



Network Functions Virtualisation (NFV) Release 5; Architectural Framework; Report on NFV support for virtualisation of RAN

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Reference

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Contents

Intellectual Property Rights	5
Foreword.....	5
Modal verbs terminology.....	5
1 Scope	6
2 References	6
2.1 Normative references	6
2.2 Informative references.....	6
3 Definition of terms, symbols and abbreviations.....	10
3.1 Terms.....	10
3.2 Symbols.....	10
3.3 Abbreviations	10
4 Introduction and overview.....	11
4.1 Introduction to the virtualised RAN	11
4.1.1 Overview	11
4.1.2 The concept of RAN disaggregation and functional splits	11
4.1.3 Open and virtualised RAN.....	12
4.2 State of the art and other organizations landscape.....	13
4.2.1 Overview of SDOs activities on vRAN	13
4.2.1.1 Introduction.....	13
4.2.1.2 ETSI NFV	13
4.2.1.3 3GPP	13
4.2.1.4 O-RAN Alliance (O-RAN)	14
4.2.1.5 Small Cell Forum (SCF)	14
4.2.1.6 CPRI Forum	14
4.2.1.7 IEEE.....	14
4.3 Characteristics of the virtualised RAN	14
4.3.1 Reference architecture and functional splits in O-RAN.....	14
4.3.2 Cloudification, management and orchestration.....	15
4.4 Problem statement	15
5 NFV support for the virtualised RAN	16
5.1 Overview	16
5.1.1 Introduction.....	16
5.1.2 Terminology alignment.....	17
5.2 Key issues and potential solutions.....	18
5.2.1 Key Issue A: Architectural Mappings.....	18
5.2.1.1 Introduction	18
5.2.1.1.1 Overview	18
5.2.1.1.2 NFV-MANO with container management and multi-site connectivity support.....	18
5.2.1.1.3 O-RAN Orchestration related architecture elements	19
5.2.1.1.4 Challenges related to architectural elements mapping.....	20
5.2.1.2 Potential Solutions	21
5.2.1.2.1 Overview	21
5.2.1.2.2 Solutions for challenge A1: SMO and O-Cloud boundaries and mapping of interfaces	21
5.2.1.2.3 Solutions for challenge A3: Physical Infrastructure Management	23
5.2.1.3 Gap analysis	26
5.2.1.4 Evaluation and concluding remark.....	27
5.2.2 Key Issue B: Support for Acceleration abstraction.....	30
5.2.2.1 Introduction.....	30
5.2.2.1.1 Overview	30
5.2.2.1.2 NFV-MANO support for Acceleration abstraction	30
5.2.2.1.3 O-RAN support for Acceleration abstraction	32
5.2.2.1.4 Challenges	33
5.2.2.2 Potential Solutions	34
5.2.2.2.1 Overview	34

5.2.2.2.2	Solutions for Challenge B.1: virtualised accelerator in NFV for both VM and containerized environments	35
5.2.2.2.3	Solutions for challenge B.2: Virtual and hardware acceleration resource management	36
5.2.2.2.4	Solutions for challenge B.3: Northbound interface exposed by the virtualised accelerator to the application (VNF).....	37
5.2.2.3	Gap analysis	38
5.2.2.4	Evaluation and concluding remark.....	38
5.2.3	Key Issue C: VNF descriptors and packaging	39
5.2.3.1	Introduction	39
5.2.3.1.1	Overview	39
5.2.3.1.2	Descriptors and Packaging in NFV-MANO	40
5.2.3.1.3	Descriptors and Packaging in O-RAN.....	40
5.2.3.1.4	Challenges	41
5.2.3.2	Potential Solutions	42
5.2.3.2.1	Overview	42
5.2.3.2.2	Solutions for challenge C.1: ML modelling information.....	42
5.2.3.2.3	Solutions for challenge C.2: CRDs in NFV.....	42
5.2.3.2.4	Solutions for challenge C.3: VNF dependencies and different LCM cycles	43
5.2.3.3	Gap analysis	44
5.2.3.4	Evaluation and concluding remark.....	44
5.2.4	Key Issue D: Transport Network management.....	48
5.2.4.1	Introduction	48
5.2.4.1.1	Overview	48
5.2.4.1.2	Transport Network Management in NFV-MANO	48
5.2.4.1.3	Transport Network Management in O-RAN	50
5.2.4.1.4	Challenges	51
5.2.4.2	Potential Solutions	52
5.2.4.2.1	Overview	52
5.2.4.2.2	Solutions for challenge D.1: O-Cloud boundaries and network demarcation points.....	52
5.2.4.2.3	Solutions for challenge D.2: Network management boundaries.....	53
5.2.4.2.4	Solutions for challenge D.3: Time synchronization	53
5.2.4.2.5	Solutions for challenge D.4: Transport Network Slicing.....	54
5.2.4.2.6	Solutions for challenge D.5: Transport specific protocols.....	54
5.2.4.3	Gap analysis	55
5.2.4.4	Evaluation and concluding remark.....	55
6	Recommendations	57
6.1	Overview	57
6.2	Recommendations for solutions	57
6.3	Recommendations related to the NFV architectural framework	59
6.4	Recommendations related to functional aspects.....	59
6.5	Recommendations related to NFV descriptors and other artifacts	60
6.6	Recommendations related to interfaces and information model.....	61
6.7	Recommendations related to cross organization collaboration	62
7	Conclusion.....	62
Annex A:	Virtualised RAN Use Cases.....	63
A.1	Introduction	63
A.2	Use cases from O-RAN WG1	63
A.3	Use cases from O-RAN WG6	69
Annex B:	Background information on Functional Splits.....	75
B.1	Introduction	75
Annex C:	Change history	77
History	78

