: For example the modern Linux operating system uses the Symmetric MultiProcessing (SMP) mode, so the system process and application will be located at different CPU cores. To run the VM and guarantee the VM performance, the capability to assign the specific CPU cores to a VM is the way to do that. And at the same time, CPU isolation will reduce the inter-core affinity. Please refer to https://docs.openstack.org/senlin/pike/scenarios/affinity.html

5.4.3.4. Support for Dynamic HugePages Allocation

Common: When an application requires high performance and performance determinism, the reduction of paging is very helpful. vO-DU, vO-CU and even near-RT RIC can require performance determinism. The cloud platform needs to be able to support the ability to provide this mechanism to applications that require it.

This requires the cloud platform to support ability to dynamically allocate the necessary amount of the faster memory (a.k.a. HugePages) to the container or VM as necessary, and also to relinquish this memory allocation in the event of unexpected termination.

[4] Other options include things such as Linux signal, softwareirq, and perhaps using a common process. Because the pre-emptive kernel could interrupt the low priority process and occupy the CPU, it will get more chance to run the high priority process. Then through proper application design, it will have guaranteed time/resource and can have deterministic performance.

Container-only: For example, the cloud platform can achieve this by supporting implementation of Manage HugePages in Kubernetes. For more details please refer to https://kubernetes.io/docs/tasks/manage-hugepages/scheduling-hugepages/ .

VM-only: For example, the OpenStack Nova flavor setting can be used to configure the HugePage size for a VM instance. See https://docs.openstack.org/nova/pike/admin/huge-pages.html

5.4.3.5. Support for Topology Manager

Common: Some of the cloud infrastructure which is targeted in the scenarios in this document may have servers which utilize a multiple-socket configuration which comes with multiple memory regions. Each core[5] is connected to a memory region. While each CPU on one socket can access the memory region of the CPUs on another socket of the same board, the access time is significantly slower when crossing socket boundaries, and this will affect performance significantly.

The configuration of hardware with multiple memory regions is also known as Non-Uniform Memory Access (NUMA) regions. To support automated and dynamic placement of CNFs/microservices or VMs based on cloud infrastructure that has multiple NUMA regions and guarantee the response time of the application (especially for vO-DU), it is critical to be able to ensure that all the containers/VMs are associated with core(s) which are connected to the same NUMA region. In addition, if the application relies on access to hardware accelerators and/or I/O which uses memory as a way to interact with the application, it is also critical that those also use the same NUMA region that the application uses.

The cloud platform will need to provide the mechanism to enable managing the NUMA topology to ensure the placement of specified containers/VMs on cores which are on the same NUMA region, as well as making sure that the devices which the application uses are also connected to the same NUMA region.

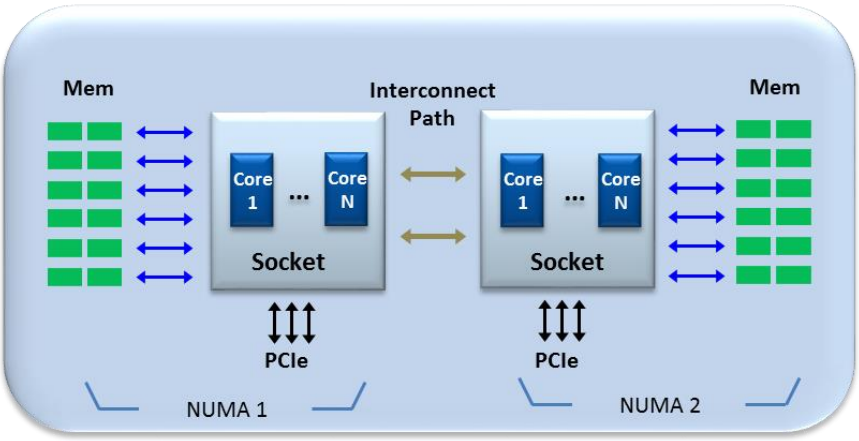

Figure 14: Example Illustration of Two NUMA Regions

5.4.3.6. Support for Scale In/Out

Common: The act of scaling in/out of containers/ VMs can be based on triggers such as CPU load, network load, and storage consumption. The network service usually is not just a single container or VM, and in order to leverage the container/ VM benefit, the network service usually will have multiple containers/ VMs. But if demand is changing dynamically, especially for the O-CU, the service needs to be scaled in/out according to service requirements such as subscriber quantity.

For example, when the number of subscribers increases, the system needs to start more container/ VM instances to ensure the service quality. From the cloud platform perspective, it could monitor the CPU load; if the load reaches a level such as 80%, it needs to scale out. If the CPU load drops 40%, it could then scale in.

Different services can scale in/out depending on different criteria, such as the CPU load, network load and storage consumption. Support for scale in/out can be helpful in implementing on-demand services.

[5] In this document, we use the terms core and socket in the following way. A socket, or more precisely the multichip platform that fits into a server socket, contains multiple cores, each of which is a separate CPU. Each core in a socket has some dedicated memory, and also some shared memory among other cores of the same socket, which are within the same NUMA zone.

Editor's Note: Support for scale up/down is not discussed at this time, but may be revisited in the future.

5.4.3.7. Support for Device Plugin

Common: For vO-DU, vO-CU and near-RT RIC applications, hardware accelerators such as SmartNICs, FPGAs and GPUs may be required to meet performance objectives that can't be met by using software only implementations. In other cases, such accelerators can be useful as an option to reduce the consumption of CPU cycles to achieve better cost efficiency.

The cloud platform will need to provide the mechanism to support those accelerators. This in turn requires support the ability to discover, advertise, schedule and manage devices such as SR-IOV, GPU, and FPGA.

Container-only: For example, the cloud platform can achieve this by supporting implementation of Device Plugins in Kubernetes. For more details please check: https://kubernetes.io/docs/concepts/extend-kubernetes/compute-storage-net/device-plugins/.

VM-only: The PCI passthrough feature in OpenStack allows full access and direct control of a physical PCI device in guests. This mechanism is generic for any kind of PCI device, and runs with a Network Interface Card (NIC), Graphics Processing Unit (GPU), or any other devices that can be attached to a PCI bus. Correct driver installation is the only requirement for the guest to properly use the devices.

Some PCI devices provide Single Root I/O Virtualization and Sharing (SR-IOV) capabilities. When SR-IOV is used, a physical device is virtualized and appears as multiple PCI devices. Virtual PCI devices are assigned to the same or different guests. In the case of PCI passthrough, the full physical device is assigned to only one guest and cannot be shared.

See https://wiki.openstack.org/wiki/Cyborg

5.4.3.8. Support for Direct IRQ Assignment

VM-only: The general-purpose platform has many devices that will generate the IRQ to the system. To develop a performance-sensitive application, inclusion of low-latency and deterministic timing features, and assigning the IRQ to a specific CPU core, will reduce the impact of housekeeping processes and decrease the response time to desired IRQs.

5.4.3.9. Support for No Over Commit CPU

VM-only: The "No Over Commit CPU" VM creation option is able to guarantee VM performance with a "dedicated CPU" model.

In traditional telecom equipment design, this will maintain the level of CPU utilization to avoid burst and congestion situations. In a virtualization environment, performance-sensitive applications such as vO-DU, vO-CU, and RIC will need the platform to provide a mechanism to secure the CPU resource.

5.4.3.10. Support for Specifying CPU Model

VM-only: OpenStack can use the CPU model setting to configure the vCPU for a VM. For example, QEMU allows the CPU options to be "Nehalem", "Westmere", "SandyBridge" or "IvyBridge", or alternatively it could be configured as "host-passthrough". This allows VMs to leverage advanced features of selected CPU architectures. For the vO-CU and vO-DU design and implementation, there will be some algorithm and computing functions that can leverage host CPU instructions to realize some benefits such as performance. The cloud platform needs to provide this capability to VMs.

