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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.

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

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

[i.1] ETSI GR NFV 003: "Network Functions Virtualisation (NFV); Terminology for Main Concepts in NFV".

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

[i.3] Recommendation ITU-R M.2083-0: "MT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond".

[i.4] ETSI TS 123 501 (V16.10.0): "5G; System architecture for the 5G System (5GS) (3GPP TS 23.501 version 16.10.0 Release 16)".

[i.5] Common Public Radio Interface (CPRI).

[i.6] 3GPP TR 38.801 (V14.0.0): "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on new radio access technology: Radio access architecture and interfaces (Release 14)".

[i.7] ETSI TS 138 300 (V16.7.0): "5G; NR; NR and NG-RAN Overall description; Stage-2 (3GPP TS 38.300 version 16.7.0 Release 16)".

[i.8] ETSI TS 138 401 (V16.7.0): "5G; NG-RAN; Architecture description (3GPP TS 38.401 version 16.7.0 Release 16)".

[i.9] ETSI TS 138 470 (V16.5.0): "5G; NG-RAN; F1 general aspects and principles (3GPP TS 38.470 version 16.5.0 Release 16)".

[i.10] ETSI TS 138 460 (V16.3.0): "5G; NG-RAN; E1 general aspects and principles (3GPP TS 38.460 version 16.3.0 Release 16)".

[i.11] ETSI TS 138 410 (V16.4.0): "5G; NG-RAN; NG general aspects and principles (3GPP TS 38.410 version 16.4.0 Release 16)".

[i.12] 3GPP TR 32.842 (V13.1.0): "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Study on network management of virtualised networks (Release 13)".

[i.13] ETSI TS 128 622 (V16.9.0): "Universal Mobile Telecommunications System (UMTS); LTE; 5G; Telecommunication management; Generic Network Resource Model (NRM) Integration Reference Point (IRP); Information Service (IS) (3GPP TS 28.622 version 16.9.0 Release 16)".

[i.14] 3GPP TR 23.742 (V16.0.0): "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on Enhancements to the Service-Based Architecture (Release 16)".

[i.15] ETSI GR NFV-IFA 037 (V4.1.1): "Network Functions Virtualisation (NFV) Release 4; Architectural Framework; Report on further NFV support for 5G".

[i.16] ETSI GR NFV-EVE 017 (V1.1.1): "Network Functions Virtualisation (NFV); Management and Orchestration; Report on the support of real-time/ultra-low latency aspects in NFV related to service and network handling".

[i.17] ETSI GS NFV-IFA 001 (V1.1.1): "Network Functions Virtualisation (NFV); Acceleration Technologies; Report on Acceleration Technologies & Use Cases".

[i.18] ETSI GS NFV-IFA 002 (V2.4.1): "Network Functions Virtualisation (NFV) Release 2; Acceleration Technologies; VNF Interfaces Specification".

[i.19] ETSI GS NFV-IFA 004 (V2.4.1): "Network Functions Virtualisation (NFV) Release 2; Acceleration Technologies; Management Aspects Specification".

[i.20] ETSI GS NFV-IFA 018 (V3.1.1): "Network Functions Virtualisation (NFV); Acceleration Technologies; Network Acceleration Interface Specification; Release 3".

[i.21] ETSI GS NFV-IFA 019 (V3.1.1): "Network Functions Virtualisation (NFV); Acceleration Technologies; Acceleration Resource Management Interface Specification; Release 3".

[i.22] ETSI TS 128 541 (V16.10.0): "5G; Management and orchestration; 5G Network Resource Model (NRM); Stage 2 and stage 3 (3GPP TS 28.541 version 16.10.0 Release 16)".

[i.23] 3GPP TR 32.864 (V15.0.0): "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Study on management aspects of virtualised network functions that are part of the New Radio (NR) (Release 15)".

[i.24] SmallCellForum SCF159 (V159.07.02): "Small cell virtualisation functional splits and use cases".

[i.25] SmallCellForum SCF222 (V222.10.03): "5G FAPI: PHY API Specification".

[i.26] SmallCellForum SCF225 (V225.2.0.0): "5G nFAPI Specification".

[i.27] IEEE 1914.1™-2019: "IEEE Standard for Packet-based Fronthaul Transport Networks".

[i.28] ORAN-WG1-ARCH (V08.00.13): "O-RAN Architecture Description".

[i.29] ORAN.WG8.AAD (V04.00): "Base Station O-DU and O-CU Software Architecture and APIs".

[i.30] O-RAN, O-RAN.WG6.CAD (V04.02): "Cloud Architecture and Deployment Scenarios for O-RAN Virtualised RAN".

[i.31] O-RAN, O-RAN.WG6.O2-GA&P (V08.00): "O2 Interface General Aspects and Principles".

[i.32] ETSI GS NFV-IFA 010: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Functional requirements specification".

[i.33] ETSI GR NFV-EVE 018 (V5.1.1): "Network Functions Virtualisation (NFV) Release 5; Evolution and Ecosystem; Report on Multi-tenancy in NFV".

[i.34] ETSI GR NFV-EVE 019 (V4.1.1): "Network Functions Virtualisation (NFV) Release 4; Architectural Framework; Report on VNF generic OAM functions".

[i.35] ETSI GS NFV-IFA 032: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Interface and Information Model Specification for Multi-Site Connectivity Services".

[i.36] ETSI GS NFV-IFA 030: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Multiple Administrative Domain Aspect Interfaces Specification".

[i.37] ETSI GR NFV-IFA 028 (V3.1.1): "Network Functions Virtualisation (NFV) Release 3; Management and Orchestration; Report on architecture options to support multiple administrative domains".

[i.38] ETSI GR NFV-REL 011 (V4.1.1): "Network Functions Virtualisation (NFV) Release 4; Management and Orchestration; Report on NFV-MANO software modification".

[i.39] ETSI GS NFV-IFA 005: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Or-Vi reference point - Interface and Information Model Specification".

[i.40] ETSI GS NFV-IFA 006: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Vi-Vnfm reference point - Interface and Information Model Specification".

[i.41] ETSI GR NFV-IFA 024 (V4.3.1): "Network Functions Virtualisation (NFV) Release 4; Information Modeling; Report on External Touchpoints related to NFV Information Model".

[i.42] ETSI GR NFV-IFA 023 (V3.1.1): "Network Functions Virtualisation (NFV); Management and Orchestration;Report on Policy Management in Mano; Release 3".

[i.43] ETSI GR NFV-IFA 042 (V4.1.1): "Network Functions Virtualisation (NFV) Release 4; Management and Orchestration; Report on policy information and data models for NFV-MANO".

[i.44] ETSI GS NFV-IFA 014: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Network Service Templates Specification".

[i.45] ETSI GS NFV-IFA 027: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Performance Measurements Specification".

[i.46] ETSI GS NFV-TST 008 (V3.3.1): "Network Functions Virtualisation (NFV) Release 3; Testing; NFVI Compute and Network Metrics Specification".

[i.47] O-RAN.WG1.Use-Cases-Analysis-Report (V06.00): "O-RAN Working Group 1 Use Cases Analysis Report".

[i.48] O-RAN.WG10.OAM-Architecture (V13.00): "O-RAN Operations and Maintenance Architecture".

[i.49] ETSI GR NFV-IFA 029 (V3.3.1): Network Functions Virtualisation (NFV) Release 3; Architecture; Report on the Enhancements of the NFV architecture towards "Cloud-native" and "PaaS"".

[i.50] O-RAN.WG6.ORCH-USE-CASES (V02.01): "Orchestration Use Cases and Requirements for O-RAN Virtualised RAN".

[i.51] ETSI GS NFV-IFA 031: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Requirements and interfaces specification for management of NFV-MANO".

[i.52] ETSI GS NFV-IFA 036 (V5.2.1): "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Requirements for service interfaces and object model for container cluster management and orchestration specification".

[i.53] ETSI GS NFV-IFA 007: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Or-Vnfm reference point - Interface and Information Model Specification".

[i.54] ETSI GS NFV-IFA 008: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Ve-Vnfm reference point - Interface and Information Model Specification".

[i.55] ETSI GS NFV-IFA 011: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; VNF Descriptor and Packaging Specification".

[i.56] ETSI GS NFV-REL 006 (V3.1.1): "Network Functions Virtualisation (NFV) Release 3; Reliability; Maintaining Service Availability and Continuity Upon Software Modification".

[i.57] ETSI GR NFV-IFA 041 (V4.1.1): "Network Functions Virtualisation (NFV) Release 4; Management and Orchestration; Report on enabling autonomous management in NFV-MANO".

[i.58] ETSI GS NFV-IFA 045 (V5.2.1): "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Faults and alarms modeling specification".

[i.59] ETSI GR NFV-EVE 022 (V5.1.1): "Network Functions Virtualisation (NFV) Release 5; Architectural Framework; Report on VNF configuration".

[i.60] ETSI GS NFV-SOL 001 (V4.3.1): "Network Functions Virtualisation (NFV) Release 4; Protocols and Data Models; NFV descriptors based on TOSCA specification".

[i.61] ETSI GR NFV-TST 006 (V1.1.1): "Network Functions Virtualisation (NFV); Testing; Report on CICD and Devops".

[i.62] ETSI GS NFV 006 (V4.4.1): "Network Functions Virtualisation (NFV) Release 4; Management and Orchestration; Architectural Framework Specification".

[i.63] IEEE 802.1Q™-2018: "IEEE Standard for Local and Metropolitan Area Network--Bridges and Bridged Networks".

[i.64] ETSI GS NFV-IFA 013: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Os-Ma-nfvo reference point - Interface and Information Model Specification".

[i.65] O-RAN.WG6.AAL-GAnP (V04.00): "O-RAN Acceleration Abstraction Layer General Aspects and Principles".

[i.66] O-RAN.WG6.AAL-Common API (V03.00.05): "O-RAN Working Group 6 Acceleration Abstraction Layer Common API".

[i.67] ETSI GS NFV-SOL 004 (V4.3.1): "Network Functions Virtualisation (NFV) Release 4; Protocols and Data Models; VNF Package and PNFD Archive specification".

[i.68] ETSI GS NFV-SOL 007 (V4.3.1): "Network Functions Virtualisation (NFV) Release 4; Protocols and Data Models; Network Service Descriptor File Structure Specification".

[i.69] ETSI GS NFV-IFA 047: "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Management data analytics Service Interface and Information Model specification".

[i.70] O-RAN-WG4.CUS.0 (V08.00): "O-RAN Working Group 4 (Open Fronthaul Interfaces WG) Control, User and Synchronization Plane Specification".

[i.71] ETSI GR NFV-IFA 044 (V5.1.1): "Network Functions Virtualisation (NFV) Release 5; Management and Orchestration; Report on Flexible VNF Deployment".

[i.72] ETSI GR NFV-IFA 035 (V5.1.1): "Network Functions Virtualisation (NFV) Release 5; Architectural Framework; Report on network connectivity integration and operationalization for NFV".

[i.73] ETSI GS NFV-SOL 005 (V4.3.1): "Network Functions Virtualisation (NFV) Release 4; Protocols and Data Models; RESTful protocols specification for the Os-Ma-nfvo Reference Point".

[i.74] O-RAN.WG9.XTRP-MGT.0(V04.00): "Management interfaces for Transport Network Elements".

[i.75] O-RAN.WG9.XPSAAS (03.00): "Xhaul Packet Switched Architectures and Solutions".

[i.76] ORAN-WG9.XTRP-SYN.0 (03.00): "Synchronization Architecture and Solution Specification".

[i.77] ETSI TS 128 533 (V16.8.0): "5G; Management and orchestration; Architecture framework (3GPP TS 28.533 version 16.8.0 Release 16)".

[i.78] O-RAN.WG6.O2-O2dms-Interface-ETSI-NFV-profile (V01.00): "O-RAN Working Group 6 O-RAN, O-Cloud O2dms Interface Specification, Profile based on ETSI NFV protocol and data models".

[i.79] ONF oneM2M TR-547 (V1.1): "TAPI Reference Implementation Agreement".

[i.80] ETSI GR NFV-IFA 049 (V5.1.1): "Network Functions Virtualisation (NFV) Release 5; Architectural Framework; VNF generic OAM functions specification".

[i.81] IEEE 1914.3™-2018: "IEEE Standard for Radio over Ethernet Encapsulations and Mappings".

[i.82] ETSI GS NFV-IFA 053 (V5.2.1): "Management and Orchestration; Requirements and interface specification for Physical Infrastructure Management".

[i.83] ETSI GR NFV-IFA 022 (V3.1.1): "Network Functions Virtualisation (NFV) Release 3; Management and Orchestration; Report on Management and Connectivity for Multi-Site Services".

[i.84] ETSI GR NFV-IFA 051 (V5.1.1): "Network Functions Virtualisation (NFV) Release 5; Architectural framework; Report on VNF management gap analysis with open source projects".

[i.85] O-RAN.WG10.AppPkg (V1.0.4): "O-RAN Application Package Specification".

[i.86] O-RAN.WG11.SecReqSpecs (V09.00): "Security Requirements and Controls Specifications".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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.

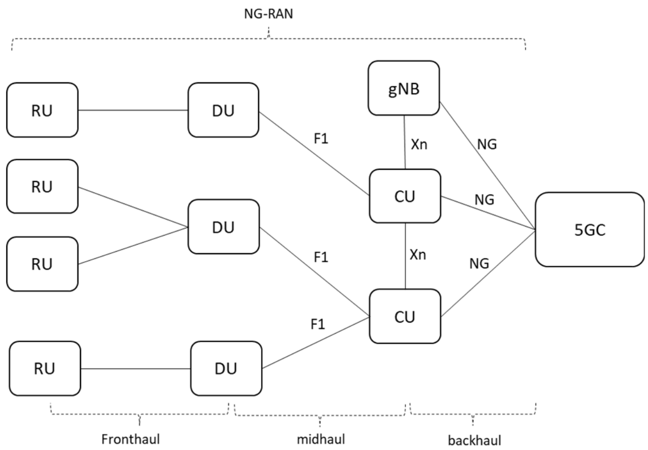

Figure 4.1.2-1: NG-RAN architecture according to ETSI TS 138 401 [i.8] and 3GPP TR 38.801 [i.6]

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 **s**upport 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 5GS 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 SFC 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 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.

4.4 Problem statement

As specified in ETSI GS NFV-IFA 010 [i.32], NFV-MANO supports the definition of Network Services (NS), composed by both Physical Network Functions (PNFs) and VNFs implemented across multivendor environments. Although in the 5GCN the decision to implement a NF as a VNF or a PNF is rather straightforward in the case of vRAN a multifaceted analysis is considered, especially under the light of partial virtualisation.

For example, it is foreseen that offloading a NF to hardware (or software) accelerators, will be essential when virtualising O-DUs but not necessary for O-CUs. Inside the O-DU partial virtualisation can be exploited where for example decoding is offloaded to an accelerator, while other functionalities like modulation/demodulation can be executed without hardware support. On the one hand, in a NFV-MANO-controlled RAN environment, RAN VNFs are expected to be optimally controlled following NFV-MANO procedures and descriptors like use of NSDs, VNF onboarding, NS and VNF LCM, licensing, etc. On the other hand, isolation by means of performance, management and operations of the non-virtualised RAN NFs is expected to be also guaranteed. Relevant to RAN infrastructure management (computing, networking, storage), the virtual substrate can be hypervisor-based, or container based; in the present document both are considered.

Past rich experience with ETSI NFV defined NFV-MANO deployments, could offer a remedy to several challenges related to RAN virtualisation and orchestration complexity, but also to issues like fault, performance, and policy management. However, as the implications of RAN softwarization and virtualisation are not yet clearly understood, the present document aims to identify key technical challenges and provide possible recommendations towards exposing, controlling, and managing RAN NF as VNFs and avoid confounding when ETSI NFV architectural framework is applied in the RAN. In more detail, the present document is about:

- Investigating the advances concerning the virtualisation of RAN and profiling the NFV architectural framework to determine the level of support it can offer to vRAN use cases.
- Analysing possible mapping solutions of the NFV architectural framework to the O-RAN architecture and the different functional blocks like SMO and O-Cloud.
- Analysing NFV-MANO indispensable constitutes that will enable deployment, operation and management of a container and hypervisor-based virtualisation layer for the RAN.
- Investigate the RAN VNF networking which enables communication between RAN VNF, PNFs, and communication with external entities. Transport connectivity is related to all fronthaul, midhaul, backhaul networking, considering potential WIM involvement.
- Provide an analysis of potential enhancements to NFV-MANO concerning capabilities, such as acceleration, platform capabilities (synchronization, real-time, etc.).

In vRAN many aspects of NFVI provisioning and HW/SW management, are expected to be affected in consideration of vRAN deployment characteristics. For example, small but highly distributed site deployments have a huge impact on the network design. Depending on the deployment scenario FAPI or nFAPI could be exploited, affecting also the overall VNF design and requirements by means of Connection Points (CP), Service Access Points (SAP) and acceleration layer. Issues like hardware acceleration, time synchronization and network slicing are within the scope of the present document and will be further analysed providing recommendations when and if necessary. However, topics relevant to pure NR and NG-RAN aspects like trade-offs between different functional splits, spectrum management, mobility management, etc. are out of scope of the present document.

5 NFV support for the virtualised RAN

5.1 Overview

5.1.1 Introduction

Several deployment scenarios have been considered by O-RAN in O-RAN-WG6-CAD [i.30] like deployment of NFs either as VNFs or PNFs and deployment of NFs in regional, edge or remote clouds. In the present document, it is assumed that O-CU, O-DU and Near RT-RIC can be exposed as VNFs, and O-RU is realized as a PNF. It is also assumed that the transport network (backhaul, midhaul, fronthaul) are the transport network constituents which provide the intended connectivity over local or distributed NFVI-PoPs/sites, which in terms of O-RAN would correspond to O-Cloud sites.