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) Network Functions Virtualisation (NFV).

Modal verbs terminology

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1 Scope

The present document analyses the NFV framework to determine how it can further support virtualised RAN (vRAN) use cases. Several key technical challenges are identified relevant to architectural, operational and management aspects, in case the NFV architectural framework is leveraged to support virtualisation of the RAN. For each technical challenge a detailed analysis is provided, together with a description of potential solutions. Potential gaps in ETSI NFV specifications are articulated and a comparison between the different potential solutions is also accommodated.

In addition, an analysis of vRAN use cases from relevant specifications from other SDOs is performed, together with a mapping to the current NFV concepts supported by the NFV architectural framework.

The present document also provides recommendations for enhancements to the NFV architectural framework and its functionality, aiming to provide further support for vRAN use cases.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

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

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

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- [i.2] NGMN Alliance: "5G White Paper", 2015.
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STANDARD PREVIEW

3 Definition of terms, symbols and abbreviations

3.1 Terms

ETSI GR NFV-IFA 046 V5.1.1 (2023-05)

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For the purposes of the present document, the terms given in ETSI GR NFV 003 [i.1] apply.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in ETSI GR NFV 003 [i.1] and the following apply:

5GCN	5G Core Network
5GS	5G System
AAL	Acceleration Abstraction Layer
AALI	Acceleration Abstraction Layer Interface
AMF	Access and Mobility Management Function
ASIC	Application-Specific Integrated Circuit
CRD	Custom Resource Definition
CSE	Connectivity Service Endpoint
CU	Centralized Unit
DU	Distributed Unit
EPD	Extensible Para-virtualised Device
FPGA	Field-Programmable Gate Array
GPU	General Purpose Processor
LPU	Logical Processing Unit
MDA	Management Data Analytics
NFO	Network Function Orchestration

NSMF	Network Slice Management Function
NSSMF	Network Slice Subnet Management Function
PAP	Policy Administration Point
PF	Policy Function
RAN	Radio Access Network
RIC	RAN Intelligent Controller
RU	Radio Unit
SMO	Service Management and Orchestration
TNE	Transport Network Element
UC	Use Case
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communications
VF	Virtual Function
VID	VLAN Identifier

4 Introduction and overview

4.1 Introduction to the virtualised RAN

4.1.1 Overview

The 5G system (5GS) was designed to satisfy stringent requirements by means of several KPIs like throughput, delay, and reliability in challenging use cases, as originally described by NGMN in "NGMN 5G White Paper" [i.2] and ITU IMT 2020 specifications (like in [i.3]), but also beyond. It greatly evolves both the packet core and the Radio Access Network (RAN) of the previous generation mobile network, where compared to the 4G design, several key technological innovations were introduced. These span from control-user plane decoupling and migrating the packet core to a Service Based Architecture (SBA), to the introduction of the 5G New Radio (NR) and the Next Generation-RAN (NG-RAN). 5G NR develops under the 3GPP RAN TSG and mainly targets outperforming spectrum efficiency and high frequency band utilization. It is considered as an umbrella term though, covering for example the radio interface, radio spectrum usage and massive MIMO technology. NG-RAN is the term used to refer to RAN architectural related aspects, as defined in ETSI TS 123 501 [i.4].