5.4.4. Storage Requirements

The storage requirements are the same for both VM and Container based implementations.

For O-RAN components, the VNF/CNF needs storage for the image and for the VNF/CNF itself. It should support different scale, e.g., for a Regional Cloud vs. an Edge Cloud. The cloud platform needs to support a large-scale storage solution with redundancy, medium and small scale storage solutions for two or more servers, and a very small scale solution for a single server.

5.5. Sync Architecture

Synchronization mechanisms and options are receiving significant attention in the industry. When requirements are better understood for various deployment scenarios, we can discuss which are applicable to each.

Editor's Note: O-RAN Working Groups 4 and 5 are addressing some aspects of synchronization, and more discussion of Sync is expected in future versions of this document.

5.6. Operations and Maintenance Considerations

Management of a cloudified RAN introduces some new management considerations, because the mapping between Network Functionality and physical hardware can be done in multiple ways, depending on the Scenario that is chosen. Thus, management of aspects that are related to physical aspects rather than logical aspects need to be designed with flexibility in mind from the start. For example, logging of physical functions, scale out actions, and survivability considerations are affected.

The O-RAN Alliance has defined key fundamentals of the OAM framework (see [8] and [9], and refer to Figure 1). Given the number of deployment scenario options and possible variations of O-RAN Managed Functions (MFs) being mapped into Managed Elements (MEs) in different ways, it is important for all MEs to support a consistent level of visibility and control of their contained Managed Functions to the Service Management & Orchestration Framework. This consistency will be enabled by support of the common OAM Interface Specification [9] for Fault Configuration Accounting Performance Security (FCAPS) and Life Cycle Management (LCM) functionality, and a common Information Modelling Framework that will provide underlying information models used for the MEs and MFs in a particular deployment.

A key motivation for the Managed Element concept is that an ME is a tightly integrated and tested group of MFs that are deployed together. This has implications on how software updates are managed, because all software updates need to retain the property that all MFs in the ME have been tested together.

Depending on the deployment scenario and other considerations, the MFs may be grouped in different ways. An interface is required to each ME, which can manage the communications to each MF that is contained within it. The O-RAN Operations and Maintenance Architecture [8] document presents many examples of how the O1 interface can connect to either individual MFs, or to an integrated ME that contains multiple MFs. To introduce the general concept, Figure 15 below shows an example where there is one O1 interface of each type. However, again it must be stressed that there are multiple legitimate options that are being considered, and that reference [8] is the authoritative source of operations options.

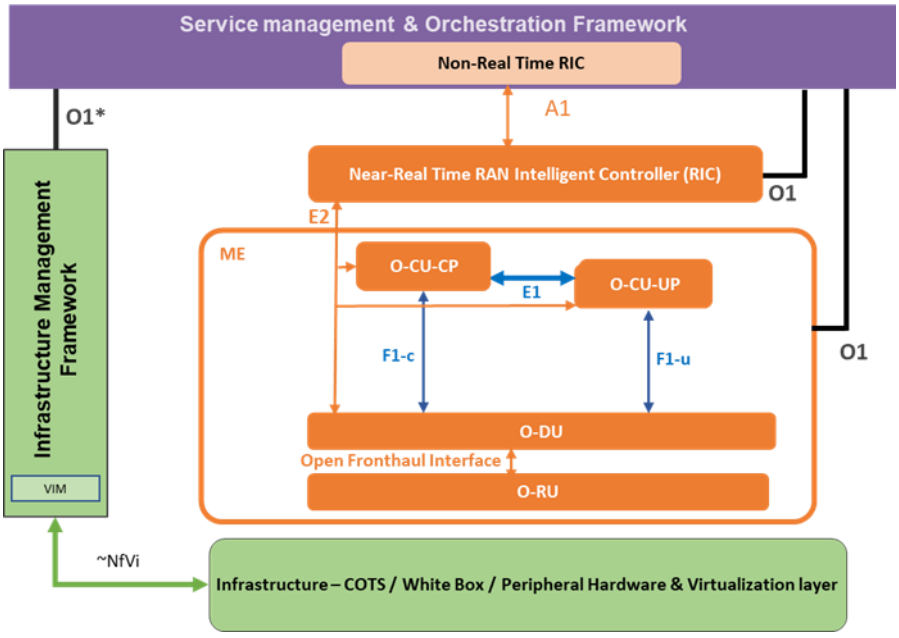

Figure 15: RAN OAM Logical Architecture – One Example

In Figure 15, the O1 interface to the near-RT RIC is only managing that single function, so we can think of this as having just one MF in an ME. However, the other O1 interface is to a ME that contains multiple MFs. In this case, how do messages get to the correct MF?

Figure 16 below shows a high-level diagram of how an O1 interface relates to an ME that contains multiple MFs. The ME provides the functionality (light blue entity) to link the O1 interface termination in the ME and each MF that lies within the ME.

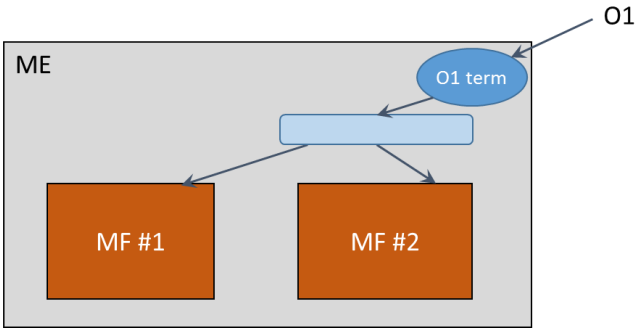

Figure 16: O1 Termination and MFs in an ME

The Service Management and Orchestration (SMO) framework will need a consistent and standardized view of the Managed Functions that are contained within any Managed Element, regardless of the grouping of MFs in MEs. The figure below shows a separate dashed line for each MF that is presented to the SMO.

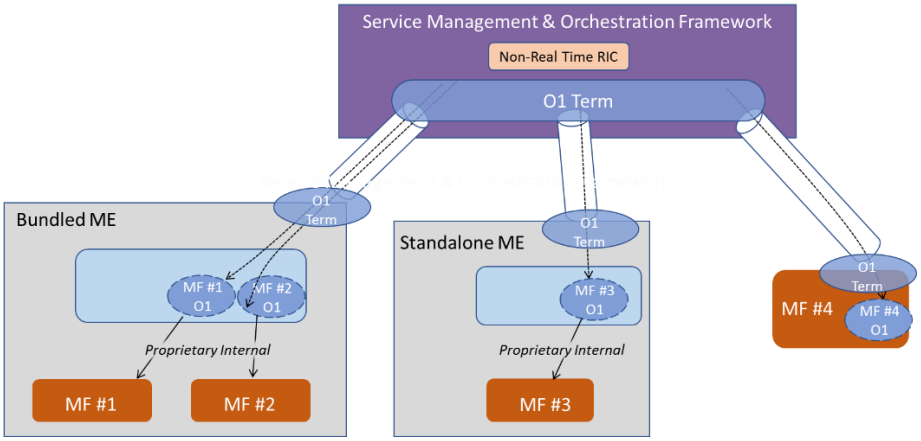

Figure 17: Three types of O1 Terminations in MEs/MFs

Note that the way in which the O1 termination is related to the MF is different in each case:

- In the first case (shown on the left), the ME contains multiple MFs and a function that terminates the O1 interface to each MF. That function also provides proprietary communication to each MF.
- In the second case, the ME contains just one MF, but has the same functionality to communicate to the MF.
- In the third case, the MF presents a compliant O1 interface.

It should be noted that in addition to MEs that provide RAN functionality, there are MEs that provide Cloud Platform functionality. Both are required for Network Functions provided by a cloud platform, because the Cloud Platform and the RAN functionality are decoupled. For example, there may be Cloud Platform resources that are not currently assigned to RAN functions, but they still need to be monitored and managed. In this case the SMO would manage those cloud platform resources via O1*. This is illustrated below.