According to the use cases analysis provided in Annex A, when building an NFV-MANO VNF aware disaggregated vRAN ecosystem, the following challenges are expected to be addressed, when profiling the NFV-MANO framework:

- Architecture mapping: This concerns to profiling the NFV-MANO architectural framework to O-RAN architecture (e.g. consider NFVO as part of the SMO, VIM/CISM as part of O-Cloud, VNFM as part of the SMO). See also use cases 7, 19, 20 in clause A.2 and use cases 1, 7 to 11 in clause A.3. In addition, the role of EM as defined in NFV-MANO is not clear in O-RAN (see also use case 4 in clause A.2 and use case 14 in clause A.3). When it comes to architectural mappings, another consideration is related to the concepts and terminology, VNF naming and identification between SMO/O-Cloud and NFV-MANO, so that same resource and deployment management views for both VIM/CISM and NFVI/CISI can be determined.

- Transport network management: Requirements are about preserving IP addressing or FQDN for moving VNFs, for example by building a local network inside a moving vehicle (see use case 3 in clause A.2). Transport network slicing relationship with NFV-MANO's WIM has not been investigated enough (see use cases 8, 9, 10 in clause A.2). In addition, transport network demarcation points management is an open issue, like also support new paradigms like XHAUL have not been considered by NFV-MANO.

- Time synchronization: Network configuration and management of time synchronization, to support distributed decision making (see use cases 11 and 17 in clause A.2).

- NFVI management: Hardware resources operating in the O-Cloud are subject to SMO and IMS control (see use cases 2 to 6 and 15, 16 in clause A.3. See use cases 17, 18, 19 in clause A.3 regarding NFVI fault management). In principle this is not the case in ETSI NFV specifications regarding NFVI control, however some level of resource control is made through CIS Cluster Management (CCM) for containerized systems (ETSI NFV-IFA 036 [i.52]).

- NFV support for near-RT RIC and xApps: Supporting near-RT RIC functionality when near-RT RIC is exposed as a VNF imposes several challenges such as need for partial VNF packaging, granular VNFC LCM, CRD and API aggregation for containerized solutions (see use cases 12 and 13 in clause A.3).

In addition to the analysis provided in Annex A, although not explicitly nominated in the use cases provided, the following key challenges have been also identified:

- **Exposing VNFs with hardware acceleration support:** virtualising the O-CU and exposing as a VNF is rather straightforward (considering additional features like accelerating I/O data transfers). However, this is not the case for O-DU where demanding High-PHY processing imposes additional challenges, thus hardware or software acceleration for compute-intensive processing is expected to support vRAN deployments. Since O-DU (but also could be for O-CU) performance relies on acceleration support, relevant work in NFV-MANO is expected to be reconsidered in the light of new O-RAN AAL interface specification and AAL management activities by O-RAN WG6.

- **Automation, policy management:** Another substantial dimension to consider is about network automation and policy procedures. ETSI GR NFV-IFA 023 [i.42], ETSI GR NFV-IFA 041 [i.57] and ETSI GR NFV-IFA 042 [i.43] are making an initial endeavour for delineating autonomous management and policy management, respectively, in the context of ETSI NFV ecosystem. However, as these topics are highly complex and inherently embedded in the O-RAN logical functions like the SMO and both the non-near-RT and near-RT RIC, still the way and the level these solutions can be leveraged by O-RAN is not comprehensible. Note that besides ETSI NFV activities, other SDOs like ETSI ZSM, ETSI ENI and 3GPP-SA5 are also working on these topics, however no single standardized and/or open-source solution is applied to all domains, the demarcation points of interoperability of the different frameworks is unclear.

Important additional challenges to further elucidate are the following. Although ETSI NFV-MANO has considered multiple aspects related to reliability, these is no standardized interface that could enable actions like VNF migration. Also enabling a way to perform load balancing and dynamic associations over pools of hybrid VIM and CISM based solutions is an open discussion. As these challenges are not relevant to compulsory operations when considering NFV-MANO applicability in O-RAN, these will not be further analysed.

5.1.2 Terminology alignment

The concepts of virtualisation and application exposure as VNFs embraced by both ETSI NFV and O-RAN are in principle the same, Table 5.1.2-1 provides a mapping of terms and concepts.

Table 5.1.2-1: Terminology mapping

O-RAN	NFV-MANO
Workload	VNF (VM-based or containerized), PNF
O-RAN Network Function (logical Node)	Application hosted by a VNF or PNF
NF Deployment	VNF instance
Deployment Descriptor	VNFD (for VNF), NSD (for NS)
O-Cloud Instance	NFVI, VIM, CISM. See note.
SMO (NFO as part of FOCOM)	NFVO. See note.
O-Cloud Node or O-Cloud Compute Node (e.g. server)	NFVI Node
NOTE: Concrete mapping of the different NFV-MANO FBs and functions to O-RAN architectural entities depend on the architectural mapping solution. For example, VNFM operations can be considered part of SMO or part of O-Cloud and SMO has multiple orchestration functionalities (NFO, FOCOM) that might not map 1:1 to NFVO. See key issue A described in clause 5.2.1 for further analysis.	

The terminology mapping sets the baseline for all the key issues analysis. Depending on the architectural mapping, variations might arise, like for example which NFV FBs are covered by a O-Cloud Instance.

5.2 Key issues and potential solutions

5.2.1 Key Issue A: Architectural Mappings

5.2.1.1 Introduction

5.2.1.1.1 Overview

This key issue is about providing a logical mapping of the different NFV-MANO Functional Blocks (FBs) and logical functions to the O-RAN architectural elements. Mapping of the different elements will also facilitate the assessment regarding the relationship of NFV-MANO reference points and interfaces specifications with O-RAN interfaces like O1 and O2.

5.2.1.1.2 NFV-MANO with container management and multi-site connectivity support

The NFV-MANO architectural framework is specified in ETSI GS NFV 006 [i.62], where the functionality of the NFV-MANO Functional Blocks (FBs), reference points, functions and service interfaces are described.

In Figure 5.2.1.1.2-1 the NFV-MANO architectural framework with support for containers is depicted according to Figure 5.2-3 from ETSI GS NFV 006 [i.62].

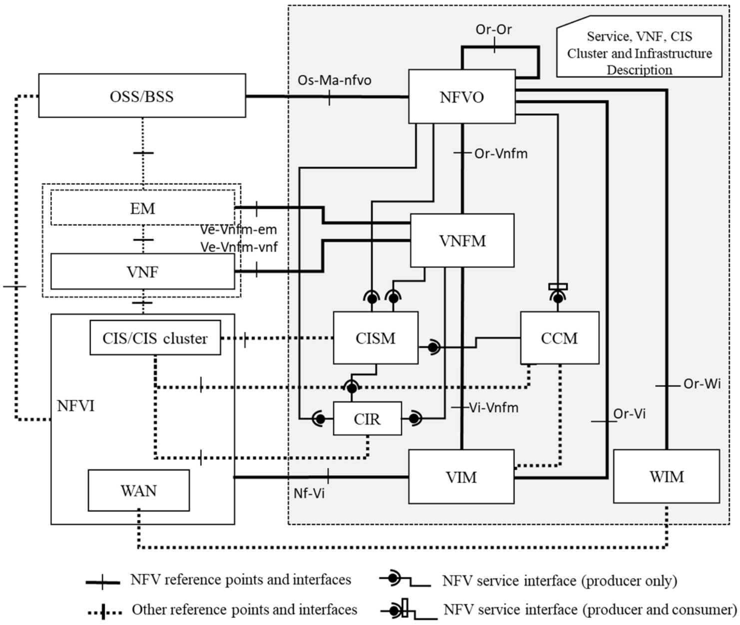

Figure 5.2.1.1.2-1: NFV-MANO architectural representation including Release 4 features

The Container Infrastructure Service (CIS) is the execution environment for a container cluster where the container-based services run; Container Infrastructure Service Management (CISM) is responsible for the management of containerized workloads executed by CIS; and CIS Cluster Management (CCM) is responsible for the resource management of CIS clusters. Container Image Registry (CIR) is responsible container image management. From the management perspective note that these are logical functions integrated in the NFV-MANO architecture and are not introducing new FBs. WIM is used for the management of the connectivity between different NFVI-PoPs. The architecture depicted in Figure 5.2.1.1.2-1 will be the one used for the mapping with the different elements which constitute the O-RAN architecture.

5.2.1.1.3 O-RAN Orchestration related architecture elements

The overall O-RAN reference architecture has been introduced in ORAN-WG1 "O-RAN Architecture Description" [i.28] and a high-level description has been provided in clause 4.3.1. For the ease of understanding, in the following the main functionality and the internal structure and operations of O-Cloud and SMO are briefly summarized, as these are the indispensable components for the architectural mapping with NFV-MANO.

In O-RAN an O-Cloud denotes a set of cloud resources (physical and virtual systems and networks), over which physical and virtualised Network Functions (e.g. O-DU, O-CU) can be deployed and operate. O-Cloud is responsible to provide several services for both the platform and the NF deployments like life cycle management support (e.g. upgrade, scaling, healing), software management, FCAPS operations (e.g. FM, PM) and inventory services. In O-Cloud, IMS is the entity which is responsible for the cloud platform related operations and DMS is the entity responsible for the NF deployments related operations. An O-Cloud hosts one IMS and multiple DMSs, while DMSs are created by the IMS. See O-RAN WG6-O2 GA&P [i.31] for a detailed discussion.

O-RAN SMO is the entity used for the orchestration, management, and control of all O-Clouds (platform and deployments) and the instantiated O-RAN NFs of the vRAN system. Inside the SMO the Network Function Orchestration (NFO) is defined as the set the logical services for managing NF deployments and the Federated O-Cloud Orchestration and Management (FOCOM) are the logical services provided for the orchestration of the O-Cloud platforms. SMO terminates the O2 interface which is composed of O2ims and O2dms parts. The O-Cloud terminates on the other end. O2ims interface is used for the O-Cloud platform management and terminates inside the SMO in FOCOM; O2dms is used for the management of the NF deployments and terminates inside the SMO in NFO. A single SMO entity can manage multiple O-Clouds. See O-RAN WG6-O2 GA&P [i.31] for a detailed discussion.

The functional decomposition inside SMO is still not standardized and no standard interfaces currently are defined for the communication between the different SMO components. Communication between the different components (e.g. between FOCOM and Non-RT RIC) are considered implementation specific. An SMO is also responsible for hosting/providing several additional key services like it terminates O1 interface, and also hosts Non-RT RIC running multi-vendor rApps (e.g. Network optimization, network automation). Additional SMO functionality is related to functions which enable network slicing support for the vRAN.

5.2.1.1.4 Challenges related to architectural elements mapping

Functionalities relevant to cloudification and orchestration in NFV-MANO and O-RAN are very similar. However, in case NFV-MANO is applied to cover the relevant aspects of the O-RAN architecture, the demarcation points between orchestration, VNF management and cloud resources management are not yet defined. The reason is mainly the SMO's internal complex structure like also the fact that both the SMO and O-Cloud provide a rich set of functionalities potentially embracing more than one FB's capabilities.

For this key issue the following challenges are identified:

- Challenge #A.1: SMO and O-Cloud boundaries and mapping of interfaces. SMO and O-Cloud boundaries in respect to the NFV-MANO model are not well defined. Although some NFV-MANO FBs can be directly mapped to O-RAN elements (like NFVO can be directly mapped to be part of the SMO and VIM to be part of the O-Cloud) this is not the case for the logical placement of FBs like the VNFM. Furthermore, it is not well defined to which NFV-MANO FBs and operations, O-Cloud resources, and deployment management services (i.e. IMS and DMS) are mapped. For example, an O-Cloud might have its own specific O2dms service API profile(s).

- Challenge #A.2: OSS as part of SMO. OSS functionality could be also part of the SMO. For example, rApps are considered part of SMO but can be mapped to OSS operations which are outside the NFV-MANO scope. In addition, the SMO operates on top of a multi-cloud federation; thus, mapping to multi-domain NFV-MANO is expected to be further elaborated.

- Challenge #A.3: *Physical Infrastructure Management*. Hardware resources operating in the O-Cloud are subject to SMO (e.g. O-Cloud blueprints definition) and IMS (e.g. inventory) control. Currently, in referenced ETSI NFV specifications, some level of resource control can be made through CIS Cluster Management (CCM) for containerized systems (ETSI GS NFV-IFA 036 [i.52]), and NFVI capacity management and Host reservation (ETSI GS NFV-IFA 005 [i.39]), however other aspects to provide full NFVI control are not covered by ETSI NFV specifications.

Clarification points:

- Non-RT RIC like also the associated rApps, are not part of NFV-MANO's scope. rApps re-assemble the properties of OSS applications and they reside inside the SMO, which is not however the case in NFV-MANO, where OSS and NFV-MANO have a clear separation of responsibilities and a standardize interface defined for their communication (ETSI GS NFV-IFA 013 [i.64]). NFV-MANO policies related functions like PAP and PFs as defined in ETSI GR NFV-IFA 023 [i.42] and the management data analytics (MDA) studied in ETSI GR NFV-IFA 041 [i.57] are relevant by means of Non-RT RIC functionality. However, as there is no NFV-MANO FB or function that can be directly mapped to the Non-RT RIC, this discussion is rather out of scope of the present document.

- O1 termination inside SMO is related to VNF config management investigated by ETSI GR NFV-EVE 019 [i.34] and ETSI GR NFV-EVE 022 [i.59]. This is relevant to EM functionality and the interactions with ETSI NFV-MANO through defined interfaces; however, EM detailed functionality and mapping to O-RAN elements is rather out of scope of the present document.

- Near-RT RIC is one key component of the O-RAN architecture but is not mappable to any ETSI-MANO FB or function. Similarly, to the Non-RT RIC there is some relevance to the policy making and enforcement and to MDA.

- Management aspects for PNFs (like RU deployed as PNFs) are out of NFV-MANO scope. The virtualisation of the O-RU is for future study by the O-RAN WGs.

- According to O-RAN WG6-CAD [i.30] different deployment models have been considered, where NFs can be distributed over regional, edge and remote clouds. Although in NFV-MANO there is no such granularity, this differentiation can be covered by the NFV-MANO multi-domain and multi-site deployments concepts. To simplify the analysis, it will be only considered that a domain can correspond to any possible different type of cloud (e.g. edge).

5.2.1.2 Potential Solutions

5.2.1.2.1 Overview

The present clause describes possible logical architectural mapping solutions. For all the different approaches it is considered that IMS deploys DMSs, and that IMS can communicate with the different DMSs. For example, IMS could retrieve OAM data from the DMS to re-expose inventory and capacity data to the SMO. Aligned with the NFV-MANO architecture it is also considered that OSS is outside SMO orchestration and management responsibility, and challenge #A.2 will not be investigated further in the present document.

5.2.1.2.2 Solutions for challenge A1: SMO and O-Cloud boundaries and mapping of interfaces

5.2.1.2.2.1 Potential solution SOL-A1-1

The present potential solution considers that O-Cloud is not responsible for the VNF management which is instead performed at the SMO level. This means that VNFM resides in the SMO, and it can potentially terminate the O2dms interface by implementing NFO functionality. In principle, NFO functionality could also reside in NFVO. NFVO also provides FOCOM functionality and terminates the O2ims interface used for the overall resource orchestration.

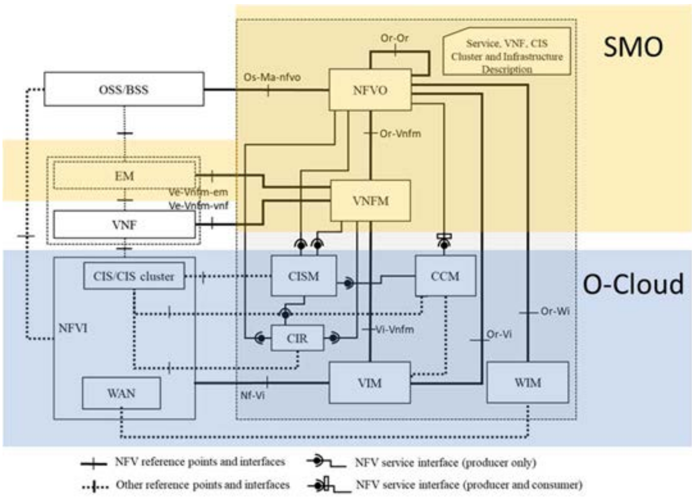

Figure 5.2.1.2.2.1-1: Architectural mapping for potential solution SOL-A1-1

The mapping proposal is depicted in Figure 5.2.1.2.2.1-1. For this proposal, the following relationships between NFV-MANO and O-Cloud elements are considered:

1) NFVO maps to SMO: NFVO is responsible to provide FOCOM functionality and termination of O2ims, and potentially also NFO functionality and O2dms support.

2) VNFM maps to SMO: VNFM maps to SMO and provides NFO related operations. It can potentially terminate all or partially O2dms interface functionality.

3) EM maps to SMO: this is also relevant to the O1 termination inside SMO, however the way EM operations as considered by NFV-MANO can be applied in O-RAN is still not yet clear. Nonetheless, it is considered in the present mapping that the NFVO provides element management capabilities.

4) NFVI maps to O-Cloud: NFVI maps to O-Cloud resources, however, note that NFVI management aspects are not fully covered by existing NFV-MANO specifications, in particular regarding the management of physical infrastructure. Thus, full IMS functionality cannot be fully supported.

5) CIS maps to O-Cloud: CIS maps to O-Cloud resources when considering container-based deployments.

6) VIM maps to O-Cloud: VIM maps to O-Cloud and provides IMS and DMS functionality related to management of VM-based virtualised resources.

7) CISM map to O-Cloud: CISM maps to O-Cloud DMS functionality related to management and orchestration of OS container-based deployments.