The present document investigates the advances concerning the virtualisation of the RAN and profiles the NFV framework to determine how it can support virtualised RAN (vRAN) use cases. The basic concepts and terminology used are introduced, based on the major SDOs' and industrial fora activities that are driving the transformation of the RAN into an open, disaggregated, and virtualised system.

4.1.2 The concept of RAN disaggregation and functional splits

In a monolithic design, a single integrated base station (either 4G eNB, 5G ng-eNB or a gNB) provides the full set of RAN control and user plane functionalities that enable user equipment (UE) access to the mobile network. These functionalities span from the management of radio resources, control plan signalling (e.g. UE handover), data packet transportation, baseband processing (e.g. channel coding, modulation), to the radio frequency (RF) part for single/multi-antenna transmission/reception.

Following a basic disaggregation model, a monolithic base station is decomposed into two parts:

- 1) Remote Radio Heads (RRHs) which include the RF part, the power amplifier and the analogue-to digital or digital-to-analogue converter being mounted externally and co-located with the antenna; and
- 2) Base Band Units (BBUs) located in a centralized pool being responsible for the baseband processing.

The link connecting a BBU and a RRH is known as fronthaul, and CPRI [i.5] is the standardized interface used for the BBU to RRH communication. This disaggregation model is also known as Cloud-RAN. Although Cloud-RAN heralds an evolving change, its extreme need for bandwidth on the fronthaul makes the wide adoption difficult towards 5G, especially for challenging URLLC use cases. In this regard, the functional split concept was introduced to relocate RAN functions between BBUs and RRHs. Main SDOs working on the topic are 3GPP, O-RAN Alliance, Small Cell Forum and CPRI [i.5]. Note that different standardization bodies are using their individual terminologies to articulate the concept of functional splits. To avoid confusion in this study, the terminology used by 3GPP (primarily), and O-RAN (when necessary) are followed.

In Figure 4.1.2-1, a high-level view of the NG-RAN architecture is depicted presenting the different functional components and relevant interfaces. In 3GPP TR 38.801 [i.6] the 5G RAN functions and the functional splits concept have been initially described. Detailed specification of the NG-RAN architecture and the different components for 5G are in ETSI TS 138 300 [i.7] and ETSI TS 138 401 [i.8]. The idea is that a single 5G gNB can be decomposed into a Centralized Unit (CU) and Distributed Units (DUs), to flexibly deploy RAN functionalities over different sites. Depending on the split, different functionality is allocated to DUs and CUs. Splits 1 to 5 consider functionality reallocation above the MAC and have been considered as High Layer Splits (HLS). Splits 6 to 8 are relevant to different splitting options below MAC and are considered as Low Layer Splits (LLS). Split option 8 is the one that was used in the case of "legacy" BBU - RRH decoupling followed by Cloud-RAN. In principle a DU hosts RAN functions between LLS and HLS and aggregates multiple RUs, and a CU hosts all RAN functions above HLS and aggregates several DUs. F1 interface is used for the communication between a CU and a DU according to ETSI TS 138 470 [i.9]. RU is responsible for Low-PHY and RF processing, like D/A and digital beamforming (depending on the split). Background information about the disaggregated RAN and the functional splits concept is provided in Annex B.