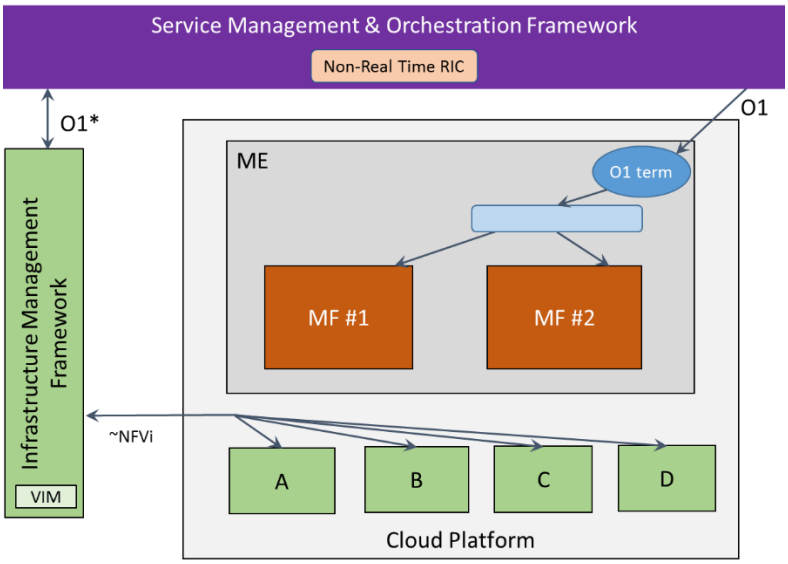

Figure 18: O1* Interface to Manage Cloud Platform Resources (in addition to O1 for RAN MEs)

5.7. Transport Network Architecture

While a Transport Network is a necessary foundation upon which to build any O-RAN deployment, a great many of the aspects of transport do not have to be addressed or specified in O-RAN Alliance documents. For example, any location with cloud servers will be connected by layer 2 or layer 3 switches, but we do not need to specify much if anything about them in this document.

The transport media used, particularly for fronthaul, can have an effect on aspects such as performance. However, in the current version of this document we have been assuming that fiber transport is used.

Editor's Note: Other transport technologies (e.g., microwave) are also possible, and could be addressed at a later date.

That said, the use of an (optional) Fronthaul Gateway (FH GW) will have noteworthy effects on any O-RAN deployment that uses it.

5.7.1. Fronthaul Gateways

In the deployment scenarios that follow, when the O-DU and O-RU functions are not implemented in the same physical node, a Fronthaul Gateway is shown as an *optional* element between them. A Fronthaul Gateway can be motivated by different factors depending on a carrier's deployment, and may perform different functions.

The O-RAN Alliance does not currently have a single definition of a Fronthaul Gateway, and this document does not attempt to define one. However, the Fronthaul Gateway is included in the diagrams as an optional implementation to acknowledge the fact that carriers are considering Fronthaul Gateways in their plans. Below are some examples of the functionality that could be provided:

- A FH GW can convert CPRI connections to the node supporting the O-RU function to eCPRI connections to the node that provides O-DU functionality.
  - Note that when there is no FH GW, it is assumed that the Open Fronthaul interface between the O-RU and O-DU uses Option 7-2, as mentioned earlier in Section 4.1. When there is a FH GW, it may have an Option 7-2 interface to both the O-DU and the O-RU, but it is also possible for the FH GW to have a different interface to the O-RU/RU; for example, where CPRI is supported.
- A FH GW can support the aggregation of fiber pairs.
- A FH GW must support the following forwarding functions:
  - Downlink: Broadcast traffic from O-DU to each O-RU (and cascading FH GW, if present)
  - Uplink: Summation of traffic from O-RUs

- A FH GW can provide power to the NEs supporting the O-RU function, e.g. via Power over Ethernet (PoE) or hybrid cable/fibers

5.8. Overview of Deployment Scenarios

The description of logical functionality in O-RAN includes the definition of key interfaces E2, F1, and Open Fronthaul. However, as noted earlier, this does not mean that each Network Function block must be implemented in a separate PNF/VNF/CNF. Multiple logical functions can be implemented in a single PNF/VNF/CNF (for example O-DU and O-RU may be packaged as a single appliance).

We assume that when Network Functions are implemented as different PNF/VNF/CNFs, the interfaces between them must conform to the O-RAN specifications. However, when multiple Network Functions are implemented by a single PNF/VNF/CNF, it is up to the operator to decide whether to enforce the O-RAN interfaces between the embedded Network Functions. However, note that the OAM requirements for each separate Network Function will still need to be met.

The current deployment scenarios for discussion are summarized in the figure below. This includes options that are deployable in both the short and long term. Each will be discussed in some detail in the following sections, followed by a summary of which one or ones are candidates for initial focus. Please note that, to help ease the high-level depiction of functionality, a single O-CU box is shown with an F1 interface, but in detailed discussions of specific scenarios, this will need to be discussed properly as composed of an O-CU-CP function with an F1-c interface and an O-CU-UP function with an F1-u interface. Furthermore, there would in general be an unequal number of O-CU-CP and O-CU-UP instances.

Figure 19 below shows the Network Functions at the top, and each identified scenario shows how these Network Functions are deployed as proprietary PNFs or as VNFs/CNFs running on an O-RAN compliant O-Cloud. The term O-Cloud is defined in Section 4. Please note that the requirements for an O-Cloud are driven by the Network Functions that need to be supported by the hardware, so for instance an O-Cloud that supports an O-RU function would be different from an O-Cloud that supports O-CU functionality.

Finally, note that in the high-level figure below, the User Plane (UP) traffic is shown being delivered to the UPF. As will be discussed, in specific scenarios it is sometimes possible for UP traffic to be delivered to edge applications that are supported by Mobile Edge Computing (MEC). However, note that the specification of MEC itself is out of scope of this document.

Note that vendors are not required to support all scenarios – it is a business decision to be made by each vendor. Similarly, each operator will decide which scenarios it wishes to deploy.

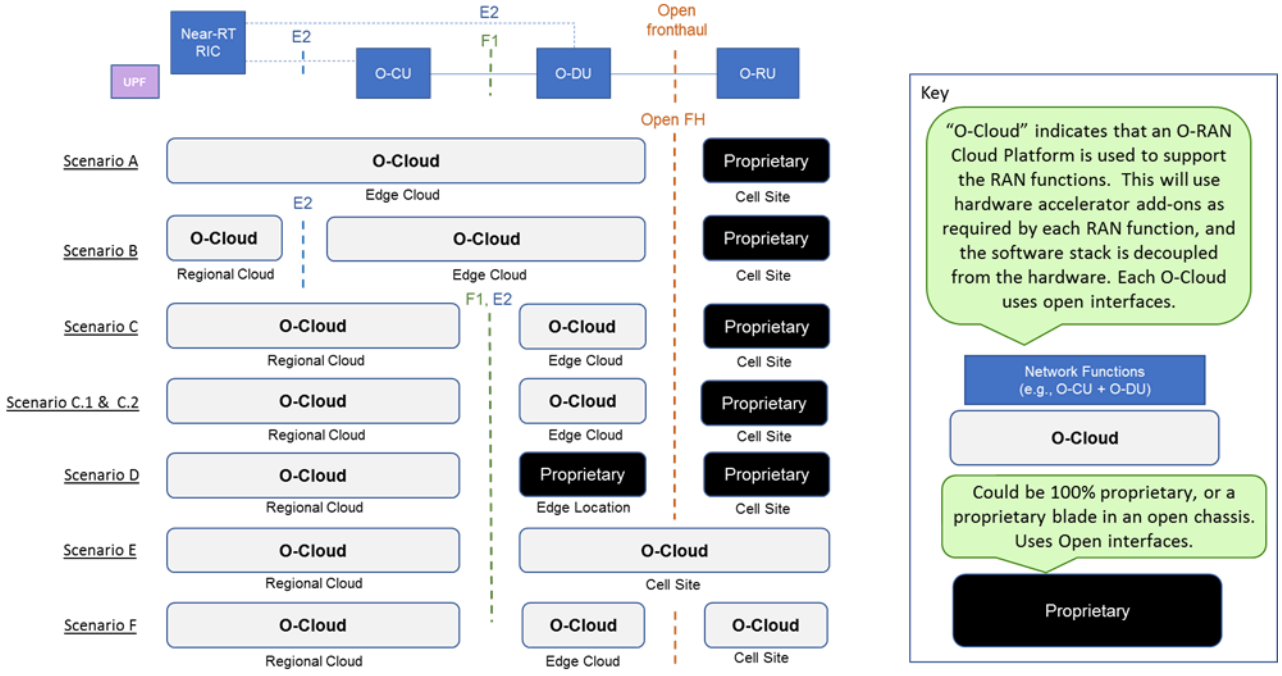

Figure 19: High-Level Comparison of Scenarios

Each scenario is discussed in the next section.