8) CCM maps to O-Cloud: CCM maps to O-Cloud and provides part of the IMS related functionality.

9) CIR maps to O-Cloud: CIR maps to O-Cloud and provides part of the IMS related functionality.

10) WIM maps to O-Cloud: WIM maps to O-Cloud. A functionality in the O-RAN architecture equivalent to the multi-site network connectivity has not been defined yet.

5.2.1.2.2.2 Potential solution SOL-A1-2

The present potential solution considers that O-Cloud is responsible for the VNF management. This means that in this case VNFM functionality resides in the O-Cloud and O2dms interface aspects are expected to be considered not only externally, but also internally to the O-Cloud. Regarding the interaction with the SMO, O2dms terminates to NFO which is fully supported by the NFVO. Like in the previous case NFVO is also used to terminate O2ims interface and provide FOCOM functionality.

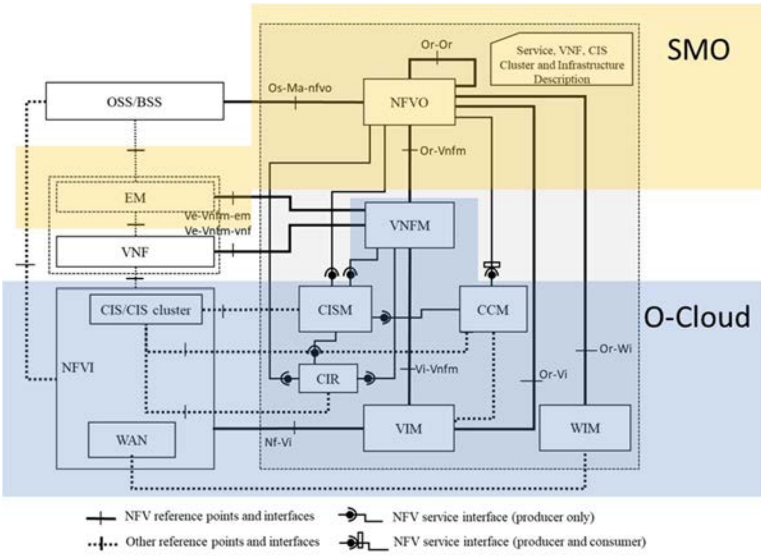

Figure 5.2.1.2.2.2-1: Architectural mapping for potential solution SOL-A1-2

The mapping proposal is depicted in Figure 5.2.1.2.2.2-1. For this proposal, the following relationships between NFV-MANO and O-Cloud elements are considered:

1) NFVO maps to SMO: NFVO is responsible to provide both FOCOM and NFO functionality and termination of O2ims and O2dms (fully or partially) respectively.

2) VNFM maps to O-Cloud: VNFM maps to O-Cloud and provides DMS related functionality. In this case, it is considered that DMS handles "NF-level" deployment functionality. It also potentially exposes O2dms interface to the SMO (NFVO). VNFM abstracts individual resource abstraction instances across O-Cloud sites whose resources are managed by VIMs/CISMs.

3) EM maps to SMO: same as in Solution A1.

4) NFVI maps to O-Cloud: same as in Solution A1.

5) CIS maps to O-Cloud: Same as in Solution A1.

6) VIM maps to O-Cloud: Same as in Solution A1. In particular, the VIM provides the DMS related functionality concerning the management and orchestration of VM-based virtualised resources for VNFs.

7) CISM map to O-Cloud: Same as in Solution A1. In particular, the CISM provides the DMS related functionality concerning the management and orchestration of OS containers and workloads for VNFs.

8) CCM maps to O-Cloud: Same as in Solution A1.

9) CIR maps to O-Cloud: Same as in Solution A1.

10) WIM maps to O-Cloud: Same as in Solution A1.

NOTE: Not all interfaces of the reference point between EM and VNFM are mappable to O-Cloud to SMO interactions.

5.2.1.2.3 Solutions for challenge A3: Physical Infrastructure Management

5.2.1.2.3.1 Overview

In the following several solutions are described related to physical infrastructure management. Physical infrastructure management operations to consider are related to NFVI inventory (e.g. inventory of compute and rack resources, etc.), resource provisioning, including configuration for provisioning (e.g. back-up and restore of configuration for network equipment, software installation, etc.), NFVI resources FM/PM monitoring and handling of NFVI resources operations. In all solutions, Physical Infrastructure Management (PIM) is introduced as a new logical function to clearly identify where the physical infrastructure management functionality can be "hosted" in the NFV architectural framework and determine the possible interactions with other entities of such a framework. By identifying PIM functionality, a specific area of management and a management domain, i.e. related to physical infrastructure, could be acknowledged. In all the solutions described PIM functionality is related to operations inside a single NFVI-PoP. PIM functionality is not regarded to be related to the management of physical infrastructure used for the transport networks over which multi-site connectivity services are instantiated according to ETSI GS NFV-IFA 032 [i.35].

5.2.1.2.3.2 Potential solution SOL-A3-1

According to the defined CIS cluster management in ETSI GS NFV-IFA 036 [i.52], CCM interacts with infrastructure management functions for the provisioning of virtual resources (towards a VIM) and bare-metal compute resources (towards other infrastructure managers). Currently, ETSI GS NFV-IFA 005 [i.39] specifies the support of various interfaces related to aspects of NFVI management, including physical infrastructure management such as: NFVI capacity management and compute host reservation management interfaces, defined in clauses 7.11 and 7.10 of ETSI GS NFV-IFA 005 [i.39], respectively. The present solution proposes extending the functionality provided by the VIM to additional areas of physical infrastructure management such as: physical resources provisioning (including configuration and allocation of resources to compose NFVI sites), physical resources monitoring (including fault, performance, and logging).

5.2.1.2.3.3 Potential solution SOL-A3-2 (PIM function in OSS)

In this solution the PIM function can control holistically the NFVI resources irrelevant of who is using these resources (VIM or CCM). PIM function is used to provision physical resources to compose the NFVI sites on which the VIM can then perform virtualised resource management. PIM function is also used to provision physical resources requested by CCM in case of containers on bare metal. For the case of VM-based CIS cluster resource provisioning is made through VIM and CCM interaction. PIM function is also responsible for FM/PM data exposure on behalf of NFVIPIM is only responsible for the management and FM/PM data exposure of resources residing inside NFVI-PoPs (network, compute, storage, etc.). Resource management for resources outside the NFVI-PoP are out of PIM scope.

In this solution PIM is considered to be part of OSS. In this case the NFV-MANO is provided pre-provisioned physical resources, which can be made aware to the NFVO by interacting with the PIM over the Os-Ma-nfvo reference point. In turn the NFVO can make the CCM and VIM aware of the pre-provisioned physical resources by updating the inventory of available resources to both CCM and VIM. In this solution VIM and CCM are not direct users of PIM. This solution assumes that this capability is available by NFVO on relevant interfaces either produced or consumed by the NFVO. The NFVO can collect relevant physical infrastructure resources monitoring data of concern for the objects managed by the NFV-MANO framework. The southbound interface between OSS and NFVI are assumed to consider the operations to support PIM functionality. Interactions between PIM and NFVI are implementation specific. Figure 5.2.1.2.3.3-1 depicts a visualization of the solution.

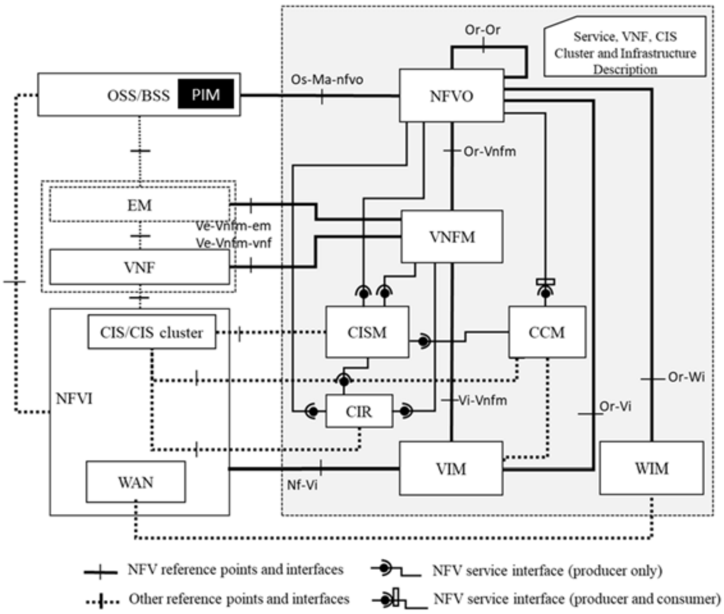

Figure 5.2.1.2.3.3-1: PIM function in OSS

5.2.1.2.3.4 Potential solution SOL-A3-3 (PIM outside OSS and outside NFV-MANO)

Like the previous case, this solution considers the operation of a PIM function controlling holistically the NFVI resources irrelevant of who is using these resources (VIM or CCM).

In this solution PIM resides outside OSS, but also outside NFV-MANO. Virtualised resource management is still performed over the Nf-Vi reference point however physical resource management made by PIM function is made through interaction over new interfaces exposed by the PIM (towards VIM and CCM). In this solution VIM and CCM are direct users of PIM. Interactions between PIM and NFVI are implementation specific. PIM function is responsible for FM/PM data exposure on behalf of NFVI, which can be consumed directly by VIM, CCM, etc. PIM services could be also offered to other functions like CISM related for example to storage management and provisioning. Figure 5.2.1.2.3.4-1 depicts a visualization of the solution.

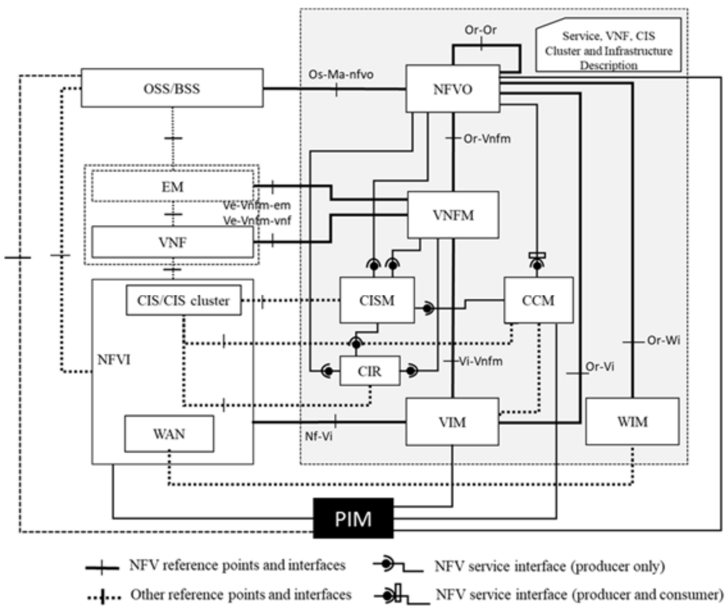

Figure 5.2.1.2.3.4-1: PIM function outside OSS and outside NFV-MANO

Interactions between NFVO and PIM are also expected based on the assumption that certain PIM functionality is mappable to IMS services exposed over the O2 interface, and those services can be consumed by the FOCOM. FOCOM functionalities are mappable to NFVO as per clauses 5.2.1.2.2.1 and 5.2.1.2.2.2.

5.2.1.2.3.5 Potential solution SOL-A3-4 (PIM inside NFV-MANO)

Like the previous case, this solution considers the operation of a PIM function controlling holistically the NFVI resources irrelevant of who is using these resources (VIM or CCM). In this solution in contrast with SOL-A3-3, PIM function is considered to be an NFV-MANO function or functional block. Interactions between PIM and NFVI are implementation specific. Like in solution SOL-A3-2 PIM function is responsible for FM/PM data exposure on behalf of NFVI, consumed by VIM, CCM, etc. PIM services could be also offered to other functions like CISM related for example to storage management and provisioning. Interactions between NFVO and PIM are also expected based on the assumption that certain PIM functionality is mappable to IMS services exposed over the O2 interface, and those services can be consumed by the FOCOM. FOCOM functionalities are mappable to NFVO as per clauses 5.2.1.2.2.1 and 5.2.1.2.2.2.

Figure 5.2.1.2.3.5-1 depicts a visualization of the solution.

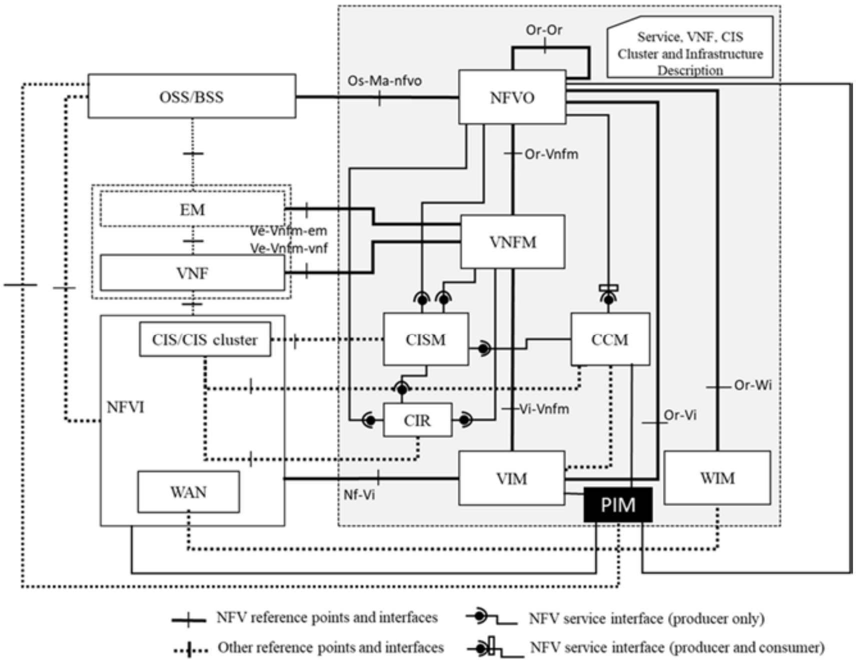

Figure 5.2.1.2.3.5-1: PIM function inside NFV-MANO

5.2.1.2.3.6 Potential solution SOL-A3-5 (PIM function as part of NFVI)

This solution considers the operation of a PIM function controlling the NFVI resources as a function residing in NFVI. Interactions between PIM and the actual NFVI resources are implementation specific. Like in the previous solutions PIM function is also responsible for FM/PM data exposure on behalf of NFVI regarding physical resources. Interactions between PIM and VIM are over Nf-Vi reference point, while a new interface is considered for the interactions between PIM and CCM. Interaction between PIM and OSS are also possible, where in that case PIM is the endpoint residing in NFVI for the communication with the relevant management functions residing in OSS. PIM services could be also offered to other functions like CISM related for example to storage management and provisioning. Interactions between NFVO and PIM are also expected based on the assumption that certain PIM functionality is mappable to IMS services exposed over the O2 interface, and those services can be consumed by the FOCOM. FOCOM functionalities are mappable to NFVO as per clauses 5.2.1.2.2.1 and 5.2.1.2.2.2.

Figure 5.2.1.2.3.6-1 depicts a visualization of the solution.

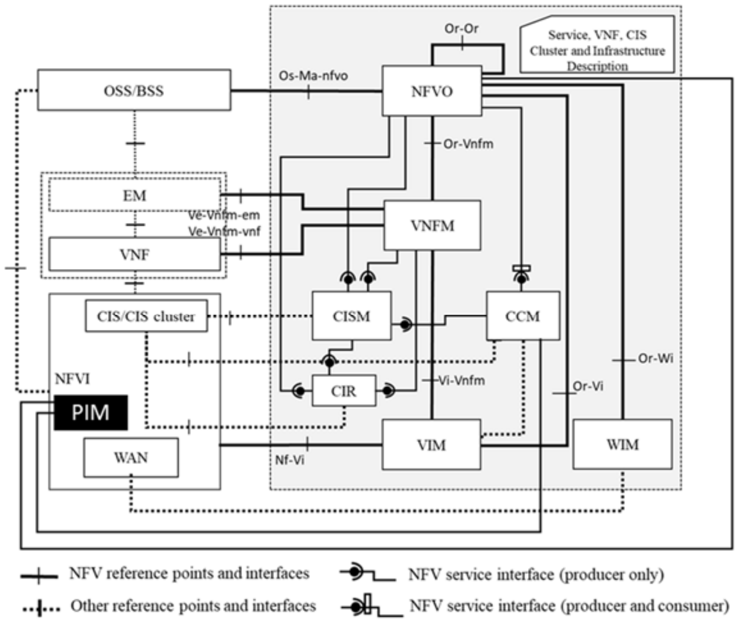

Figure 5.2.1.2.3.6-1: PIM function inside NFVI

5.2.1.3 Gap analysis

For supporting the solutions described the following gaps have been identified regarding the mapping of the NFV-MANO architectural framework to O-RAN architecture.

Gap #1.1: For both of the solutions (SOL-A1-1 and SOL-A1-2) the decisions will affect the usage or not of the relevant NFV-MANO interfaces when supporting the design of O2dms. To support solution SOL-A1-1, the NFO functionality boundaries between VNFM and NFVO are not defined, so the endpoint of O2dms to the VNFM and/or NFVO is unclear. To support solution SOL-A1-2, part of DMS functionality is supported by VNFM and by VIM/CISM, therefore O2dms exposure is unclear from the O-Cloud DMS side.

Gap #1.2: In O-RAN there is no distinction between VIM and CISM functionality, as both can be considered part of O-Cloud and functionality is offered by a single function, the DMS. Whether to consider VIM as a realization of the CISM has been analysed in ETSI GR NFV-IFA 029 [i.49]. Placement of the CISM functionality in the NFV-MANO architectural framework as an independent function or merged with other functions is not yet fully defined.