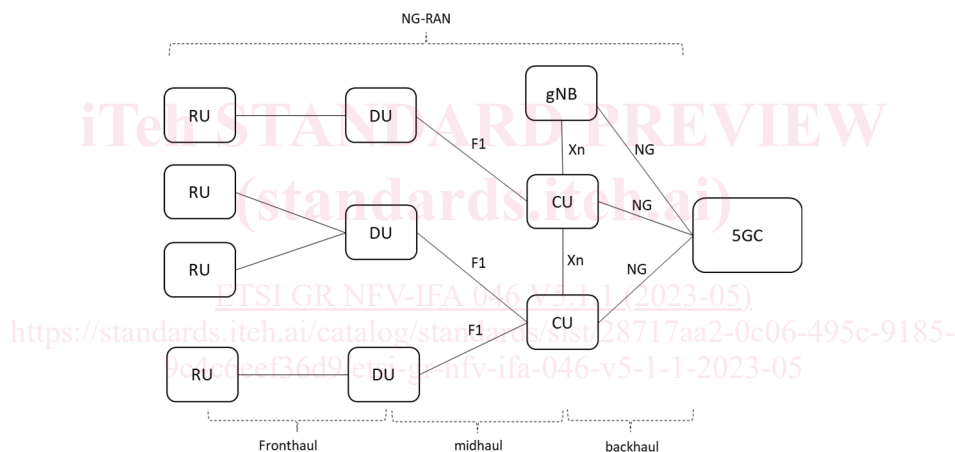


Figure 4.1.2-1: NG-RAN architecture according to ETSI TS 138 401 [i.8] and 3GPP TR 38.801 [i.6]

3GPP also splits CU functionality into Control Plane (CU-CP) and User Plane (CU-UP) functions, where E1 is the interface between them specified in ETSI TS 138 460 [i.10]. Communication between NG-RAN and 5GCN is realized over the NG interface according to ETSI TS 138 410 [i.11]. On the user plane, GTP-U based communication is used between NG-RAN node (CU or gNB or ng-eNB) and the UPF residing in 5GCN (N3 interface). On the control plane, communication is over the (NG-C) interface defined between the NG-RAN node and AMF residing in the 5GCN (N2 interface). NG interface is following the point-to-point model and is not part of SBA. Xn is the interface between CUs or between CUs and integrated gNBs. For the transport network part, as shown in Figure 4.1.2-1 *fronthaul* link is the link between a DU and a RU, *midhaul* the link between a DU and a CU and *backhaul* the link between a CU and 5GCN. In the case of Cloud-RAN (split 8), fronthaul is used to denote the link between BBU and RRH and backhaul the link BBU to 5GCN; there is no midhaul link.

4.1.3 Open and virtualised RAN

Besides achieving performance related KPIs, another key goal of 5G is to provide substantial deployment flexibility. Such goal has been achieved in the core network, via decomposing the EPC system into several control/user plane 5GCN network functions (NFs) and by leveraging softwarization technologies, such as Network Function Virtualisation (NFV) and Software Defined Networking (SDN). 5GCN network functions can be exposed as Virtual Network Functions (VNFs) and the full benefits of adopting NFV-MANO can be exploited. From the 3GPP perspective, the concept is described for 4G core in 3GPP TR 32.842 [i.12] and for 5GCN in 3GPP TR 23.742 [i.14], where the relationship and mapping between 3GPP defined NFs and ETSI NFV defined VNFs is also investigated.

RAN softwarization is about running the RAN protocol stack in software and exploiting the microservices concept for RAN NFs. Virtualisation of the RAN is about running the software on top of a virtual substrate on top of off-the-self hardware. Although 5GCN offers the foundation over which the NFV concept can be demonstrated and the NFV-MANO can be applied in the mobile network, the idea of disaggregating and virtualising the RAN (although not new), only recently has been endorsed by the industry. The reason is that unlike the functional decomposition in the core network, several inherent challenges exist for the RAN towards full softwarization and virtualisation, such as stringent time-critical function placement (e.g. hybrid automatic repeat request) and compute intensive operations (e.g. channel decoder).

Different SDOs are trying to delineate the concept, derive deployment models and standardize the relevant interfaces that will enable control, management, and orchestration of the virtualised RAN. However currently the Technology Readiness Level (TRL) is still rather low. Many technical challenges are still to be met before all the functionalities around a vRAN ecosystem can be precisely articulated and eventually delineate NFV aware RAN implementations.

4.2 State of the art and other organizations landscape

4.2.1 Overview of SDOs activities on vRAN

4.2.1.1 Introduction

Main SDOs working on the topic are 3GPP, O-RAN Alliance and Small Cell Forum which derive specifications covering interface and architectural aspects. Telecom Infra Project (TIP) is an industrial community with the goal of accelerating the adoption of an open virtualised RAN; ONF is focusing on the RAN control aspects but also on the SDN-based transport network; CPRI Forum and IEEE 1914 (NGFI) work is on the fronthaul network.