6. Deployment Scenarios and Implementation Considerations

This section reviews each of the deployment scenarios in turn. For a given scenario, the requirements that apply to the proprietary or O-Cloud platforms may become more specific and unique, while many of the logical Network Function requirements will remain the same.

Please note that in all of the scenario figures of this section, the interfaces are logical interfaces (e.g., F1, E2, etc.). This has a couple of implications. First, the two functions on each side of an interface could be on different devices separated by physical transport connections (e.g., fiber or Ethernet transport connections), could be on different devices within the same cloud platform, or could even exist within the same server. Second, the functions on each side of an interface could be from the same vendor or different vendors.

In addition, please note that all User Plane interfaces are shown with a solid lines, and all Control Plane interfaces use dashed lines.

6.1. Scenario A

In this scenario, the near-RT RIC, O-CU, and O-DU functions are all virtualized on the same cloud platform, and interfaces between those functions are within the same cloud platform.

This scenario supports deployments in dense urban areas with an abundance of fronthaul capacity that allows BBU functionality to be pooled in a central location with sufficiently low latency to meet the O-DU latency requirements. Therefore it does not attempt to centralize the near-RT RIC more than the limit that O-DU functionality can be centralized.

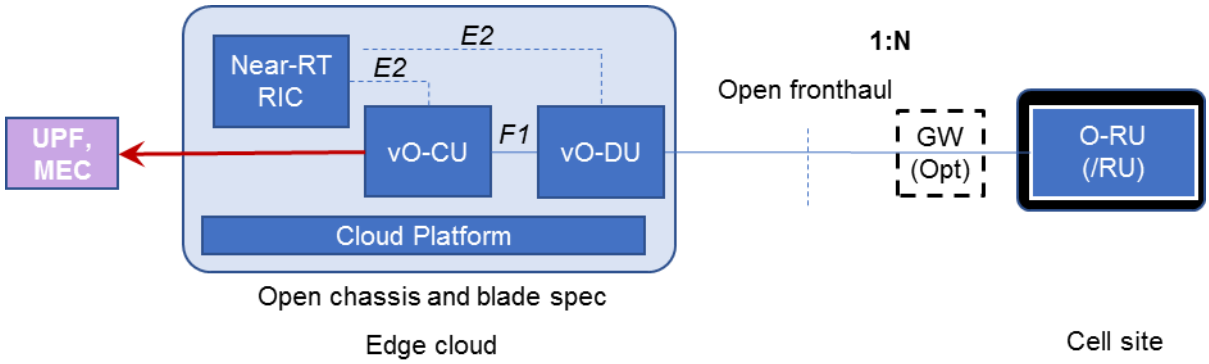

Figure 20: Scenario A

Also please note that if the optional FH GW is present, the interface between it and the Radio Unit might not meet the O-RAN Fronthaul requirements (e.g., it might be an Option 8 interface), in which case the Radio Unit could be referred to as an "RU", not an "O-RU". However, if FH GWs are defined to support an interface such as Option 8, it could be argued that the O-RU definition at that time will support Option 8.

6.1.1. Key Use Cases and Drivers

Editor's Note: This section is FFS.

6.2. Scenario B

In this scenario, the near-RT RIC Network Function is virtualized on a Regional Cloud Platform, and the O-CU and O-DU functions are virtualized on an Edge Cloud hardware platform that in general will be at a different location. The interface between the Regional Cloud and the Edge cloud is E2. Interfaces between the O-CU and O-DU Network Functions are within the same Cloud Platform.

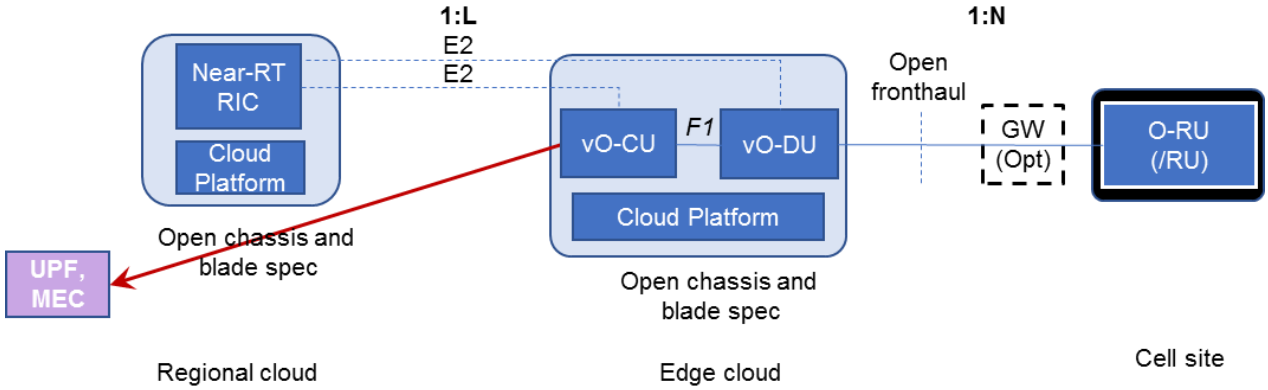

Figure 21: Scenario B

This scenario is to support deployments in locations with limited remote fronthaul capacity and O-RUs spread out in an area that limits the number of O-RUs that can be supported by pooled vO-CU/vO-DU functionality while still meeting the O-DU latency requirements. The use of a FH GW in the architecture allows significant savings in providing transport between the O-RU and vO-DU functionality.

As discussed earlier in Section 5.1.3, the O-CU and O-DU functions can be virtualized using either simple centralization or pooled centralization. The desire is to have support for pooled centralization, although we need to understand what needs to be developed to enable such sharing. Perhaps pooling will be a later feature, but any initial solution should not preclude a future path to a pooled solution.

6.2.1. Key Use Cases and Drivers

In this case, there are multiple O-RUs distributed in an area served by a centralized vO-DU functionality that can meet the latency requirements. Depending on the concentration of the O-RUs, N could vary, but in general is expected to be engineered to support < 64 TRPs per O-DU.[6] The near-RT RIC is centralized further to allow for optimization based on a more global view (e.g., a single large metropolitan area), and to reduce the number of separate near-RT RIC instances that need to be managed.

The driving use case for this is to support an outdoor deployment of a mix of Small Cells and Macro cells in a relatively dense urban setting. This can support mmWave as well as Sub-6 deployments.

In this scenario, a given "virtual BBU" supports both vO-CU and vO-DU functions, and can connect many O-RUs. Current studies show that savings from pooling are significant but level off once more than 64 Transmission Reception Points (TRPs) are pooled. This would imply N would be around 32-64. This deployment should support tens of thousands of O-RUs per near-RT RIC, so L could easily exceed 100.