Gap #1.3: To support solution SOL-A1-2, single NFVO interacting with multiple VNFMs deployed in different administrative domains has not been considered by the ETSI NFV specifications. Multidomain interactions have only been specified between NFVOs on different administrative domains. This gap assumes that SMO and O-Cloud reside on different administrative domains.

Gap #1.4: Another issue to consider when profiling NFV-MANO FBs to the O-RAN architecture is related to the ability of NFVO to provide FOCOM functionality. In the case that O2ims comprises the management of O-Cloud infrastructure, which further results in physical and virtual infrastructure management done within the O-Cloud by the O-Cloud IMS, interfaces used and the communication properties like the ones between NFVO and VIM related to NFVI management (such as capacity information and NFVI resources reservation specified in ETSI GS NFV-IFA 005 [i.39]) are of relevance. However existing NFV-MANO specifications are not covering all management aspects towards NFVI, e.g. fulfilment and provisioning management of physical resources, also necessary for the case of CIS clusters based on baremetal, as specified in ETSI GS NFV-IFA 036 [i.52]. Thus, currently NFVO is not able to provide the expected full set of FOCOM functionality inside the SMO. Additional functionality, either part of or outside the NFVO, would be expected.

Gap #1.5: PIM functionality as described in clause 5.2.1.2.3.1 is not yet supported by ETSI NFV specifications.

5.2.1.4 Evaluation and concluding remark

Table 5.2.1.4-1 provides pros/cons analysis of the solutions described for this key issue.

Table 5.2.1.4-1: Solutions evaluation for Key Issue 1

Challenge	Solution	Pros	Cons	Additional considerations/remarks
A1: SMO and O-Cloud boundaries and mapping of interfaces	SOL-A1-1	- Clearer logical boundaries between infrastructure resource provisioning (responsibility of O-Cloud) and network function management and orchestration (responsibility of SMO). DMS, which is responsible for the NFs deployment, resides in O-Cloud side, but it handles this from a pure resource provisioning perspective without any NF-level abstraction considerations. - Better support for O-Cloud federation (multiple O-Clouds) of resources provisioning for VNFs, since all VNFs are managed centrally by VNFM residing in the SMO. See note 1.	- Unclear division of NFO functions make more complex determining the boundaries between applicable NFVO and VNFM functionality to cover the overall NFO functionality. - Related interactions with DMS and termination of O2dms partially in VNFM and NFVO and the interactions with the IMS are to be further analysed, since NFO and FOCOM functionality have not been precisely articulated. - Different de facto VNFM-CISM/VIM will result in multiple technology dependent interfaces between SMO and O-Cloud.	- Depending on the O-Cloud design only one or both types of deployments might be assumed (VM and container), simplifying SMO interactions, but limiting deployment options.
	SOL-A1-2	- A good step towards technology agnostic (VM/containers) abstract API exposure to SMO by O-Cloud. Note however that NFVO still handles certain technology specific aspects (e.g. different types of networks) so solution is not end-to-end technology agnostic. - Simplifies SMO operations and communication with O-Cloud for hybrid deployments (VM/containers). - SMO/NFVO do not need to perform low level granular resource deployment and management which is offloaded to the O-Cloud/VNFM - VNFM is logically mapped to the O-Cloud side and can abstract the resource deployment across different O-Cloud site instances (i.e. a VNFM can interact with several VIM/CISM controlling corresponding O-Cloud resource sites/NFVI-PoPs).	- O-Cloud provider is expected to "handle VNF" level compositions, which is not expected by a "pure" IaaS or PaaS type of provider. - Additional complexity in the O-Cloud because of hosting "VNFM" functionality. - DMS functionality can be provided by VNFM but also VIM/CISM. O2dms termination in O-Cloud is challenging. - If no standardization of the interfaces, if applicable, between IMS and DMS is developed from the O-RAN side, VNFM can become tightly coupled with IMS and other O-Cloud elements impeding the realization of multi-vendor O-Clouds.	- From a deployment perspective the number of entities providing VNFM functionality that can be assumed per O-Cloud instance, considering that multiple DMSs could be expected, is a design option. For example, to handle various types of deployments or tenancy requirements, O-Cloud resources site federation, etc. - Further study is expected to determine if any interoperable interfaces are relevant between VNFM in DMS role and IMS within the same O-Cloud.

Challenge	Solution	Pros	Cons	Additional considerations/remarks
	SOL-A3-1 (VIM extensions)	- Leverages currently defined physical infrastructure management capabilities already present in current referenced VIM specifications. - No new reference point or interface is defined; resource management operations are over existing communication channels (Nf-Vi towards NFVI and VIM to CCM). - All infrastructure (virtual and physical) management aspects are clearly identified towards a single entity thus enabling consolidation of infrastructure management. - Correlation of physical and virtual infrastructure can be performed without having to involve other management entities.	- Additional complexity introduced in VIM because of extending further beyond its current physical infrastructure management functionality. - Difficult to map VIM operations to a single O-Cloud management entity (i.e. IMS/DMS).	
	SOL-A3-2 (PIM in OSS)	- No new reference point is defined; resource management operations are over existing communication channels (Os-Ma-nfvo).	- Only applicable to resource pre-provisioning. - Not able to handle dynamic scenarios. - Additional complexity introduced to NFVO, e.g. additional interactions with CCM and VIM to make them aware of inventoried physical resources for respective CCM and VIM consideration. - Complex paths of information exchange to enable correlation of physical and virtual infrastructure, and unclear responsible entity (for example is it VIM, is it NFVO, is it other entity in OSS/BSS?)	See note 2.
	SOL-A3-3 (PIM outside MANO/OSS)	- Able to handle scenarios with dynamic resource provisioning. - Possible direct mapping of PIM to O-Cloud IMS operations. - Correlation of physical and virtual infrastructure can be performed by VIM through direct exposure of physical infrastructure management towards the VIM.	- New interfaces to be defined between PIM and VIM and between PIM and CCM. - Unclear boundary of PIM regarding its placement (neither part of NFVI, OSS/BSS or NFV-MANO framework). - Resource management requests are possible from two sources either OSS or NFV-MANO entities, which could cause state management issues.	See notes 2 and 3.

Challenge	Solution	Pros	Cons	Additional considerations/remarks
	SOL-A3-4 (PIM in MANO)	- Able to handle scenarios with dynamic resource provisioning. - Possible direct mapping of PIM to O-Cloud IMS operations. - Physical infrastructure management information can be used, referenced, and correlated at multiple levels within NFV-MANO, e.g. physical inventory information can be considered for end-to-end resources orchestration by NFV-MANO.	- New interfaces to be defined between PIM and VIM and between PIM and CCM. - Resource management requests are possible from two sources either OSS or NFV-MANO entities, which could cause state management issues.	See notes 2, 3 and 4.
	SOL-A3-5 (PIM in NFVI)	- Able to handle scenarios with dynamic resource provisioning. - No new reference point or interface is defined for resource management operations called by VIM (Nf-vi). Only interactions between PIM and CCM and PIM and VIM to be further specified. - Correlation of physical and virtual infrastructure can be performed by VIM through direct exposure of physical infrastructure management towards the VIM.	- Resource management requests are possible from two sources either OSS or NFV-MANO entities, which could cause state management issues.	See notes 2, 3 and 4.
NOTE 1: Although the concept of cloud federation is supported by O-RAN, multi- O-Cloud operations and interactions with the SMO entities have not been precisely articulated. In this regard an initial assessment is presented without detailing all possible interactions between SMO and O-Cloud. NOTE 2: NFV does not define how interactions between PIM and NFVI are realized. In principle these are regarded to be either implementation specific or out-of-scope. NOTE 3: Interactions between CISM and PIM are also possible (e.g. for storage management and provisioning). NOTE 4: Since NFVO is related to FOCOM operations, and PIM functionalities are expected to be part of IMS, PIM interactions with NFVO are also to be considered.				

In summary solution SOL-A1-1 does not preclude the case of VM- based virtualisation, however, seems more appealing for the case of containerized workloads. It also provides a clear separation between resources management and NF management and can be applied over multi-domain environments without additional considerations from NFV-MANO point of view. Solution SOL-A2-2 on the other hand seems more appropriate for mixed VM/containers environments.

Regarding physical infrastructure management, all the solutions proposed consider that certain extensions are necessary by means of VIM and CCM functionality to handle physical resource management aspects. Also, in case of a PIM function-based solution, interactions between CISM and PIM are also possible. Among the analysed solutions, specific benefits in some of them can be identified such as: a) more dynamic physical infrastructure management, which is expected in NFV use cases where more network dynamicity and service provisioning speed are key, and b) enable more efficient exchange of information and delineate points where correlation between physical and virtual infrastructure can be identified. Interactions between NFVO and PIM are also expected based on the assumption that certain PIM functionality is mappable to IMS services exposed over the O2 interface, and those services can be consumed by the FOCOM. FOCOM functionalities are mappable to NFVO as per clauses 5.2.1.2.2.1 and 5.2.1.2.2.2.

According to previous NFV framework developments, NFVI operations (related to PIM functionality) already exist but have not been modelled explicitly. Furthermore Nf-Vi reference point has not been specified precisely. This makes difficult to understand which (expected) IMS functionality related to physical resource management could be mapped to ETSI NFV operations. By means of future standardization work related to PIM functional requirements and communication channels/service interface for PIM operations can be considered. Best practices and existing interfaces can be used to realize these channels.

According to the analysis provided a number of challenges are still to be addressed regarding the architectural mapping between NFV-MANO and the O-RAN architecture. Each solution may find its proponents in the light however of the fact that the functionality of the different O-RAN elements, like DMS, IMS and SMO have not yet been fully delineated by the O-RAN technical reports and specifications.

5.2.2 Key Issue B: Support for Acceleration abstraction

5.2.2.1 Introduction

5.2.2.1.1 Overview

This key issue is about profiling the NFV-MANO acceleration abstraction framework, to the O-RAN acceleration abstraction solution developed in the context of O-RAN WG6 activities. In both designs, hardware and software-based acceleration is considered, and the goal is to provide abstract interfaces exposed over virtualised acceleration resources. Furthermore, both consider a management interface to manage virtualised acceleration resources. Nevertheless, several challenges exist as the ETSI NFV and O-RAN acceleration abstraction solutions are not fully compatible/aligned. The main difference is that in O-RAN the Acceleration Abstraction Layer Interface (AALI) interface resides between the AAL Application and the AALI implementation, while in ETSI NFV the interface defined is about communication between the VNF and NFVI over the Vn-Nf reference point, regarding acceleration resources. In ETSI NFV the VNF is hosting an extensible para-virtualised device (EPD) fronted driver (in the guest VM) and in the NFVI side an EPD backend driver resides in the host machine. Interface interactions are between the EPD frontend driver and the EPD backend driver (see ETSI GS NFV-IFA 002 [i.18]). An EPD implements one or more instances of Virtual Accelerators. In ETSI NFV, the interface between EPD frontend towards the Network Functions is out of scope, although the same interface requirements apply to both the northbound interface of an EPD driver towards the applications and the interface between the EPD frontend and the EPD backend.

5.2.2.1.2 NFV-MANO support for Acceleration abstraction

In ETSI NFV the technical approach adopted considers software or hardware accelerators as additional resources which can be virtualised and exposed as virtual accelerators to the VNF layer. On the management plane virtual accelerators can be managed by the VIM using the same principles and reasoning like in the case of virtual compute, virtual network and virtual storage, operating on top of physical resources managed by the NFVI. The relevant specifications aimed to realize the concept are the following:

- ETSI GS NFV-IFA 001 [i.17] (Release 2) provides a classification of acceleration types and describes several uses cases related to compute acceleration (e.g. Virtual Base Station (VBS) L1 Acceleration and DPI), network acceleration (e.g. Load Balancing and NAT) and storage acceleration (e.g. NVMe over fabric enabled acceleration).
- ETSI GS NFV-IFA 002 [i.18] (Release 2) specifies an acceleration architectural model for NFV, while analysing both VNF and virtualisation layer related aspects. It also defines functional requirements for the abstract interface between VNFs and NFVI regarding virtual acceleration operations over the Vn-Nf reference point, like also the relevant information models. These requirements apply to both the northbound interfaces of an EPD driver towards the applications and the interface between the EPD frontend and the EPD backend.
- ETSI GS NFV-IFA 004 [i.19] (Release 2) is about management of acceleration resources (residing in NFVI nodes) from the VIM. It also describes a set of requirements regarding acceleration feature discovery and lifecycle management of acceleration resources.
- ETSI GS NFV-IFA 018 [i.20] (Release 3) is about network acceleration where a common interface allows a network intensive VNF to accelerate its data plane processing by offloading packet processing tasks to a dedicated switch.

- ETSI GS NFV-IFA 019 [i.21] (Release 3) is about stage 2 work (based on ETSI GS NFV-IFA 004 [i.19] findings) and defines the relevant acceleration resource management interfaces.

In ETSI NFV, virtualised accelerators are operating on top of hardware solutions (e.g. FPGA, GPU, NDU, SmartNICs) or software-based solutions (e.g. DPDK), where the abstraction is created in the virtualisation layer (e.g. in the hypervisor). Acceleration drivers/libraries residing on the VNF (VM) but also on the host device are considered. The ETSI NFV acceleration abstraction architectural proposal is depicted in Figure 5.2.2.1.2-1. In Figure 5.2.2.1.2-1, left side depicts the generic case, the right side the case where DPDK is utilized, and the host kernel is bypassed.

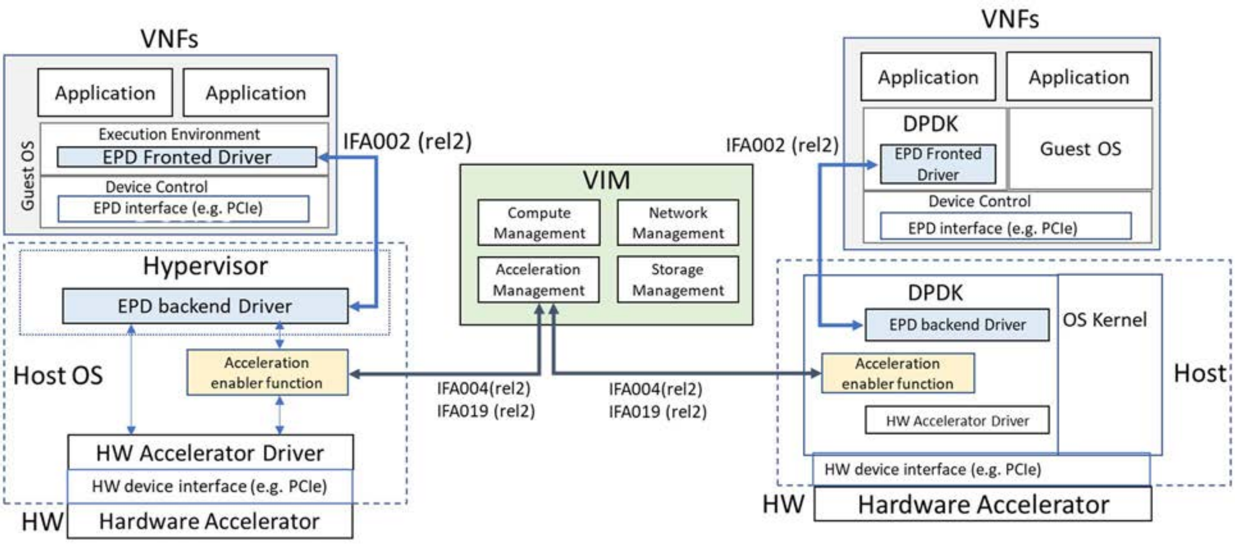

Figure 5.2.2.1.2-1: NFV-MANO acceleration abstraction architectural proposal according to ETSI GS NFV-IFA 002 [i.18] and ETSI GS NFV-IFA 004 [i.19]

The main elements of the framework are the following:

- Extensible Para-virtualised Device (EPD): EPD implements one or more instances of Virtual Accelerators.
- EPD backend driver: it allows for NFVI acceleration abstraction. It implements an adaptation layer to the hardware or to hypervisor domain resources.
- EPD frontend driver: for each specified virtual accelerator, the VNFCs to be accelerated include an EPD frontend driver, running in the VNF's execution environment.
- HW accelerator: the acceleration hardware can be collocated on the same compute node or located on a remote node as a network attached accelerator.
- Acceleration management function: it resides in the VIM and oversees the global management of the acceleration resources.
- Acceleration enabler: is in the NFVI node (e.g. as software in a host server), or API library provided by the accelerator driver. Provides local management of acceleration resources inside the NFVI-node.

In ETSI NFV the two interfaces specified are the abstract interface between the EPD fronted driver and the EPD backend, specified in ETSI GS NFV-IFA 002 [i.18], and the abstract interface between the VIM and the acceleration enabler function running in the host, specified in ETSI GS NFV-IFA 004 [i.19] and ETSI GS NFV-IFA 019 [i.21]. The VIM maintains the list of available acceleration resources and their consumption by VNFs so that orchestration can properly identify instantiation targets for new VNFs. VNF leveraging of accelerators is independent from accelerator types and locations. Out of ETSI NFV scope are:

a) the structure of EPD/EPD drivers (backend, frontend);

b) the north bound interface API modelling of the frontend driver towards the applications; and

c) interactions between the EPD backend and the actual hardware.

5.2.2.1.3 O-RAN support for Acceleration abstraction

In O-RAN a large set of WG6 activities focus on acceleration resources management and exposure of hardware and/or software acceleration resources in a vendor independent way to the O-RAN applications. The basic principles of operation are investigated in O-RAN.WG6.AAL-GAnP [i.65], where also a baseline architecture has been devised.

Both lookaside and inline acceleration models have been considered. In inline mode after data processing in the accelerator, post processed data are not send back to the host CPU and can be sent out through the egress port. In lookaside mode the host CPU receives back the result from the accelerator after processing. Both lookaside and inline are also considered by ETSI NFV specifications.