In the following, key standards and reports are summarized, which will serve as a baseline for the present document study. Although the baseline functional splits have been defined by 3GPP, the discussion is still open and other organizations like O-RAN have also made proposals and recommendations. As the topics handled by these organizations are highly complex, in the following a synopsis is provided and is not to be considered as an exhaustive investigation. Background information about the disaggregated RAN and functional splits concept is provided in Annex B.

4.2.1.2 ETSI NFV

A study regarding NFV support for 5G networks is presented in ETSI GR NFV-IFA 037 [i.15]. Although this study is not investigating NG-RAN related issues, nevertheless a set of key challenges and derived requirements are analysed for enabling NFV at large, and NFV-MANO in particular, for 5G NFs. Use cases and deployment scenarios considering NFV-MANO support for low latency services are presented in ETSI GR NFV-EVE017 [i.16]. The following ETSI NFV-IFA 001 [i.17], ETSI GS NFV-IFA 002 [i.18], ETSI GS NFV-IFA 004 [i.19] (for release 2) and ETSI GS NFV-IFA 018 [i.20], ETSI GS NFV-IFA 019 [i.21] (for release 3) are covering aspects related to the acceleration abstraction layer and acceleration resource management interfaces.

4.2.1.3 3GPP

The overall 5G is described in ETSI TS 123 501 [i.4], NG-RAN architecture and the different components are detailed in ETSI TS 138 300 [i.7] and ETSI TS 138 401 [i.8]. Network Resource Models (NRM) according to SA5 for NG-RAN are presented in ETSI TS 128 541 [i.22] (stage 2 and stage 3). Management of converged networks and networks that include virtualised network functions using agent-manager paradigm is in ETSI TS 128 622 [i.13]. From the 3GPP perspective, the concept of enabling NFV-MANO is described for 4G in 3GPP TR 32.842 [i.12] and for 5G in 3GPP TR 23.742 [i.14], where the relationship and mapping between 3GPP defined NFs and ETSI NFV defined VNFs is also considered. In 3GPP TR 32.864 [i.23] management aspects of virtualised network functions that are part of the NR are described. In more detail 3GPP TR 32.864 [i.23] demonstrates possible solutions to expose as VNFs the virtualised parts of a 5G base station (i.e. gNB) and describes the relevant NFV-MANO-side technical aspects like NSDs instantiation and adding VNFFGD for the gNB. Although it can serve as a baseline for the present document, is not aligned with latest standardization activities in bodies like the O-RAN Alliance.

4.2.1.4 O-RAN Alliance (O-RAN)

O-RAN was founded in 2018 with the goal of delineating an open virtualised RAN and driving the development of the relevant interfaces' specifications and system design aspects. O-RAN specifications are aligned with 3GPP work, but also go beyond by nominating new paradigms like AI-based RAN Intelligent Controller (RIC), Service Management and Orchestration (SMO) and the Acceleration Abstraction Layer (AAL) for the RAN. In O-RAN standardization work is split among eleven WGs, each with a concrete mission. Regarding NG-RAN functional splits, O-RAN endorsed split 2 between DU and CU and splits 7.2 and 8 between DU and RU. In principle split 7.2 allocates High PHY to DU and Low PHY to RU, where two variations have been further specified splits 7.2.a and 7.2.b depending on where precoding is supported (in cat. A precoding is supported in DU, in cat. B precoding is supported in RU). Open Fronthaul Interface is the topic of O-RAN WG4, which is of relevance for connectivity and transport network related aspects. While all the WG activities are relevant for the goals of the present document study, focus is given on the work delivered by WG1 (use cases and overall architecture), WG6 (cloudification and orchestration), WG9 (Open X-haul Transport Workgroup) and WG10 (Operation and Maintenance).

4.2.1.5 Small Cell Forum (SCF)

Several use cases and functional splits deployment scenarios have been described by SCF in SCF159 [i.24]. In SCF222 [i.25], the FAPI interface for 5G between the MAC and the PHY is defined. According to SCF222 [i.25] MAC, PHY and RF both reside on the DU, while higher layers (i.e. RLC, PDCP, SDAP, RRC) reside on the cloudified CU. FAPI is the internal interface that enables MAC-PHY communication and configuration of the PHY. In case the MAC layer and PHY are physically decoupled (split 6 according to 3GPP), the reference interface is the 5G Network FAPI (nFAPI), which is considered a wrapper over FAPI, enabling communication over the network. nFAPI is defined in SCF 225 [i.26] and can be used for the MAC-PHY communication either HLS is used or not (CU and DU are separated or not), where in both cases the RU hosts the PHY and the RF.