Below is a summary of the cardinality requirements assumed for this scenario.

Table 2: Cardinality and Delay Performance for Scenario B

	Attribute	RIC – O-CU	O-CU – O-DU	O-DU – O-RU/RU
	Example Cardinality	L = 100+	M=1	N = 1-64

6.3. Scenario C

In this scenario, the near-RT RIC and O-CU Network Functions are virtualized on a Regional Cloud Platform with a general server hardware platform, and the O-DU Network Functions are virtualized on an Edge Cloud hardware platform that is expected to include significant hardware accelerator capabilities. Interfaces between the near-RT RIC

[6] It is assumed that one O-RU is associated with one TRP. For example, if a cell site has three sectors, then each sector would have at least one TRP and hence at least three O-RUs.

and the O-CU network functions are within the same Cloud Platform. The interface between the Regional Cloud and the Edge cloud is F1, and an E2 interface from the near-RT RIC to the O-DU must also be supported.

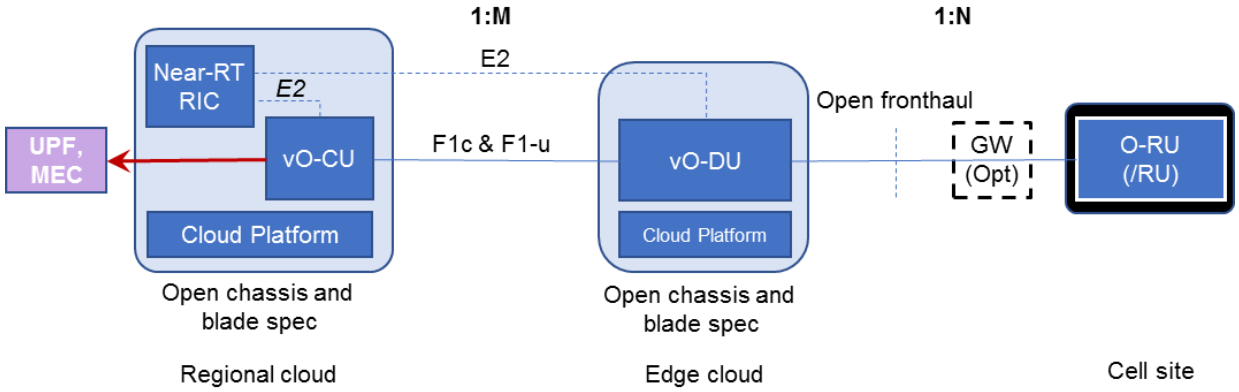

Figure 22: Scenario C

This scenario is to support deployments in locations with limited remote Fronthaul capacity and O-RUs spread out in an area that limits the number of O-RUs that can be pooled while still meeting the O-DU latency requirements. The O-CU Network Function is further pooled to increase the efficiency of the hardware platform which it shares with the near-RT RIC Network Function.

However, note that if a service type has tighter O-CU delay requirements than other services, then that may either severely limit the number of O-RUs supported by the Regional cloud, or a method will be needed to separate the processing of such services. This will be discussed further in the following C.1 and C.2 Scenarios.

The use of a FH GW in the architecture allows significant savings in providing transport between the O-RU and vO-DU functionality.

6.3.1. Key Use Cases and Drivers

In this case, there are multiple O-RUs distributed in an area where each O-RU can meet the latency requirement for the pooled vO-DU function. The near-RT RIC and O-CU Network Functions are further centralized to realize additional efficiencies.

A use case for this is to support an outdoor deployment of a mix of Small Cells and Macro cells in a relatively dense urban setting. This can support mmWave as well as Sub-6 deployments.

In this scenario, as in Scenario B, the Edge Cloud is expected to support roughly 32-64 O-RUs. This deployment should support tens of thousands of O-RUs per near-RT RIC.

Below is a summary of the cardinality and the distance/delay requirements assumed for this scenario.

Table 3: Cardinality and Delay Performance for Scenario C

	Attribute	RIC – O-CU	O-CU – O-DU	O-DU – O-RU/RU
	Example Cardinality	L= 1	M=100+	N=Roughly 32-64

6.3.2. Scenario C.1, and Use Case and Drivers

This is a variation of Scenario C, driven by the fact that different types of traffic (network slices) have different latency requirements. In particular, URLLC has more demanding user-plane latency requirements, and Figure 23 below shows how the vO-CU User Part (vO-CU-UP) could be terminated in different places for different network slices. Below, network slice 3 is terminated in the Edge Cloud. This scenario is also suitable in case there isn't enough space or power supply to install all vO-CUs and vO-DUs in one Edge Cloud site.

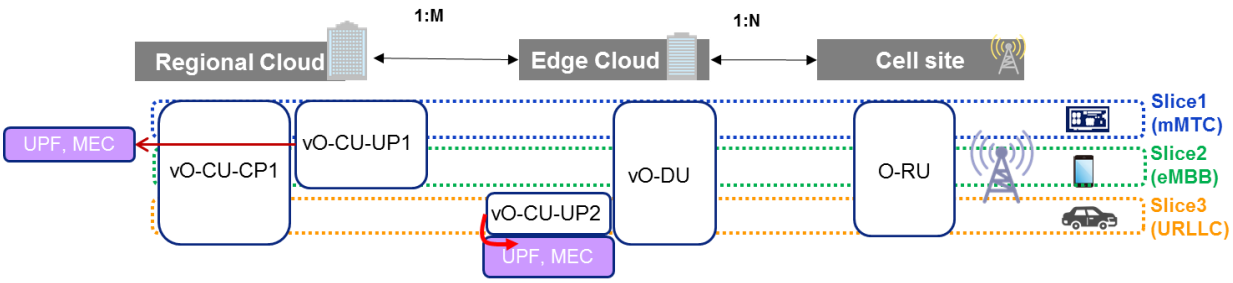

Figure 23: Treatment of Network Slices: MEC for URLLC at Edge Cloud, Centralized Control, Single vO-DU

In Scenario C.1, all O-CU control is placed in the Regional Cloud, and there is a single vO-DU for all Network Slices. Only the placement of the vO-CU-CP differs, depending on the network slice. Below is the diagram of this scenario, using the common diagram conventions of all scenarios.

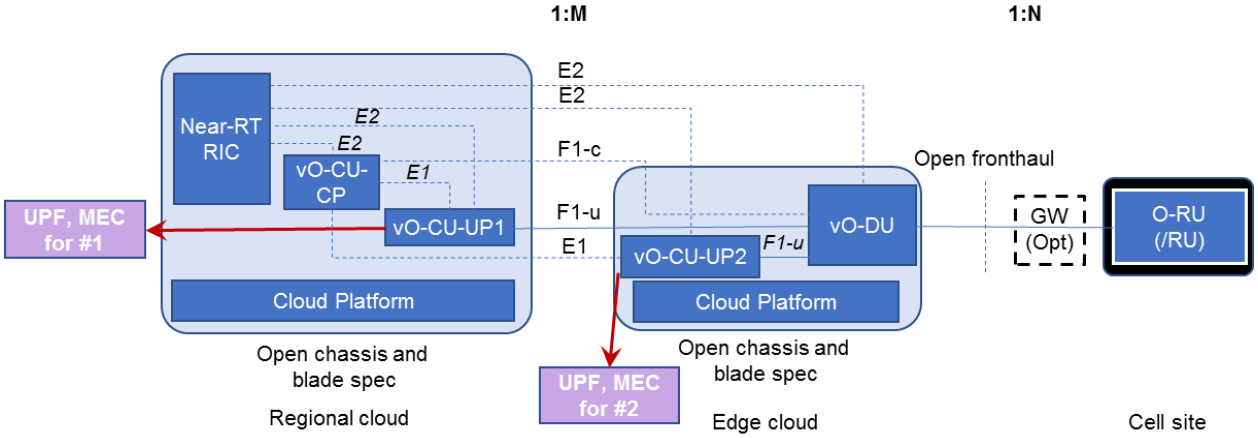

Figure 24: Scenario C.1

Below is a summary of the cardinality and the distance/delay requirements assumed for this scenario. The URLLC user plane requirements are what drive the placement of the vO-CU-UP function to be in the Edge cloud.