A high-level representation of the O-RAN AAL architecture is depicted in Figure 2.1-1 in O-RAN.WG6.AAL-Common API [i.66].

The following terminology and definitions are considered according to O-RAN.WG6.AAL-GAnP [i.65]:

- **Hardware (HW) Accelerator:** is a specialized HW implementation (e.g. ASIC, FPGA, DSP and GPU) that can offload processing from application(s) running on General Purpose Processors (GPUs).
- **Acceleration Abstraction Layer (AAL):** specifies a common and consistent set of interfaces used by different types of Hardware accelerators within an O-Cloud instance.
- **Acceleration Abstraction Layer Interface (AALI):** is the interface between an application and an AALI Implementation in the O-Cloud instance.
- **AALI Implementation:** is a realization of an AALI including but not limited to the software libraries, drivers and Hardware Accelerator.
- **AAL Profile:** specifies a set of Accelerated Functions that an accelerator processes on behalf of an application within an O-RAN Cloudified Network Function.
- **AAL Logical Processing Unit (AAL-LPU):** is a logical representation of resources within an instance of a HW Accelerator.
- **AAL Queue:** is part of specific AAL profile API's and is defined as an abstract construct that is used by the application to group operations together and may access specific resources (compute, I/O) of an AAL-LPU supporting specific AAL profile(s).
- **HW Accelerator Manager:** is an acceleration management function, that provides management capabilities for the HW Accelerator(s) in the O-Cloud Node. Management capabilities include but not limited to lifecycle management, configuration, updates/upgrades and failure handling.

Regarding the relevant interfaces and APIs, O-RAN AAL group considers *Profile Specific APIs* and a *Common API*. While AAL profiles are expected for both O-CUs and O-DUs, referred specifications are focusing on O-DU related functionalities:

- **Profile specific API (AALI-P):** is used to perform fine grained control for a specific profile. For example, an O-DU AAL profile can specify a set of Accelerated Functions within the O-DU protocol stack. In the case of O-DU Downlink [i.65], clause 5.1.3.3.3 "AAL_PDCCH_HIGH-PHY" profile is defined executed in inline mode. The set of accelerated functions associated with the processing of PDCCH DM-RS are PDCCH DM-RS sequence generation, Modulation, precoding, etc.).

The Common API is specified in O-RAN.WG6.AAL-Common API [i.66] is about profiling independent aspects and has the following distinct parts:

- **AAL-C-Mgmt:** is about common administrative operations/actions/events from the accelerator Manager toward the O-Cloud IMS (e.g. configuration services, fault management services, etc.).
- **AAL-C-App:** is about common operations/actions/events toward RAN applications. It is used by an application to discover, configure, and manage the logical AAL resources assigned to the application (e.g. set AAL-Profile-Instance Configuration, start AAL-Profile-Instance, etc.). AAL Transport Abstraction API is about message/data exchange over different transports (Ethernet, Shared memory, PCIe) and is also part of AALI-C-App.

5.2.2.1.4 Challenges

Based on the descriptions contained in previous clauses, the following tables are used to profile and compare various aspects the ETSI NFV acceleration abstraction approach and O-RAN acceleration abstraction framework. Related challenges are then also identified.

Table 5.2.2.1.4-1 summarizes specific items in the O-RAN acceleration abstraction framework and whether the ETSI NFV acceleration abstraction approach contains a corresponding element.

Table 5.2.2.1.4-1: Comparison of architectural elements

O-RAN	Managed by	O-RAN interface	ETSI NFV
HW Accelerator Manager	O-Cloud	O2ims, AAL-C-Mgmt	Acceleration Manager in VIM according to ETSI GS NFV-IFA 004 [i.19] and ETSI GS NFV-IFA 019 [i.21].
LPU	O-Cloud	O2ims, AAL-C-Mgmt, AAL-C-App	In NFV, the virtual accelerator is built around the concept of EPD. In O-RAN LPU re-assembles properties of both the fronted and backend EPD but in contrast to NFV is also applicable to containerized environments.

Table 5.2.2.1.4-2 provides a comparison between ETSI NFV and O-RAN at the interface level.

Table 5.2.2.1.4-2: Comparison of ETSI NFV to O-RAN interfaces

O-RAN AAL API	ETSI-NFV
AAL-C-App	ETSI GS NFV-IFA 002 [i.18] interface is about communication between VNF and NFVI based on the EPD abstraction (which is different than the LPU concept), however some actions like "*InitAccRequest" used also for capabilities retrieval in NFV* could be mapped to *operations like "getAalLpuInfo"* over the AAL-C-App interface in O-RAN. Operations like "Attach AAL-Profile-Instance" are not possible according to ETSI GS NFV-IFA 002 [i.18].
AAL-C-Mgmt	Partially covered by ETSI GS NFV-IFA 004 [i.19] and ETSI GS NFV-IFA 019 [i.21] Acceleration Resource Management Interface. However, ETSI NFV specifications do not specify LPU management.
AAL profiles (e.g. High-PHY, FEC, etc.)	There is no AAL profile concept in NFV. Specific profiles (e.g. IPsec, etc.) in NFV only drive requirements for the EPD frontend-backend communication.

Table 5.2.2.1.4-3 provides a comparison between ETSI NFV and O-RAN by means of requirements.

Table 5.2.2.1.4-3: Comparison of acceleration abstraction requirements (according to ETSI GS NFV-IFA 001 [i.17])

ETSI NFV	O-RAN
Acceleration abstraction can be entirely contained in the hypervisor. Para-virtualisation can also be utilized in the VM.	O-RAN specifications do not seem to concern about paravirtualisation, and instead focus is on container-based solutions. Acceleration abstractions as defined by ETSI NFV can be internal to the AAL implementation.
The acceleration hardware can be on the same chip as the processor or elsewhere, connected through standard interfaces or proprietary interfaces.	In O-RAN as well both standard interfaces or proprietary interfaces can be exploited.
The programming or configuration of the acceleration hardware is hardware-specific, is done at Compute Node initialization so that VIM inventory is updated with created accelerators.	O-Cloud inventory is updated accordingly. Configuration of the accelerator is through the AAL-C-Mgmt and configuration of the AAL Profile instances through the AAL-C-App interface.
Ability for VNFs to indicate the type of accelerators it could use.	Similar, in O-RAN this association is described on the appropriate VNF descriptors and handled over O2dms.
The NFVO and VIM are expected to know about available compute resources, acceleration resources and availability of networking routes and features to support.	Similar, O-Cloud and SMO are expected to be aware of acceleration resources available.

ETSI NFV	O-RAN
The VNF Package of the VNF demanding acceleration resources (e.g. virtualised base station) provides descriptors for the NFV-MANO with possible configurations and related resources per each configuration as well as portability measures (supported abstraction layers, resources type and features).	Similar, from SMO's point of view, the necessary descriptors are expected to be provided.
Transport API abstractions and management (e.g. buffer_send, etc.) have not been specified by the referenced acceleration related ETSI NFV's specifications.	In O-RAN, a common Transport API is also under development to hide different underlying technologies (shared memory, Ethernet, etc.) when performing message passing operations by the application towards the accelerator.

As it can be concluded by analysing the previous tables, when it comes to considering acceleration abstraction layer operations and APIs according to ETSI NFV and O-RAN, there is a misalignment in terms of supported interfaces. Nevertheless, some overlapping exists when it comes to acceleration resource management.

Even though the technical approach considered is different, EPD abstractions could be embraced to support different O-RAN AAL implementations for the case of hypervisor-based virtualisation. In O-RAN the solutions described do not preclude vendor specific drivers and solutions to realize the AAL implementation, as long as the implementation exposes a vendor agnostic AAL interface to the application.

For this key issue the following challenges are identified:

- Challenge #B.1: defining a virtualised accelerator in NFV for both VM and containerized environments. A dimension to consider is about the application environment. ETSI NFV acceleration concepts were developed with VM-based solutions in mind, which is not the case in O-RAN where the focus is currently on container-based solutions. In this regard recent developments like in ETSI GS NFV-IFA 036 [i.52] have not been considered, as well as acceleration support by major open-source solutions like the device plugin architecture of Kubernetes® when devising the EPD concept.

- Challenge #B.2: Virtual and hardware acceleration resource management. Regarding acceleration resource management aspects, the functionality provided according to ETSI GS NFV-IFA 004 [i.19] and ETSI GS NFV-IFA 019 [i.21] is related (fully or partially) to O-RAN AAL-C-Mgmt interface. Besides HW acceleration management, in O-RAN the notion of acceleration virtualisation is supported by the concept of LPUs. Management of LPUs, LPU queues, etc. is not possible however when considering ETSI NFV specifications.

- Challenge #B.3: Northbound interface exposed by the virtualised accelerator to the application (VNF). This challenge is about the northbound interface from the virtual accelerator towards the VNF. ETSI GS NFV-IFA 002 [i.18] defines EPD management, configuration, monitoring and data. However, in ORAN AAL-C-APP and Profile specific models are considered, which cannot be mapped to ETSI GS NFV-IFA 002 [i.18].

- Challenge #B.4: Performance and Fault monitoring. In O-RAN acceleration resources performance monitoring is responsibility of AAL-C-Mgmt and re-exposed over the O2 (e.g. over O2ims) and the same holds for fault alarms. Notifications can also go over the AAL-C-Mgmt and some related information can be also re-exposed over the O2 interface (e.g. over O2ims). According to the mapping of O2dms and O2ims to ETSI NFV-MANO interfaces, as analysed in clause 5.2.1 of the present document, it is not possible to precisely articulate the corresponding mapping of performance and fault information related to acceleration.

5.2.2.2 Potential Solutions

5.2.2.2.1 Overview

These solutions are about enhancements in ETSI NFV acceleration framework to support the solutions defined by O-RAN. In the following a set of solutions is provided, where each solution applies to one of the challenges described in clause 5.2.2.1.4.

5.2.2.2.2 Solutions for Challenge B.1: virtualised accelerator in NFV for both VM and containerized environments

5.2.2.2.2.1 Solution SOL-B1-1

The solution is based on revising the concept of EPD and delineating the concept of a generic Virtual Accelerator entity associated with a VM (for hypervisor-based virtualisation) or a Pod (for containerized environments). The virtual accelerator similar to O-RAN will be a logical entity representing a partition of resources exploited by the application and will be able to support the main functionalities of an LPU. An AAL-LPU logically provides the execution environment for AAL-Profile-Instance(s). A virtual accelerator is not provided by the application, instead is a logical resource in the accelerator resources of compute nodes or in a pool of dedicated accelerator resources. According to the O-RAN acceleration specifications, the LPU communication to host libraries could be vendor specific. In O-RAN the concept of LPU is equally applicable to both VM-based and containerized environments. Figure 5.2.2.2.2.1-1 depicts a visual representation of the proposed mapping in case of VMs.

As a logical entity, the Virtual Accelerator is still based on the generic acceleration and abstraction model defined in ETSI GS NFV-IFA 002 [i.18] which however is advanced to support the LPU concepts and operations in both VM-based and container-based deployments.

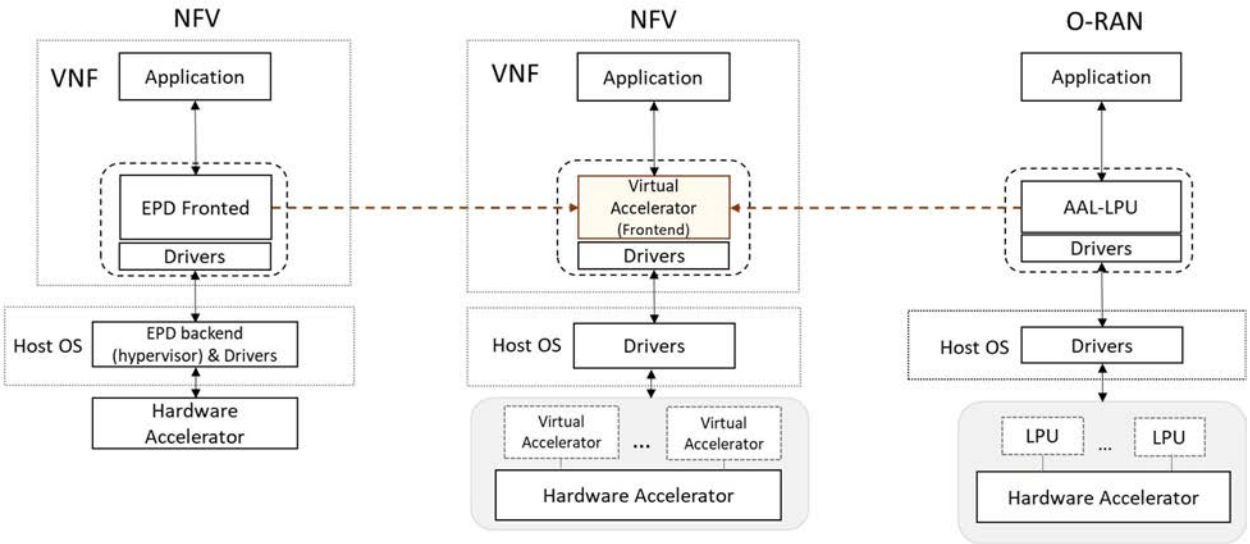

Figure 5.2.2.2.2.1-1: Virtual accelerator mapped to a O-RAN LPU for the case of VMs

As an example, for the case of hypervisor-based virtualisation a vGPU can be used to perform simultaneous, direct access to a single physical GPU from a guest VM where the corresponding vGPU driver is running. In this case the Virtual Accelerator will be a logical set of vGPU resources (essentially a set of configurations in the VM, managing this type of device through the vGPU driver running in the VM) which can be used by the application. As another example for the case of SR-IOV the LPU is associated with the VM and will be represented by a PCIe device (and its configuration) mapped to a VF by the hypervisor.

Figure 5.2.2.2.2.1-2 depicts a visual representation of the proposed mapping in case of containers, where instead of drivers, a set of libraries are used to access the accelerator. Like in the previous case, the virtual accelerator (as an O-RAN LPU) would represent a logical set of resources associated to a Pod.

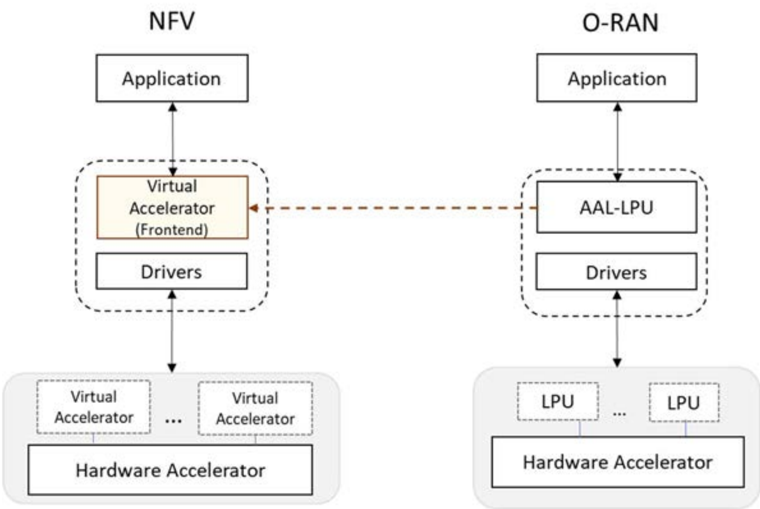

Figure 5.2.2.2.2.1-2: Proposed mapping in case of containers

As an example, for the case of container-based virtualisation a vGPU can be used to perform simultaneous, direct access to a single physical GPU from a container. This can be reflected as PCIe endpoint mapped to a vGPU. In this case the Virtual Accelerator will be a logical set of vGPU resources (essentially a PCIe endpoint together with the right set of configurations) which can be used by the application to access the vGPU. As another example for the case of SR-IOV, the LPU associated with the container will be represented by a PCIe device (and its configuration) mapped to a VF by Kubernetes®.

For both VM-based and container-based environments instantiation and management of LPUs is expected over the O2 interface.

NOTE 1: Regarding the integration of accelerators for the VM case in OpenStack® (see note 2) Cyborg project follows a different approach than the plugin architecture followed by Kubernetes®.

NOTE 2: The OpenStack® Word Mark and OpenStack Logo are either registered trademarks/service marks or trademarks/service marks of the OpenStack Foundation, in the United States and other countries and are used with the OpenStack Foundation's permission. ETSI is not affiliated with, endorsed or sponsored by the OpenStack Foundation, or the OpenStack community.

5.2.2.2.3 Solutions for challenge B.2: Virtual and hardware acceleration resource management

5.2.2.2.3.1 Solution SOL-B2-1

This solution is about the management of accelerator resources. In principle before EPD frontend can be used by VNF applications, a plug-in from EPD backend is setup and the accelerator is initialized for the usage of that VNF application. These bindings are not yet standardized by the referenced ETSI NFV specifications. The mechanism by which a EPD plug-in is injected into the VNF is beyond the scope of both ETSI GS NFV-IFA 002 [i.18] and ETSI GS NFV-IFA 019 [i.21] specifications. Furthermore, there are no means to create and manage the EPD (virtual accelerator) by the VIM, like installation of the appropriate drivers and libraries, which is a VNF triggered process. Regarding the management of the virtual accelerator, this solution considers that the virtual accelerator entity is exposed to both containerized and VM-based deployments as described in SOL-B1-1 and is managed by the corresponding management entities (i.e. VIM and CISM).

For the management of the virtual accelerator, the following items can be considered:

- During the VNF initialization, management actions are performed by the VIM/CISM for the resource allocation. As an example, in the EPD case the *InitAccRequest* operation is sent by VNF to NFVI according to ETSI GS NFV-IFA 002 [i.18]. Reusing the Virtual Accelerator concept as described in SOL-B1-1, this is expected to be a management action performed by the VIM/CISM instead, performing the appropriate resource allocation and loading the appropriate libraries and drivers to the VM or configuration to a Pod to create and allocate the appropriate virtual accelerator resources.