4.2.1.6 CPRI Forum

CPRI Forum [i.5] specifies CPRI and eCPRI protocols, which have been the de-facto fronthaul protocols, where eCPRI [i.5] demonstrates increased efficiency by means of bandwidth requirements, it is Ethernet-based and is the successor of CPRI for 5G communications.

4.2.1.7 IEEE

IEEE 1914.1 [i.27] specifies the interfaces used under the Next Generation Fronthaul Interface (NGFI), as NGFI-I between DU and RU and NGFI-II between gNB-DU and gNB-CU (similarly to F1).

4.3 Characteristics of the virtualised RAN

4.3.1 Reference architecture and functional splits in O-RAN

In ORAN-WG1-ARCH [i.28] the ORAN architecture is presented, while ORAN WG8 AAD [i.29] details the functionality and APIs specification of O-DU and O-CUs. A high-level representation of the the O-RAN logical architecture is depicted in Figure 5.1-2 in ORAN-WG1-ARCH [i.28].

The basic elements of the O-RAN architecture and interfaces are described in O-RAN WG1 "O-RAN Architecture Description" [i.28] and are summarized as follows:

- **SMO:** A Service Management and Orchestration system.
- **Non-RT RIC (Non-Real-Time RAN Intelligent Controller):** A logical function within SMO. It is comprised of the Non-RT RIC Framework and the Non-RT RIC Applications (rApps).
- **Non-RT RIC Framework:** Logically terminates the A1 interface to the Near-RT RIC and exposes to rApps, via its R1 interface, the set of internal SMO services needed for their runtime processing. The Non-RT RIC Framework functionality provides AI/ML workflow including model training, inference and updates needed for rApps.
- **rApps:** Modular applications that leverage the functionality exposed via the Non-RT RIC Framework.
- **Near-RT RIC (Near-Real-Time RAN Intelligent Controller):** A logical function that enables near-real-time control and optimization of RAN elements and resources. It can include AI/ML workflow including model training, inference and updates.
- **xApp:** An application designed to run on the near-RT RIC.
- **O-Cloud:** A cloud computing platform comprising a collection of physical infrastructure nodes that meet O-RAN requirements to host the relevant O-RAN functions, the supporting software components and the appropriate management and orchestration functions.

In addition to standard 3GPP interfaces (like Xn, NG, etc.) the following interfaces have been specified in the O-RAN architecture:

- **O1:** between SMO framework and O-RAN managed elements.
- **O2:** between SMO framework and the O-Cloud.
- **A1:** between Near-RT RIC and Non-RT RIC.
- **Open FH M-Plane:** Management interface controlling the O-RU, driven from the O-DU or for hybrid topology driven from the SMO.
- **E2:** between Near-RT RIC and different RAN elements.
- **R1:** SMO northbound towards rApps.
- **Y1:** Y1 interface allows the Y1 consumers to subscribe or request the RAN analytics information provided by Near-RT RIC.

4.3.2 Cloudification, management and orchestration

Depending on the deployment scenario O-Cloud considers functionality distribution in cell sites (O-RUs), edge cloud (e.g. O-DUs), and regional clouds (e.g. O-CUs and Near-RT RIC). The case of O-DU deployment also in the cell site has also been foreseen. While O-RU is foreseen to be exposed as a PNF, O-Cloud is expected to host both O-DU and O-CU as VNFs. O-Cloud offers the following basic services, which are exposed to SMO through the O2 interface (see O-RAN WG6 CAD [i.30] and O-RAN O2 GAP [i.31]):

- **Infrastructure Management Services (IMS):** responsible for deploying and managing cloud infrastructure. For example, manages resource pools and transport network.
- **Deployment Management Services (DMS):** responsible for managing the lifecycle of virtualised/containerized deployments on the cloud infrastructure.

Hardware or software-based acceleration is a key component for satisfying the extreme need for low latency operations required for example in a DU. Hardware Acceleration Abstraction Layer (AAL) on the cloud platform is under development to enable a vendor-agnostic and technology-agnostic (e.g. GPUs, FPGA, SmartNICs) communication between the implementation and NFs, through a AAL API. Technical aspects to RAN cloudification and VNF exposure will be analysed in detail in the following clauses.