Table 4: Cardinality and Delay Performance for Scenario C.1

	Attribute	RIC – O-CU	O-CU – O-DU	O-DU – O-RU/RU
	Example Cardinality	L= 1	M=320	N=100
Delay Max 1-way (distance)	*mMTC*	NA	625 µs (125 km)	100 µs (20 km)
	eMBB	NA	625 µs (125 km)	100 µs (20 km)
	*URLLC (**user**/control)*	NA	**100 µs (20 km)**/625 µs (125 km)	100 µs (20 km)

6.3.3. Scenario C.2, and Use Case and Drivers

This is a second variation of Scenario C, which utilizes the same method of placing some vO-CU user plane functionality in the Edge Cloud, and some in the Regional Cloud. However, instead of having one vO-DU for all network slices, there are different vO-DU instances in the Edge Cloud.

It is driven by factors including the following two use cases:

- One driver is RAN (O-RU) sharing among operators. In this use case, any operator can flexibly launch vO-CU and vO-DU instances at Edge or Regional Cloud site. For example, as shown in Figure 25, Operator #1 wants to launch the vO-CU1 instance in the Regional Cloud, and the vO-DU1 instance at subtending Edge Cloud sites. On the other hand, Operator #2 wants to install both the vO-CU2 and vO-DU2 instances at the same Regional Cloud site. Note that both operators will share the O-RU).

- Another driver is that, even within a single operator, that operator can customize scheduler functions depending on the network slice types, and can place the vO-CU and vO-DU instances depending on the network slice types. For example, an operator may launch both vO-CU and vO-DU at the edge cloud site (see Operator #2 below) to provide a URLLC service.

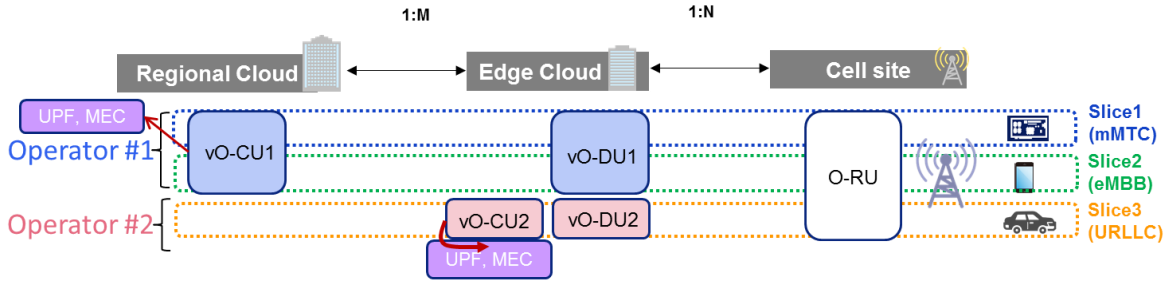

Figure 25: Treatment of Network Slice: MEC for URLLC at Edge Cloud, Separate vO-DUs

The multi-Operator use case has the following pros and cons:

Pros:

- O-RU sharing can reduce TCO
- Flexible CU/DU location allows deployments to consider not only service requirements but also limitations of space or power in each site

Cons:

- Allowing multiple operators to share O-RU resources is expected to require changes to the Open Fronthaul interface (especially the handshake among more than one vO-DU and a given O-RU).
- This change seems likely to have M-plane specification impact. Therefore, this approach would need O-RAN buy-in and approval.

Figure 26 below illustrates how different Component Carriers can be allocated to different operators, at the same O-RU *at the same time*. Note that some updates of not only M-plane but also CUS-plane specifications will be required when considering frequency resource sharing among DUs.

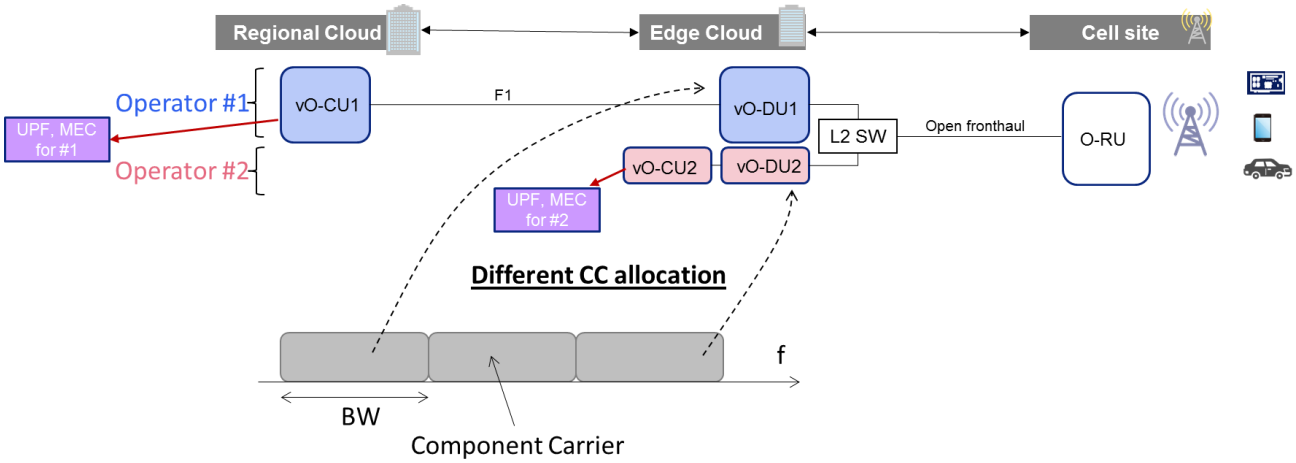

Figure 26: Single O-RU Being Shared by More than One Operator

The diagram of how Network Functions map to Networks Elements for Scenario C.2 is shown below.

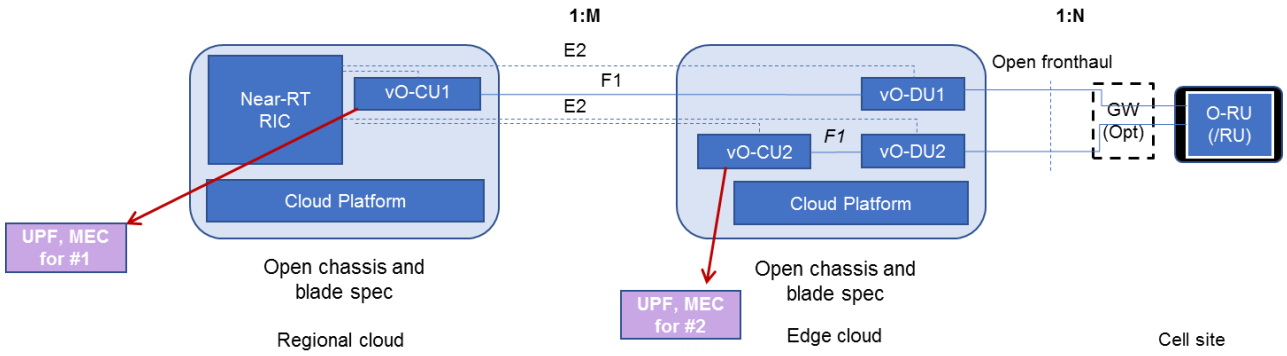

Figure 27: Scenario C.2

The performance requirements are the same as those discussed earlier for Scenario C.1 in Section 6.3.2.

6.4. Scenario D

This scenario is a variation on Scenario C, but in this case the O-DU functionality is supported by a proprietary hardware platform rather than an O-Cloud.