- During operation, management functions relevant to acceleration resources are also called by VIM/CISM and are performed by NFVI. For example, VIM could terminate subscription for notifications related to alarms sent by NFVI, which also includes CIS clusters besides compute nodes hosting VMs according to ETSI GS NFV 006 [i.62].

Regarding the applicability to the O-RAN framework:

- If parts of the VIM/CISM expose O-Cloud IMS functionality according to AAL-C-Mgmt for the management of acceleration resources (for example get AAL-HW-Accel-Information about inventory and capabilities, or get PM counters), these would be re-exposed over the O2ims interface to FOCOM in the SMO.
- If parts of the VIM/CISM expose O-Cloud DMS functionality, according to AAL-C-Mgmt for the management of acceleration resources (for example relevant to virtual accelerator status when considering VNFs LCM) these would be re-exposed over the O2dms interface to NFO in the SMO.

For containerized workloads mcioConstraintParams in ETSI GS NFV-IFA 011 [i.55] can be used to convey placement constraints considering the support of acceleration technologies (e.g. DPDK, GPU), but are not able to support explicitly the concept of LPUs and acceleration abstraction as considered by O-RAN. In this case, the solution envisions extensions to the "requested additional capabilities" specification in the VNFD, and/or explicit references to possible a registry (e.g. the NFVI capabilities registry of ETSI NFV) containing entries related to AAL and LPU.

5.2.2.2.4 Solutions for challenge B.3: Northbound interface exposed by the virtualised accelerator to the application (VNF)

5.2.2.2.4.1 Introduction

In the following two solutions are proposed (SOL-B3-1 and SOL-B3-2) regarding the northbound interface exposed to the application by the virtual accelerator. Note that part of O-RAN AAL-C-App interface operations (e.g. create AAL-Profile-Instance or set AAL-Profile-Instance configuration) can be potentially supported by exploiting the different VNF configuration methods proposed in ETSI GR NFV-EVE 022 [i.59].

5.2.2.2.4.2 Solution SOL-B3-1

This solution builds upon the virtual accelerator described in SOL-B1-1 and is about defining a northbound from the virtualised acceleration device towards the application, aligned with O-RAN AAL-C-App. Compute offloading (as described in ETSI GS NFV-IFA 001 [i.17]) would cover the case of AAL-Profile instance offloading for example performed in O-DUs, similar to O-RAN. However, the new northbound interface could be more generic to also cover requirements for compute, network and storage acceleration offloading as defined in ETSI GS NFV-IFA 001 [i.17]. This is broader in scope compared to O-RAN AAL-C-App interface. AAL-C-Mgmt interface related operations are not supported by the northbound interface and are expected to be provided by VIM/CISM. The interface described in ETSI GS NFV-IFA 002 [i.18] can be used as a baseline for the design of the new northbound interface, since interface requirements as described in ETSI GS NFV-IFA 002 [i.18] for the EPD frontend-backend communication are also applicable for the case of the northbound interface exposed by the generic Virtual Accelerator.

5.2.2.2.4.3 Solution SOL-B3-2

Based on the findings and the architecture of ETSI GS NFV-IFA 002 [i.18] extensions are introduced to cover functionality described in AAL-C-App interface. The EPD frontend and EPD backend concept is still preserved and the focus stays on AAL-Profile-Instance operations (e.g. start, stop, destroy) which are driven by the application. This solution would be however applicable only to VM-based solutions. Operations related to virtual accelerator management, like start/stop the virtual accelerator, or get virtual accelerator capabilities can be supported through extension of the Acceleration Resource Lifecycle Management interface specified in ETSI GS NFV-IFA 019 [i.21].

5.2.2.3 Gap analysis

According to O-RAN.WG6.AAL-GAnP [i.65] ETSI NFV specifications related to acceleration abstraction are used as a basis for the design of the AAL framework. To better align the two solutions, the following gaps have been identified regarding the realization of NFV-MANO solutions supporting O-RAN acceleration abstraction layer management and operations. These gaps are relevant to the challenges described in clause 5.2.2.1.4 and the solutions described in clause 5.2.2.2.2. In principle a revision of the overall virtual accelerator concept in NFV to support O-RAN LPUs functionality is expected. Potential requirements are expected to be specified in ETSI GS NFV-IFA 010 [i.32] to also consider the case of AAL in containers aligned with the approach described by O-RAN.

Gap#2.1: To realize SOL-B1-1, the referenced architectural model ETSI GS NFV-IFA 002 [i.18] and ETSI GS NFV-IFA 019 [i.21] of acceleration abstraction need to be revised to better reflect the concept of LPU described in O-RAN. The abstract model is expected to be equally applicable to both VM and container-based solutions.

Gap#2.2: This gap is related to SOL-B2-1. While according to ETSI GS NFV-IFA 002 [i.18] some management operations are possible form VNF side (e.g. get_AccCapabilities) and according to ETSI GS NFV-IFA 019 [i.21] management operations are driven by VIM (e.g. allocate acceleration resource attached to a VNFC instance) these partially cover the management of hardware accelerator and virtual accelerator resources as per the functionality expected from the O-RAN AAL-C-Mgmt interface and partially of the AAL-C-App interface (for example "get LPU status"). Also, the ETSI NFV referenced acceleration related specifications do not consider containerized deployments and management triggered by CISM related to acceleration resources. Without an equivalent functional set, it is not possible to fully map ETSI NFV functionality to O2 interface operations and align with the functionality expected by the SMO and O-Cloud.

Gap#2.3: The abstract interfaces specified in ETSI GS NFV-IFA 002 [i.18] lack the support for implementing part of the functionality and operations expected by the AAL-C-App interface (e.g. Create AAL-Profile-Instance). Attributes like *ModifyAccConfiguration* from the EPD Configuration interface could be considered by ETSI GS NFV-IFA 002 [i.18] if extended.

5.2.2.4 Evaluation and concluding remark

Table 5.2.2.4-1 provides pros/cons analysis of the solutions described for the acceleration abstraction key issue.

Table 5.2.2.4-1: Solutions evaluation for Key Issue B

Challenge	Solution	Pros	Cons	Additional considerations/remarks
B.1 virtualised accelerator in NFV	SOL-B1-1	- Virtual accelerator entity is backwards compatible with the EPD concept for the case of VMs. - Ooffers support for containerized deployments, aligned with O-RAN's technical perspective. - Can exploit ETSI GS NFV-IFA 002 [i.18] as a baseline which will be extended to support the LPU concept.	- Still relies on implementation-dependent drivers between the VNF and the hosting environment.	- Although directly applicable to support Compute and Network acceleration UCs as defined in ETSI GS NFV-IFA 001 [i.17], UCs related to Storage are not addressed. - The support of the solution impacts the Model, e.g. modifications for software-based acceleration and the way Virtual accelerator and LPUs are interpreted (e.g. in Figures 5.2.2.2.2.1-1 and 5.2.2.2.2.1-2 Virtual Accelerator resides on the HW accelerator side).

Challenge	Solution	Pros	Cons	Additional considerations/remarks
B.2 Virtual and hardware acceleration resource management	Solution SOL-B2-1	- Enriches the scope of management operations defined in ETSI GS NFV-IFA 019 [i.21] by incorporating AAL8C8Mgmt interface operations. - Mapping to O-RAN's O2 related interfaces re8exposure is rather straightforward. - Clear separation of responsibilities since virtual accelerator management operations are not allowed from VNF side.	- None.	
B.3 Northbound interface	Solution SOL-B3-1	- Directly applicable to support O-RAN use cases, aligns with AAL8C-App interface. - Can exploit ETSI GS NFV-IFA 002 [i.18] as a baseline which will be extended to support relevant AAL-C-App operations.	- Additional standardization work to realize SOL-B1-1 and SOL-B2-1 solutions.	
	Solution SOL-B3-2	- Minimum standardization effort.	- Not applicable to containerized environments. - Not directly applicable to support O-RAN use cases. - Not clear separation between management operations (VNF driven or VIM).	

ETSI NFV specifications were compiled in a way where the level of abstraction was generic enough to be able to cover a broad category of use cases described in ETSI GS NFV-IFA 001 [i.17]. In O-RAN on the other hand, the development of the acceleration abstraction interface is mainly targeting compute offloading in RAN virtualisation use cases.

The incentive for all the solutions proposed in this study is to align the two designs in a way where the ETSI NFV specifications can be used to cover the expected O-RAN functionality when O-RAN network functions are deployed as VNFs and are managed by an NFV-MANO system.

5.2.3 Key Issue C: VNF descriptors and packaging

5.2.3.1 Introduction

5.2.3.1.1 Overview

To enable multi-vendor VNF management and orchestration operations, well-defined descriptors and VNF packaging are specified by ETSI NFV. In this key issue, relevant ETSI NFV descriptors are profiled to equivalent O-RAN solutions and potential challenges and open questions are identified.

5.2.3.1.2 Descriptors and Packaging in NFV-MANO

In ETSI NFV, the following descriptors and packaging solutions are considered:

- **NSD:** defined in ETSI GS NFV-IFA 014 [i.44] is a deployment template used by NFVO for lifecycle management of an NS. It includes or references VNFDs, PNFDs, other NSDs, VLDs and VNFFGDs that constitute the NS.
- **PNFD:** is defined in ETSI GS NFV-IFA 014 [i.44] is a descriptor enabling on-boarding of PNFs and referencing them from an NSD. It focuses on geographical location and connectivity aspects (e.g. PnfExtCp) while LCM related aspects are not considered and assumed to be out-of-scope of ETSI NFV specifications.
- **VNFD:** defined in ETSI GS NFV-IFA 011 [i.55] is a deployment template that describes a VNF in terms of its deployment and operational behaviour. It is used in the process of VNF on-boarding and for managing the lifecycle of a VNF instance. VNFD is applicable for both VM-based and container-based solutions. Main information in the descriptor includes information like the type and amount of virtualised resources to be allocated for hosting and interconnecting VNF components (VNFCs) as well as additional constraints on NFVI capabilities.
- **NSD file archive:** NSD file structure is defined in ETSI GS NFV-SOL 007 [i.68]. An NSD file archive contains the NSD as a main TOSCA definitions YAML file, representing all or part of the NSD, and additional files. ETSI GS NFV-SOL 001 [i.60] specifies the structure and format of the NSD based on TOSCA specifications.
- **VNF Package:** defined in ETSI GS NFV-IFA 011 [i.55] and further specified in ETSI GS NFV-SOL 004 [i.67] is a Cloud Service ARchive (CSAR) with a well-defined structure that includes a VNFD and can include the software image(s) associated with the VNF, as well as additional artefacts. Two packaging options are defined depending on whether TOSCA-Metadata directory is available or not.
- **PNFD Archive:** its structure and format are defined in ETSI GS NFV-SOL 004 [i.67] as a CSAR, like the VNF Package. In its structure, it follows the same options as the VNF Package, however with some differences for example on licensing, testing information and the absence of software images.

In addition, in containerized solutions the VNF Package CSAR can include one or multiple Helm® charts as an artifact. Following ETSI GS NFV-IFA 011 [i.55] Helm charts are MCIOPs, which in turn are artifacts of the CSAR package.

5.2.3.1.3 Descriptors and Packaging in O-RAN

In the context of O-RAN WG10 activities the application package (AppPackage) structure is specified in O-RAN.WG10.AppPkg [i.85] and is currently under development. The packaging solution can be applicable to rApps, xApps and cloudified NFs (e.g. CUs, DUs). In case of PNFs, similar to NFV specifications, the function is also described it in terms of external connectivity.

The *AppPackage* uses CSAR packaging for bundling descriptors and metadata. The package specification includes packaging structure, format, file contents and security.

The basic descriptors considered by the AppPackage according to the Application package model described in O-RAN.WG10.OAM Architecture [i.48] (clause 6.1.1) are the following:

- MLModelDescriptor: supplied for an application employing Machine Learning technology (optional).
- DeploymentDescriptor describes the deployment options for the application that have been validated by the Solution Provider. It includes one or more DeploymentItems describing the requirements for O-Cloud deployment of the application.
- ManagementDescriptor describes the application contained in the AppPackage. It contains one or more ComponentDescriptors describing the components to be deployed as part of the application as well as elements used for FCAPS functions for the AppPackage such as an AlarmDictionary, ConfigurationModel, and SecurityDescriptor.

To integrate xAPPs and rApps into the framework descriptors are supplied to the Run Time Environment (RTE), called RTEDescriptors.

Besides the descriptors related to applications and Network Functions, O-RAN.WG6.O2-GA&P [i.31] describes Cluster Templates. A cluster template is a description for the declarative target of an O-Cloud Node Cluster. A Cluster Template instance represents a configuration of an O-Cloud Node Cluster that has known characteristics for the deployment of workloads.

5.2.3.1.4 Challenges

In principle in O-RAN VNF descriptors and packaging are focusing on containerized deployments, although VM-based solutions are also within the scope. In the context O-RAN.WG6.O2-GA&P [i.31], ETSI NFV profiling considers the adoption of ETSI GS NFV-IFA 011 [i.55] and ETSI GS NFV-IFA 014 [i.44] together with the derived stage 3 specifications as potential solution for the relevant descriptors realization.

Table 5.2.3.1.4-1 summarizes key profiling aspects relevant descriptors and packaging.

Table 5.2.3.1.4-1: ETSI NFV descriptors profiling to O-RAN framework

O-RAN	ETSI NFV	Comment
MLModelDescriptor	Not supported	Not supported by VNFD/NSD.
DeploymentDescriptor ASD or VNFD	**VNFD** VDU/osContainerDesc connectivity DeploymentFlavour	DeploymentDescriptor functionality is supported by VNFD for both VM and containerized solutions. In the case of a container-based NF application, the Application package can have either an ASD or a VNFD as a deployment descriptor, using different manifest file metadata in each case. See ETSI GR NFV-IFA 051 [i.84] for a profiling of the ASD to VNFD descriptors.
ManagementDescriptor	**VNFD** VnfIndicator MonitoringParameter VnfConfigurableProperties	ManagementDescriptor functionality can be partially supported by VNFD for both VM and containerized solutions. VNF indicators are abstract KPIs of a VNF, and Monitoring Parameters concern to metrics only on virtualised resources. VNF configurable properties can include VNF-specific configuration parameters.
SecurityDescriptor (part of the ManagementDescriptor)	**VNFD**	ETSI NFV specifications can be used to satisfy requirements described in O-RAN.WG11.Security-Requirements-specification [i.86] (clause 5.3.2.3). For example: according to ETSI GS NFV-IFA 011 [i.55] attributes like securityGroupRule can be used to satisfy requirements REQ-SEC-LCM-SD1 and REQ-SEC-LCM-SD3, Service Availability Levels (SAL) requirements are also part in the VNFD (per VNF or VDU) thus satisfying requirements REQ-SEC-LCM-SD2, REQ-SEC-LCM-SD4. Security requirements like REQ-SEC-LCM-SD5, REQ-SEC-LCM-SD6 and REQ-SEC-LCM-SD7 about resource quotas can be supported from the perspective of the VNFM and NFVO being responsible for querying and controlling the resource quota usage on behalf of the "application".
AppPackage	VNF Package	VNF Package format could be used for packaging O-RAN NF and cover the packaging aspects of AppPackage.
Cluster Template	CCD	CIS cluster descriptor (CCD) is defined in ETSI GS NFV-IFA 036 [i.52] and describes characteristics of CIS clusters (e.g. a description of the CIS cluster nodes to be used by the CIS cluster). It is directly mappable to the O-RAN Cluster Templates concept.

For this key issue, the following challenges have been identified, considering the work on both SDOs:

- **Challenge #C.1: ML models are not part of VNFD/NSD:** According to ETSI GR NFV-IFA 041 [i.57], MDA provides two main services, ML model training and processing, and management data analytics. MDA service interface and interface model as specified in ETSI GS NFV-IFA047 [i.69] and is exposed by the MDA function (MDAF). The corresponding MDA function could reside in the NFVO or could be deployed as a new FB and interact with the different FBs (e.g. VNFM and VIM). This means that that according to the referred ETSI NFV specifications, ML data would be expected to be exchanged through an interface (this is not specifically reported in ETSI GR NFV-IFA 041 [i.57]) and are not part of a specific descriptor like in the case of MLModelDescriptor.
- **Challenge #C.2: CRDs in ETSI NFV:** In case Custom Resource Definitions (CRDs) or API aggregation are used for the case of K8S based containerized deployments, these are discussed under the CIS Cluster Enhancement Capabilities (CCEC) feature in ETSI GS NFV-IFA 036 [i.52]. CRDs might be expected not only for O-RAN NFs, but also for the case of xAPPs and rAPPs. From ETSI GS NFV-IFA 036 [i.52] perspective, the CRD concept is envisioned for enhancing the capability set of the CIS cluster in a generic manner (e.g. supporting of logging and telemetry), and not from a specific application perspective, which has impacts in the end-to-end procedures and in the management done by NFV-MANO regarding when and how to enable a capability for a specific application.
- **Challenge #C.3: VNF dependencies and different LCM cycles:** another challenge is related to the way new xAPPs could be onboarded to the NFV system and be associated with the near-RT RIC when both the near-RT RIC and the xApps are exposed as VNFs (or VNFCs). In case of bundling xAPPS with near-RT RIC together in a single package, their LCM are strongly coupled and new xAPPS would imply an upgrade of the integrated xAPPs/near-RT RIC VNF package. For example, if the xApps are mapped to VNFCs of the near-RT RIC VNF, then how to upgrade/add one single VNFC without delivering the entire near-RT RIC and all the other xApps already installed/instantiated, remains a challenge.