The general assumption is that Scenario D has the same use cases and performance requirements as Scenario C, and the primary difference is in the business decision of how the proprietary solution compares with the O-RAN compliant O-Cloud solution. Implementation considerations (discussed in Section 5.1) could lead a carrier to decide that an acceptable O-Cloud solution is not available in a deployment's timeframe.

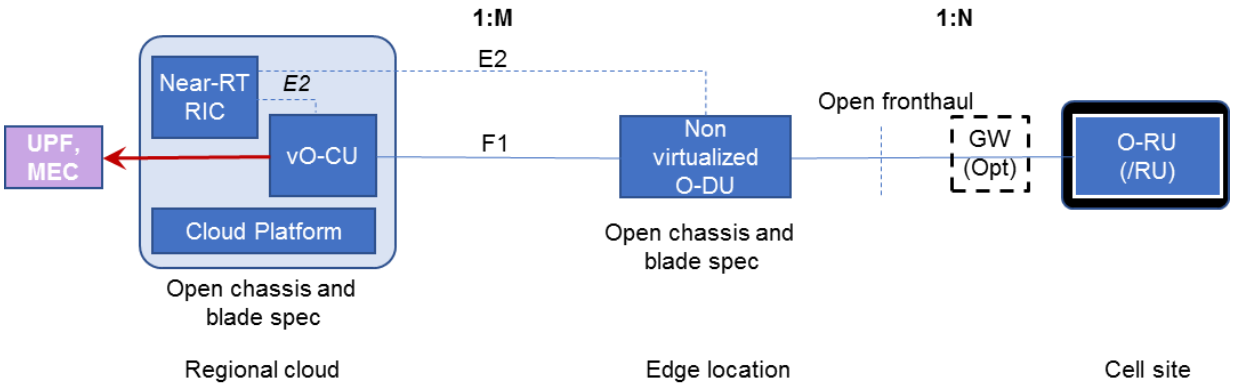

Figure 28: Scenario D

6.5. Scenario E

In contrast to Scenario D, this scenario assumes that not only can the O-DU be virtualized as in Scenario C, but that the O-RU can also be successfully virtualized. Furthermore, the O-RU and O-DU would be implemented in the same O-Cloud, which has acceleration hardware required by both the O-RU and O-DU.

Note, this seems to be a future scenario, and is not part of our initial focus.

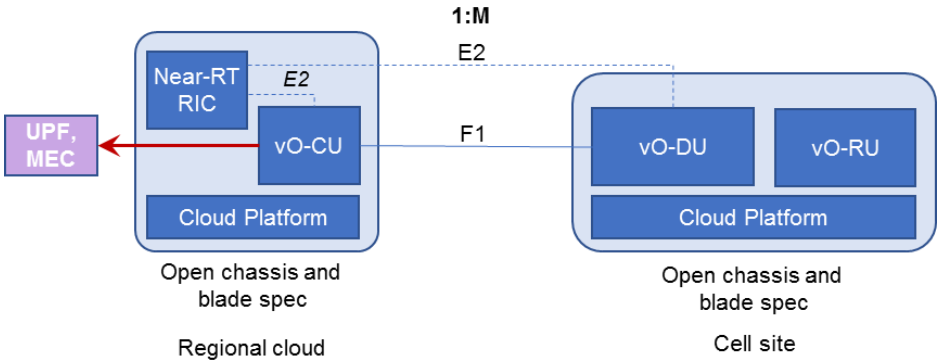

Figure 29: Scenario E

6.5.1. Key Use Cases and Drivers

Because the O-DU and O-RU are implemented in the same O-Cloud in this Scenario, it seems that the O-DU implementation must meet the environmental and accessibility requirements typically associated with an O-RU. Therefore, an indoor use case seems most appropriate.

6.6. Scenario F

This is a variation on Scenario E in which the O-DU and O-RU are both virtualized, but in different O-Clouds. This means that:

- The O-DU function can be placed in a more convenient location in terms of accessibility for maintenance and upgrades.
- The O-DU function can be placed in an environment that is semi-controlled or controlled, which reduces some of the implementation complexity.

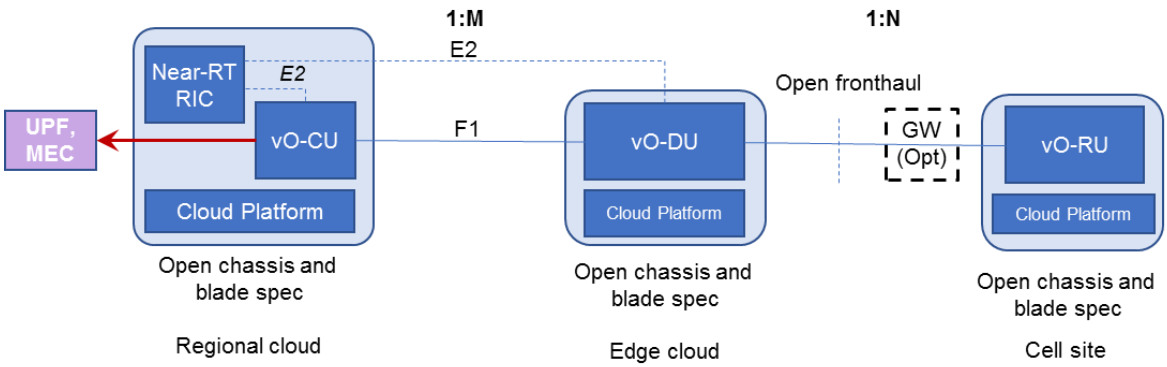

Figure 30: Scenario F

6.6.1. Key Use Cases and Drivers

Because this assumes that the O-RU is virtualized, this is a future use case.

This use case seems to be better suited for outdoor deployments (e.g., pole mounted) than Scenario E.

6.7. Scenarios of Initial Interest

More scenarios have been identified than can be addressed in the initial release of this document. Scenario B has been selected as the one to address initially, and to be the subject of detailed treatment in a Scenario document (refer back to Figure 1). Other scenarios are expected to be addressed in later work.

7. Appendix A (informative): Extensions to Current Deployment Scenarios to Include NSA

In this appendix, some extensions to (some of) the current deployment scenarios are proposed with the aim of introducing Non-Standalone (NSA) in the pictures, consistently with the scope O-RAN cloud architecture. These extensions will be the basis of the discussion for next version of the present document. In the following charts the subscript 'N' is indicating blocks related to NR, while the subscript 'E' is indicating blocks related to E-UTRA.[7] For E-UTRA, the W1 interface is indicated. Its definition is ongoing in a 3GPP work item.