The challenges above are about VNF level descriptors. ETSI GS NFV-IFA 036 [i.52] introduces and describes the concepts of CIS Cluster Descriptors (CCDs). A CCD describes the desired infrastructure resource (compute, storage and network) characteristics for a CIS cluster and is interpreted by the CCM for the management of those resources and of the CIS cluster. Furthermore, according to ETSI GS NFV-IFA 036 [i.52], a CCD can contain or reference to Managed CIS Cluster Object (MCCO) declarative descriptors (CCEC is a specific type of MCCO). CCDs are directly mappable to the concept of O-RAN Cluster Templates described in O-RAN.WG6.O2-GA&P [i.31].

5.2.3.2 Potential Solutions

5.2.3.2.1 Overview

In the following a set of solutions is provided, where each solution applies to one of the challenges described in clause 5.2.3.1.4.

5.2.3.2.2 Solutions for challenge C.1: ML modelling information

5.2.3.2.2.1 Solution SOL-C1-1 (ML model in VNFD)

This solution assumes that ML models can be fully defined or referenced following a standard modelling part of the VNFD. Thus, it proposes the inclusion of new information elements related to ML modelling into the VNFD. These information elements could be corelated or mapped to the MLModelDescriptor being considered by O-RAN.

5.2.3.2.2.2 Solution SOL-C1-2 (ML model in VNF Package)

This solution assumes that ML models might not be possible to be fully defined according to some standard modelling in descriptors used by the NFV-MANO, such as the VNFD or NSD. To onboard the ML models for their use by VNFs or NFV-MANO, the ML models could be included as artifacts in the VNF Package. If the ML models are to be also used by entities other than the NFV-MANO, corresponding non-MANO artifacts registry entries are envisioned to be also defined.

5.2.3.2.2.3 Solution SOL-C1-3 (ML model in MDA)

This solution is based on considering of ML models related information as part of the MDA framework studied in ETSI GR NFV-IFA 041 [i.57]. The onboarding of the ML models for the training done by the MDA would follow the framework specified for MDA, which is, according to the referred report, left for future specification. This solution is about models which are used by NFV-MANO entities. Models which are needed by the actual application running as a VNF are out of scope from the MDA framework according to ETSI GR NFV-IFA 041 [i.57].

5.2.3.2.3 Solutions for challenge C.2: CRDs in NFV

5.2.3.2.3.1 Solution SOL-C2-1 (CRDs for containerized NFs)

The concept of custom resource definitions for containerized deployments has been considered by ETSI GS NFV-IFA 036 [i.52] in a conceptual level (see CIS Cluster Enhancement Capabilities (CCEC), clauses 4.2.13 and clause C.2 in ETSI GS NFV-IFA 036 [i.52]). This solution is about further developing the adoption of CRDs for containerized VNFs. From ETSI NFV point of view, in case CRDs are used, features on custom resources based on the CRDs can be considered in the VNFD (when scope is applicable to a specific VNF) or NSD (when scope is applicable to various VNFs) by expressing requirements in respective descriptors related to CCEC. CCEC is expected to be delivered separately from MCIOPs according to the relationship between CCD and MCCO declarative descriptors specified in ETSI GS NFV-IFA 036 [i.52]. This determines that CRDs are handled as part of CIS cluster management processes, not VNF management ones. Therefore, the use of CRDs is not expected to affect the VNF Package structure if such CRDs can be further packaged and be delivered independently. While CRDs have cluster scoping, some could be specifically applied to a VNF/namespace and not shared with other VNFs/namespaces.

NOTE: As descriptors and package specification in O-RAN is still under development, CRDs for CIS clusters (e.g. for acceleration resources) but also CRDs for specific applications (e.g. xApps) cannot be clearly mapped to specific O-RAN specifications.

5.2.3.2.4 Solutions for challenge C.3: VNF dependencies and different LCM cycles

5.2.3.2.4.1 Solution SOL-C3-1 (Different LCM-Partial Packaging)

In O-RAN different LCM cycles for related VNFs (and VNFCs) are expected to be supported. To avoid packaging dependent VNFs together, one approach could be partial packaging as described in ETSI GR NFV-TST 006 [i.61] which provides relevant recommendations. Using partial packaging a VNF Package can contain only parts (VNFC) of the software of a VNF. These partial VNF Packages would then have a reference to VNF Package versions to where they are applicable while independent VNFC updates and upgrades are possible. When a VNFC is updated, this is also reflected with an update to the VNF version. While the referenced ETSI NFV specifications support references to external artifacts to the VNF Package, which could fulfil the need for a more flexible packaging, the functionality to support all aspects of concern of partial packaging is not currently covered by referenced ETSI NFV specifications. For example, VNF xAPPs could be deployed using partial packaging, with references to the near-RT RIC VNF package to which they apply.

5.2.3.2.4.2 Solution SOL-C3-2 (Different LCM-Common VNF)

In this solution, the concept of VNF Common Services according to ETSI GR NFV-IFA 029 [i.49] is leveraged. A VNF Common Service has a lifecycle independent from its consumers VNFs. For example, near-RT RIC could be deployed as a VNF Common Service while the xAPPs be deployed as consumer VNFs.

NOTE: The mechanism to leverage the Common Services currently does not exist in ETSI NFV referenced specifications and it is potentially to be provided by the normative phase of FEAT24. Technical investigation of the solution is For Further Study, like for example about how and where to indicate version dependencies between customer VNFs and VNF Common Services.

5.2.3.2.4.3 Solution SOL-C3-3 (Different LCM-VNF Bundle)

The concept of VNF Bundle described in ETSI GR NFV-IFA 044 [i.71] allows multiple NFs to be bundled together inside a same VNF. The bundled VNF consists of multiple NFs as set of mandatory and optional NFs, which are specified as VDU groups in the VNFD. The optional NFs can be selected during instantiation or in the later stages of bundled VNF lifecycle. Furthermore, the use case related to bundling of NFs inside a VNF in ETSI GR NFV-IFA 044 [i.71] suggests that lifecycle of different NFs is maintained independently from each other. The NFVO upon receiving a change in selection of optional NFs, compares the new selection with the current one to determine which VNFCI(s) needs to be instantiated or terminated corresponding to the VDU profile(s) identified during the comparison. NFVO triggers necessary LCM operations toward the VNFM to update the VNF, in order to implement the new NF selection. This kind of flexible VNF deployment has the potential to meet the ORAN requirement of different LCM cycles for VNFs (and VNFCs) as described in clause 5.2.3.1.4. For example, a bundled VNF may include near-RT RIC and xApps as optional NFs in a single VNF package. Flexible deployment of the bundled VNF allows the service provider to instantiate a selection of xApps along with the near-RT RIC. Unselected xApps in the VNF package can be selected later during the VNF lifecycle. Furthermore, other bundled VNFs, including different sets of xApps and optionally the near-RT RIC, can be deployed later using suitable NF selections, without the need for re-deploying the near-RT RIC and existing xApps.

NOTE: The mechanism to leverage the VNF Bundle currently does not exist in ETSI NFV referenced specifications and it is potentially to be provided by the normative phase of FEAT31. Technical investigation of the applicability of a solution based on FEAT31 is For Further Study, in particular for aspects that are outside of that feature like for example how to manage and support different versions of xApps inside the same VNF Package or partial VNF package upgrade.

5.2.3.2.4.4 Solution SOL-C3-4 (Different LCM-Independent VNFs)

This solution considers that RAN NF and xApps can be deployed as "regular" VNF, without leveraging other features introduced in other solutions for challenge C.3. To cater for potential dependencies among VNFs, these can be considered by the network operator when designing the NS. These VNFs could be part of the same NS or they could belong to a different NS. For example, in the case of O-RAN near-RT-RIC and xApps, these could be realized as normal (independent) VNFs, connected using normal ETSI NFV specified procedures. LCM dependencies are handled in another level by the corresponding management entity at the NS level, that is the NFVO. In case the dependent VNFs belong to different NSs, their dependency relationship can be described by means of a composite NS having the nested NSs as constituents and be managed by the NFVO as well.

5.2.3.3 Gap analysis

The following gaps have been identified regarding the realization of NFV-MANO solutions supporting O-RAN descriptors and packaging. These gaps are relevant to the challenges described in clause 5.2.3.1.4 and solutions described in clause 5.2.3.2. The first two gaps identified (Gap#3.1 and Gap#3.2) are related to ML modelling, whereas Gap#3.3, Gap#3.4 and Gap 3#6 are about VNF dependencies. Gap3#5 is about support in NFV of CRDs:

- **Gap#3.1:** to realize SOL-C1-1, VNFDs lack support to include or reference ML models.
- **Gap#3.2:** to realize solution SOL-C1-3, the onboarding of the ML models for the training done by the MDA would follow the framework specified for the MDA, which is, according to ETSI GR NFV-IFA 041 [i.57] left for future specification.
- **Gap#3.3:** to support solution SOL-C3-1, current VNF packaging does not fully support partial packaging. According to ETSI GR NFV-TST 006 [i.61] the concept is described, but the relevant descriptors and operations are missing.
- **Gap#3.4:** to support solution SOL-C3-2, the concept of VNF Common Service as described in ETSI GR NFV-IFA 029 [i.49] is not supported. VNF Common Services Management in PaaS (functionality and interfaces towards VNF common services), like also interactions between PaaS and NFV-MANO are not yet covered by the referenced ETSI NFV specifications.

- **Gap#3.5:** According to ETSI GS NFV-IFA 036 [i.52] CIS Cluster Enhancement Capability (CCEC) is the mechanism used to support CRDs. CCM is responsible for the lifecycle management of the CCEC. CCM interacts with the CISM or directly with the CIS cluster nodes depending on the type and form of lifecycle management of the CCEC. However, CCEC declarative descriptors are not yet standardized, and no interfaces and information elements have been specified for the interactions between CCM and other NFV-MANO functions or FBs relate to CCEC (like NFVO to perform granting for resources used by the CCEC). In this regard to support solution SOL-C2-1, current NFV-MANO and NFVI framework do not offer explicit support for CRDs. VNFD or NSD (when scope is applicable to various VNFs) can be extended to express requirements on CIS cluster enhancement capabilities.

- **Gap#3.6:** to support solution SOL-C3-3, the concept of flexible deployment by bundling multiple NFs inside a single VNF, as described in ETSI GR NFV-IFA 044 [i.71], is not yet fully supported by the referenced ETSI NFV specifications. In that regard, ETSI GR NFV-IFA 044 [i.71] identifies crucial gaps that need to be addressed for the realization of flexible VNF deployment, such as the capability to provide information about the optional NFs in the VNFD, capability to select a set of NFs at deployment time, capability to change the selection after deployment, etc. These gaps will potentially be addressed during the normative phase of FEAT31.

To realize SOL-C1-2, the functionality to provide non-MANO artifacts, is already supported according to ETSI GS NFV-SOL 004 [i.67], in the form of zip files identified by a non-MANO artifact set identifier declared in the CSAR manifest file. This can be used for providing ML models that are not intended to be processed and/or used by NFV-MANO.

5.2.3.4 Evaluation and concluding remark

Table 5.2.3.4-1 provides pros/cons analysis of the solutions described for this key issue.

Table 5.2.3.4-1: Solutions evaluation for Key Issue C

Challenge	Solution	Pros	Cons	Additional considerations/remarks
C.1	SOL-C1-1 (ML model in VNFD)	- Reuse of same modelling used in the deployment descriptor can facilitate processing by NFV-MANO and other entities (single parsers, processors can be leveraged).	- Coupling of ML models into the deployment descriptor (VNFD), while the two could potentially benefit of having fully independent lifecycles. - Data model of choice of the VNFD might not be suitable as a data model for ML (e.g. TOSCA might not be suitable for ML).	- Unclear whether the NFVO/VNFM are also intended to make a direct use of the ML models. - ML models are not tied to orchestration and deployment and do not have a standardized model.
	SOL-C1-2 (ML model in VNF Package)	- Reusability of VNF package capabilities (e.g. non-MANO artifacts) without impacting NFV-MANO functionality. - Uniform way of delivery of ML models can be achieved by leveraging the VNF package standards. - External artifacts capability of VNF packaging can be leveraged to deliver ML models independently from the "main" VNF package archive. - ML model descriptor can follow a suitable (if it is the case) data model for ML independent from the data modelling used for other descriptors.	- This solution might add additional maintenance (upgrades of individual parts in the VNF Package) and operational overhead due to bundling ML models and VNF together into the same VNF Package.	- ETSI GS NFV-SOL 004 [i.67] can be reused, when considering incorporating ML models as non-MANO or MANO artifacts that can be used by or are applicable to NFV-MANO. - ML models relevant to MANO operations related to the VNF could also be delivered using the same solution. - Partial packaging could be applied to resolve the maintenance and operational overhead.
	SOL-C1-3 (ML model in MDA)	- Reusability of the MDA framework. - ML model descriptor can follow a suitable (if it is the case) data model for ML independent from the data modelling used for other descriptors.	- MDA framework is, currently, only applicable to models for NFV-MANO entities (not applicable to VNFs). - ML models associated to VNF cannot be delivered in a uniform way, i.e. with the VNF package.	- ML Models for MDA are not currently available according to referenced ETSI NFV specifications.

Challenge	Solution	Pros	Cons	Additional considerations/remarks
C.2	SOL-C2-1 (CRDs)	- Additional flexibility to describe new type of resources (e.g. related to acceleration, storage, etc.) - Make sure that different vendors' VNFs relying on CRDs can be deployed on the same cluster.	- Challenges due to CRDs cluster scope nature. - Cluster administrators need to validate and authorize the deployment of custom resources and ensure there are no compatibility issues between them. - Control mechanisms are necessary to control which version is installed and manage version dependencies and ordering. - The impact on NFVO granting process for the extra resources specified in the CRDs captured and addressed is unclear.	- The concept of custom resource definitions for containerized deployments has been considered by ETSI GS NFV-IFA 036 [i.52] in the framework of CIS cluster enhancement capabilities.
C.3	SOL-C3-1 (Partial Packaging)	- Allows loosely coupled LCM relationship between related VNFs (and VNFCs).	- More complex framework to control version dependencies among multiple packaging parts.	- Partial packaging is not currently supported by ETSI NFV specifications.
	SOL-C3-2 (Common VNFs)	- Allows loosely coupled LCM relationship between related VNFs (and VNFCs). - Exploits PaaS framework services.	- A control mechanism is necessary to restrict the access of the Common VNF to specific customer VNFs (e.g. Near-RT-RIC is deployed as a Common VNF, and access is restricted only to specific xApp VNFs).	- Interactions between PaaS and NFV-MANO are currently not fully specified by the referenced ETSI NFV specifications.

Challenge	Solution	Pros	Cons	Additional considerations/remarks
	SOL-C3-3 (VNF Bundle)	- Allows loosely coupled LCM relationship between related VNFCs (NFs) of the VNF. - Offers support for flexible deployment, which is suitable for modular, microservices-based architecture.	- Only xApps that are included in the original VNF package can be added, upgraded or removed during the VNF lifecycle through appropriate NF selection without affecting the existing deployment. - In case of upgrading individual xApps for which different versions already exist in the VNF package, a control mechanism is required to prevent the selection of certain NFs at the same time, i.e. same xApp, different versions. - This solution might add additional maintenance (upgrades of individual parts in the VNF Package) and operational overhead due to bundling xApps and near-RT RIC together into the same VNF Package.	- The mechanism to flexibly deploy the bundled VNFs is currently not fully specified by the referenced ETSI NFV specifications. - Partial packaging could be applied to resolve the maintenance and operational overhead.
	SOL-C3-4 (LCM-independent VNFs)	- No extensions are needed to the NFV framework. - Already available solutions can be used to support non RT-RIC/near RT-RIC operations and rApps/xAPPs. - Support of invariant ids can be used to enable flexibility when considering dependencies on the NS level.	- Only xApps that are included in the original NS descriptor can be added, upgraded or removed during the NS lifecycle through appropriate VNF package onboarding without affecting the existing deployment and without changing the NSD version.	Solution is applicable to both VM-based and container-based scenarios.

Based on the above analysis several trade-offs exist when considering the solutions proposed to address challenges C.1. To address challenge C.1, SOL-C1-2 seems to provide additional benefits and flexibility in assembling, delivering and managing ML models applicable to VNF, thanks to the capabilities provided by the standardized VNF packaging.

Note that at this stage, a comprehensive technical assessment on the pros and cons analysis related solutions SOL-C1-3 (ML model in MDA), SOL-C2-1 (CRDs), SOL-C3-1 (Partial Packaging), SOL-C3-2 (Common VNFs), SOL-C3-3 (VNF Bundle) is not possible since these solutions rely on frameworks and interfaces which have not been precisely articulated in ETSI NFV. Nevertheless, the evaluation analysis presented can be served as a basis for further scrutiny and investigation, on the way ETSI NFV can support related mechanisms described by O-RAN.

5.2.4 Key Issue D: Transport Network management

5.2.4.1 Introduction

5.2.4.1.1 Overview

This key issue is about analysing how ETSI-NFV solutions can be used to support O-RAN Transport network management aspects. Standardization work from both SDOs will be summarized followed by an analysis of the challenges identified.