7.1. Scenario A

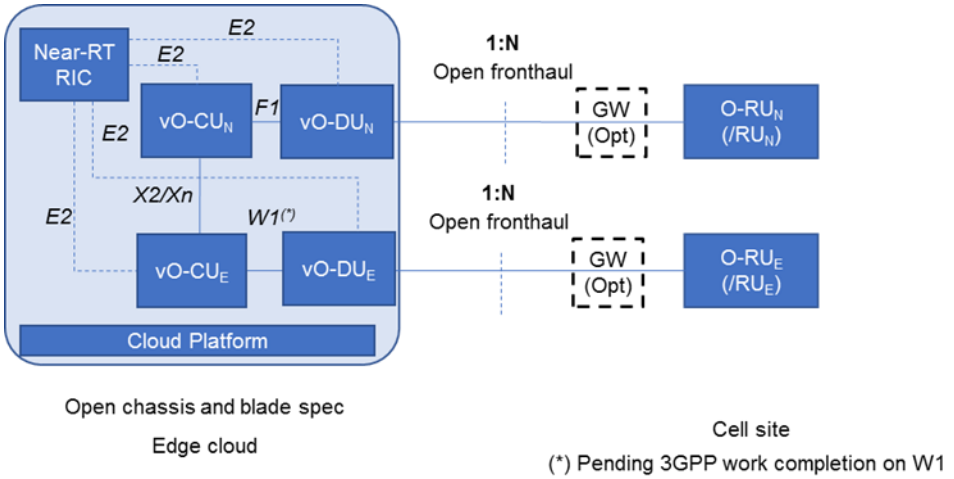

Figure 31: Scenario A, Including NSA

7.2. Scenario B

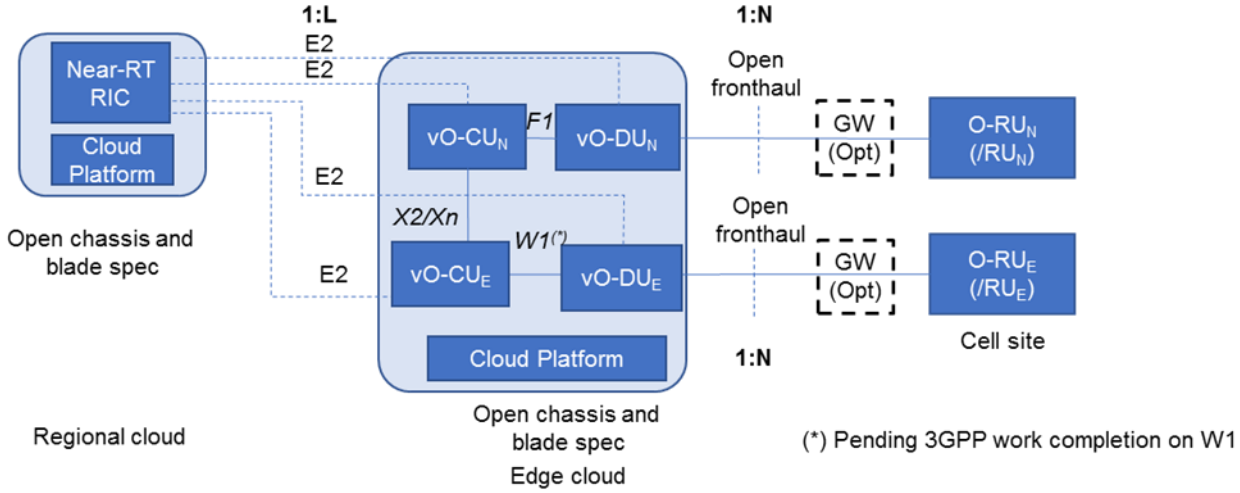

Figure 32: Scenario B, Including NSA

[7] No UPF or MEC blocks are explicitly indicated in the figures of this appendix, as the focus of this appendix is on the radio part.

7.3. Scenario C

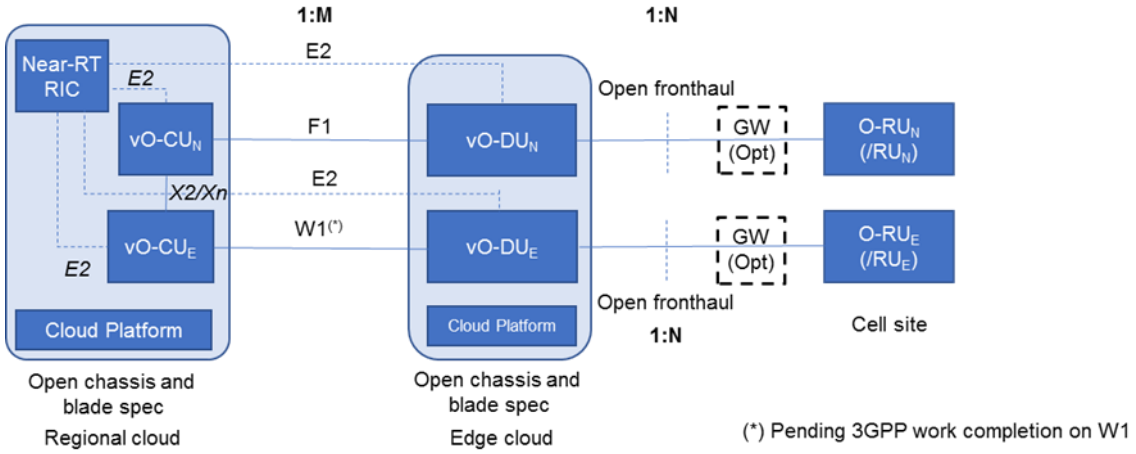

Figure 33: Scenario C, Including NSA

7.4. Scenario C.2

The scenario addresses both the single and multi-operator cases. To reduce the complexity in the figure the multi operator case is considered, so no X2/Xn interface is present between CU_N1 and CU_E2 or between CU_E1 and CU_N2.

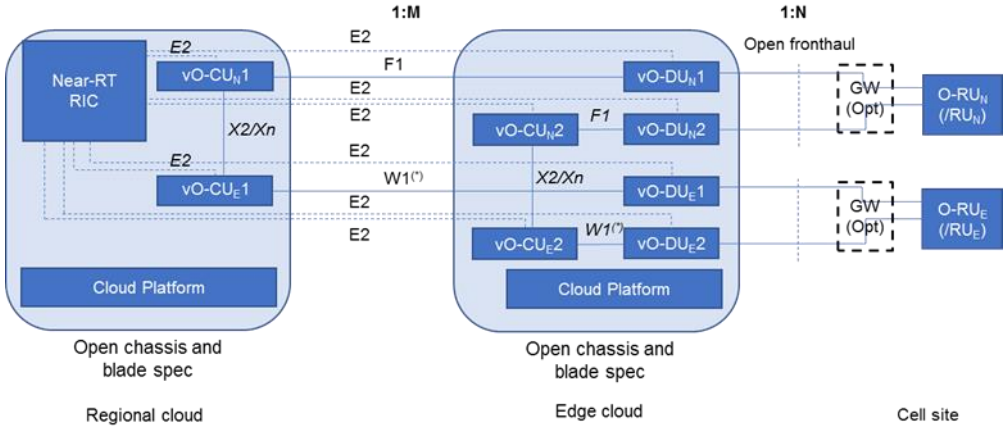

Figure 34: Scenario C.2, Including NSA

7.5. Scenario D

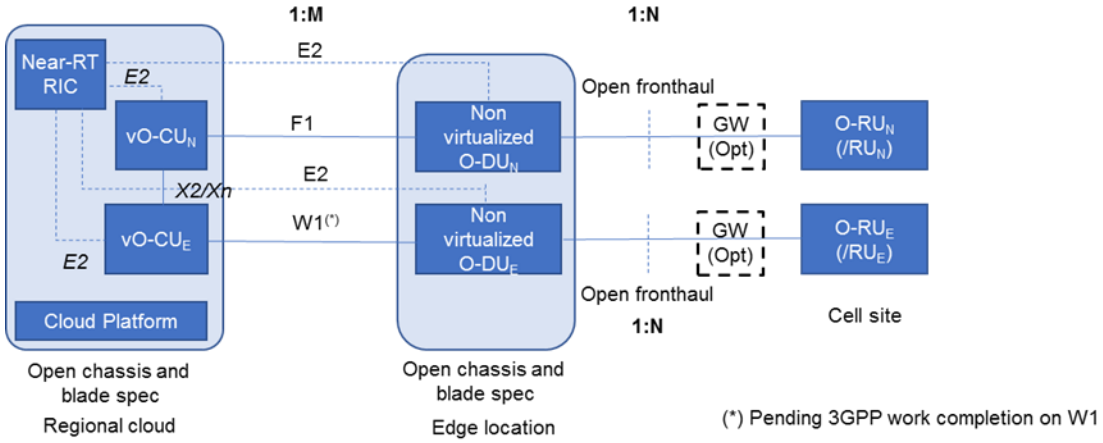

Figure 35: Scenario D, Including NSA

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