5.2.4.1.2 Transport Network Management in NFV-MANO

A report regarding the architectural framework for network connectivity support in NFV is in ETSI GR NFV-IFA 035 [i.72]. ETSI NFV activities related to multi-domain network service management are described in ETSI GS NFV-IFA 030 [i.36] and for multi-site connectivity services in ETSI GS NFV-IFA 032 [i.35]. In more detail:

- ETSI GR NFV-IFA 035 [i.72] reports intra-site (within the NFVI-PoP) and inter-site (between NFVI-PoPs) connectivity options and technologies and provides recommendations for enabling connectivity services. An NFVI-PoP can be understood as a data centre/cloud infrastructure where VNFs are deployed. In a NFVI-PoP environment, network nodes can be used to interconnect other network nodes (e.g. aggregation switch, etc.) while gateway network nodes connect the NFVI-PoP to the transport network (e.g. gateway router).
- ETSI GS NFV-IFA 032 [i.35] specifies interfaces exposed by the WIM for the management of multi-site connectivity services used to establish and manage connectivity between endpoints residing in different NFVI-PoPs/sites. WIM services are consumed by NFVO or OSS depending on whether WIM resides internally or externally to NFV-MANO. The interfaces exposed by the WIM are *MSCS Management*, *Capacity Management*, *Fault* and *Performance Management*.
- ETSI GS NFV-SOL 005 [i.73] specifies the interfaces between OSS and NFVO, based on ETSI GS NFV-IFA 013 [i.64]. Regarding transport network aspects and multi-site connectivity services, Annex E of ETSI GS NFV-SOL 005 [i.73] provides additional information about the different network gateway management models for multi-site service connectivity, which illustrate different boundary management possibilities.
- ETSI GS NFV-IFA 030 [i.36] specifies interfaces on the Or-Or reference point between NFVO placed in different administrative domain to enable multi-domain network service management. Functional requirements, interfaces, and operations to support the provisioning of network services across multiple administrative domains are specified. Interactions between orchestrators are at the Network Service level (e.g. NS LCM, NS performance management, etc.).

Based on these reports and specifications the following basic concepts and principles about intra-site and inter-site connectivity in ETSI NFV are summarized.

Intra-site Connectivity: According to ETSI GR NFV-IFA 035 [i.72] an *overlay network*, operates over an IP (L3) *underlay* transport network and provides L2 and/or L3 services to tenant systems. The overlay network and the underlay network can use completely different protocols. Tunnelling is used in the underlay network for aggregating traffic from the VMs connected to the overlay network, hiding VMs' addressing from the underlay network. Example technologies for intra-site connectivity are VLAN, Network Virtualisation (NV) VXLAN, GRE, MPLS-over-GRE. Intra-site connectivity is managed by the VIM.

Inter-site Connectivity: In NFV, inter-site network connectivity is abstracted using the notion of MSCS. A Virtual Link can encompass networks in different domains including virtualised networks residing in different NFVI-PoPs and transport networks in the WAN between the NFVI-PoPs which are abstracted as MSCS. With reference to Figure 5.2.4.1.2-1, the following architectural elements are considered:

- A Customer Edge (CE), which represents an NFVI-PoP Gateway. From one side terminates internal virtualised networks defined in the context of intra-site connectivity. On the other side is used to support inter-site connectivity and interacts with Provider Edge (PE) devices.
- Provider Edges (PEs) reside at the edge of the backbone network and connect CEs with the WAN.

- Provider (P) routers support the WAN network fabric. The PE and P devices (e.g. network routers) typically belong to a WAN infrastructure Service Provider (SP).

An MSCS is managed by the WIM which offers an abstraction to the orchestrator in a protocol agnostic way. WIM may rely on network controllers (e.g. SDN) to support the actual implementation. The WIM exposes two types of managed objects namely the Multi-Site Connectivity Service (MSCS) and the Multi-Site Network Connection (MSNC). A consumer can request the creation of a MSCS which is fulfilled by the WIM via one or more MSNCs. WIM exposed interfaces are in ETSI GS NFV-IFA 032 [i.35].

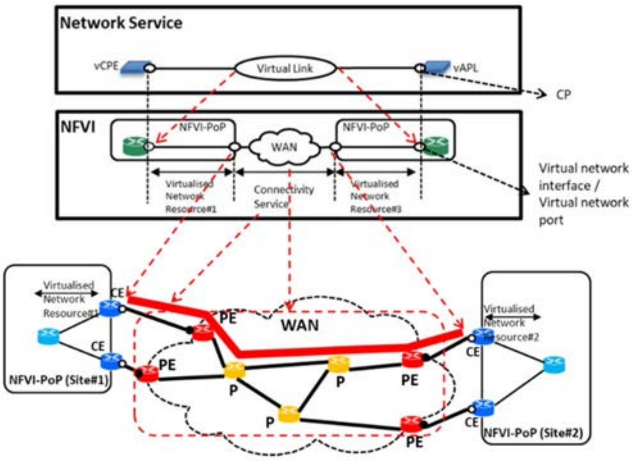

Figure 5.2.4.1.2-1: Multi-site connectivity network framework and relationship to Network Service according to ETSI GS NFV-IFA 032 [i.35]

NOTE: Red routers correspond to PEs, yellow routers to Ps and dark blue to CEs.

While PEs and Ps are under the control of WIM and internal NFVI-PoP network is under the management of the VIM, according to ETSI GS NFV-SOL 005 [i.73], different options exist when considering the management of CEs gateways. These can be either managed by:

a) The WAN provider. In this case a demarcation point exists between CEs and NFVI-PoP internal networks and the connectivity offered by CEs is managed by the WIM.

b) The NFVI-PoP provider. In this case a demarcation point exists between CEs and PEs and the connectivity offered by CEs is managed via the VIM.

c) Be co-managed by WAN and NFVI providers. In that case WIM manages the GW resources, however NFVO can interface either directly, or via the VIM, with the CEs to perform some configuration and/or monitoring related to the GW resources.

Connectivity between PEs and CEs is abstracted using Connectivity Service Endpoints (CSEs) where a MSCS can terminate. These reside in CEs and can be mapped to physical or aggregated interfaces. A CSE represents "shared context information" regarding the network links available between CEs and PEs. For example, VIM's managed object *ConnectivityServiceEndpoint* relates one to one with the WIM's managed object *ConnectivityServiceEndpointInfo.* The PE routers maintain routing information about supported VPN service(s) and can host multiple VPN nodes connecting to different NFVI-PoP Gateways.

Layer 3 VPN (L3VPN) can be used to offer a Multi-Site Connectivity Service (MSCS). By means of network protocols, different solutions can be used to support L3VPN such as MPLS, Segment Routing, etc., Layer 2 VPN (L2VPN) service can be supported by traffic engineered networks (e.g. RSVP-TE, Segment Routing) or overlay networks (e.g. GRE, VXLAN) and in more general Carrier Ethernet Service can be supported for example by MPLS-based solutions, Provider Backbone Bridged (PBB), Ethernet over OTN, Ethernet over WDM, etc.

5.2.4.1.3 Transport Network Management in O-RAN

In O-RAN, WG9 activities are related to the management of fronthaul, midhaul and backhaul segments which collectively denote the Transport Network (TN) in the O-RAN domain. From an O-Cloud perspective and NFVI-PoP point of view, according to O-RAN WG6 CAD [i.30] different deployment options exist. For example, as depicted in Figure 5.2.4.1.3-1 a DU can reside in the edge cloud (example 1 as Scenario A, B, etc., in O-RAN WG6 CAD [i.30]) or it can be deployed together with the RU in the cell site (example 2 as Scenario E in O-RAN WG6 CAD [i.30]). See O-RAN WG6 CAD [i.30], clause 5.8 for details on the different deployment options supported.

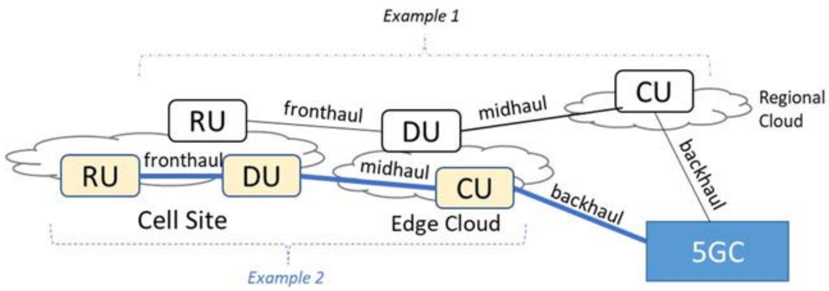

Figure 5.2.4.1.3-1: Transport Network and O-RAN NF deployment scenarios. Multiple deployment options are supported according to O-RAN WG6 CAD [i.30]

The notion of XHAUL in O-RAN WG9 refers to convergence of these segments on the packet level (Ethernet/IP layer). O-RAN WG9 specifications are not about the application interfaces operating on top of the network. For example, the Open-Fronthaul interface between O-RUs and O-DUs is defined in O-RAN WG4 and Open F1 between O-DUs and O-RUs is defined in O-RAN WG5. For the fronthaul link, Open Fronthaul (7.2x split between High PHY and Low-PHY) is defined by O-RAN WG4 considering eCPRI [i.5] or IEEE 1914.3 [i.81] as a possible transport mechanism over Ethernet or IP/UDP [i.70]. According to O-RAN-WG4.CUS [i.70] for the fronthaul link between O-RUs and O-DUs Ethernet frames can be used to carry U-plane and C-plane traffic. eCPRI and RoE (IEEE 1914.3 [i.81]) can be carried inside the payload of Ethernet frames or carried over IP/UDP. In either case Ethernet frames following the Ethernet II/DIX format are used while 802.1Q is supported to exploit the PCP mechanism for QoS handling (as an optional feature), like also VLAN tagging for L2 subnetting. Furthermore:

- O-RAN XPSAAS [i.75] describes the overall O-RAN TN architecture considering TN Elements (TNEs) and the deployed NFs like RUs and DUs. Control, data and management plane aspects are considered, while operator use cases and requirements are provided for the different deployment options. The underlay packet-switching technologies described are based on MPLS and IPv6, while the overlay service layer uses EVPN and MP-BGP L3VPNs.

- O-RAN XTRP MGT [i.74] is about the management interface covering configuration and FM/PM of the TNEs. An analysis per technology is provided (like Microwave, WDM for Fronthaul, TDM-PON, etc.) with references to the appropriate specifications (e.g. IETF). A discussion on relevant protocols is made like NETCONF/YANG for configuration management, gNMI for Performance and Fault management while also support for LCM (e.g. ITU G8052.1).

O-RAN WG9 also analyses transport network slicing, time synchronization and transport network testing issues. For example, transport network slicing is described in O-RAN XPSAAS [i.75], clause 8.7 Scenario 7 and clause 18, while Time synchronization architecture is described in ORAN XTRP SYN [i.76].

In the context of WG6 activities the cloud federation resources (e.g. edge, regional cloud infrastructures) are managed by FOCOM residing in SMO through its interaction over O2ims with the locally deployed IMSs. However, it is not yet clear if transport network is considered part of the O-Cloud infrastructure and which network management aspects are expected to be handled by the O2ims interface.

For each O-RU a port can be used to carry Control, User plane or Management plane traffic:

- Regarding VLAN configuration for the Management plane the process to follow is described in O-RAN-WG4.CUS [i.70], clause 6.2.3. The O-RU will determine whether it is connected to an access port or a trunk port. VLAN information can already be configured, or untagged Ethernet frames are used to discover DHCP servers on all Ethernet ports.

- Regarding C/U-plane to O-DU the VLAN configuration process is described in O-RAN-WG4.CUS [i.70] clause 7.3. The VLAN(s) used to carry C/U plane traffic can be different from the VLAN(s) used to support Management plane connectivity. Different VLANs can also be used to carry U-Plane and C-Plane traffic, where in this case VLAN configuration is made through NETCONF. In O-RAN C/U-plane traffic (eCPRI/IEEE 1914 frames/packets) are transported over processing elements which can then be associated with a particular C/U plane endpoint address. Three options are available regarding the endpoint identifiers a) different (alias) MAC addresses; b) a combination of VLAN identity and MAC address and c) UDP-ports and IP addresses. C/U-Plane transport connectivity is then verified using Loop-back Protocol (LB/LBM) as specified in IEEE 802.1Q-2018 [i.63] from O-DU side (clause 7.6) and by using timers to monitor the C/U plane connection on a per processing-element basis from O-RU side clause 7.10 in O-RAN-WG4-CUS [i.70].

Regarding transport network management in O-RAN a uniform network model approach has been considered. In more detail, an abstraction and model translation/mapping layer that would expose a uniform network model to other SMO components (NBI) has been introduced in O-RAN XTRP MGT [i.74], clause 9.3. In the southbound, communication with different technologies can make use of different YANG models. An example realization of the uniform network model according to O-RAN XTRP MGT [i.74] could exploit the TAPI Topology YANG model, defined by the Open Networking Foundation (ONF) in ONF oneM2M TR-547 [i.79].

5.2.4.1.4 Challenges

From a management perspective several challenges exist regarding transport network management when considering an O-RAN solution based on NFV-MANO. Positioning of the WIM functionality in the O-RAN architectural framework is a key aspect to be considered in the exposure of challenges.

For this key issue the following challenges are identified:

- **Challenge #D.1:** *O-Cloud network boundaries and network demarcation points.* In ETSI NFV the abstraction to handle transport network connectivity services is the MSCS. As described in clause 5.2.4.1.2 MSCS connects different CSEs associated to CEs which offer the network termination point for the transport network. However, in O-RAN, such approach of connectivity service abstraction like MSCS is not defined. This means that the intra-site and inter-site connectivity services defined in ETSI NFV cannot be directly mapped to the O-Cloud network services according to O-RAN WG6 (responsible for the intra O-Cloud network) or O-RAN WG9 (responsible for the transport network management) activities.

- **Challenge #D.2:** *Network management boundaries.* Currently, in the referenced O-RAN specifications there is no notion of MSCS and WIM. In an NFV-MANO-aware O-RAN deployment it is not yet clear whether OSS or SMO are expected to manage TN connectivity, whether WIM functionality is to be considered part or not of the O-Cloud (similarly to VIM/CISM) or instead be considered part of the SMO, and whether TN management can be made over the O2ims interface. Furthermore, when it comes to the inter-site connectivity services, considering that in practise TN can be deployed and managed by third parties/operators, the domain boundaries and responsibilities of the corresponding OSS, management and orchestration systems become more challenging.

- **Challenge #D.3:** *Time synchronization for TN.* In ETSI NFV there is no notion of backhaul, fronthaul or midhaul and no specific characteristics of these types of networks are considered. Especially for the fronthaul network, a key requirement is about time synchronization. ORAN XTRP SYN [i.76] details the syncE and PTP based synchronization solution and architecture. ETSI GS NFV-SOL 005 [i.73] defines the attribute *connectivityServiceEndpointConfigDatas* that enables the API consumer to provide information relevant for the configuration of the connectivity service endpoints. However, the referenced data type does not contain provisions related to time synchronization. Network-based synchronization is considered from an end-to-end perspective and is not only about enabling synchronization functionality on the network gateway system.

- **Challenge #D.4:** *transport network slicing.* ETSI TS 128 533 [i.77] specifies the network slice management entities. The main management functionalities provided from Network Slice Management Function (NSMF) and Network Slice Subnet Management Function (NSSMF) are the ones also considered by ETSI GR NFV-IFA 037 [i.15]. ETSI GR NFV-IFA 037 [i.15] describes different scenarios where ETSI NFV defined NS can be mapped to one or multiple network slice subnet instances (managed by NSSMF) which constitute one integrated network slice instance (managed by NSMF). Solution #3D in clause 5.4.3.4 of ETSI GR NFV-IFA 037 [i.15] describes management of network slice transport network connectivity with MSCSs. O-RAN approach also adopts the 3GPP specifications on managing network slicing. However, as TN-NSSMF is out of 3GPP scope, WIM interactions, not only with slice aware TN-NSSMF and OSS, but also with SMO are not clear when considering the O-RAN architecture. Also, for the moment is not yet clear how to consider WIM functionality in an O-RAN context (see also challenge #D.2). In addition, from NS perspective requirements about more advanced options like "hard" or "soft" slicing are not described in ETSI NFV specifications. In "hard" slicing resource allocation is physical layer characteristics while in "soft" slicing multiplexing gains are maximized and resource allocation and QoS management is made in higher layers, clause 9.1 in O-RAN XPSAAS [i.75]. Furthermore, Gap #3.1 from ETSI GR NFV-IFA 037 [i.15] still applies regarding support for providing via the NS LCM interface information about expected values of L2 networks when the CPs of the NS constituents are not in trunk mode.

- **Challenge #D.5:** *support of specific RAN-related protocols*. Certain parts of the O-RAN-based deployment, such as fronthaul, reference to specific types of protocols that encapsulate the upper application layer messages. An example is the CPRI/eCPRI in the open fronthaul, as specified in O-RAN-WG4.CUS [i.70]. The use of these protocols can make optional certain layers in the OSI stack, presumed specific use of certain transport technologies, as well as concern to the use and placement of specific interworking functions. How these can be supported or interworked with multi-site and intra-site connectivity managed by NFV-MANO is to be further explored. For example, a concrete issue is related to the way VLAN information can be shared between EM and NFV-MANO to support establishing connectivity between O-RUs and O-DUs for dynamic scenarios, where pre-provisioning is not possible and irrelevant of whether EM is considered part of SMO or not. Also, like ETSI GR NFV-IFA 037 [i.15] gap#3.1 network pre-provisioning performed by the OSS/BSS and the CPs of the NS constituents when not in trunk mode is currently not supported.

5.2.4.2 Potential Solutions

5.2.4.2.1 Overview

In the following a set of solutions is provided, where each solution applies to one of the challenges described in clause 5.2.4.1.4.

5.2.4.2.2 Solutions for challenge D.1: O-Cloud boundaries and network demarcation points

5.2.4.2.2.1 Solution SOL-D1-1 (NFVI-PoP network gateway as an O-Cloud gateway)

This solution applies the ETSI NFV defined network abstractions and network boundaries in an O-RAN based O-Cloud deployment. Firstly, the solution proposes the following correspondences to help determine the network boundaries:

- NFVI/DC network gateway in ETSI NFV is assumed to map to an O-Cloud site gateway in O-RAN.
- Virtualised network resources/primary & secondary container cluster networks in ETSI NFV are assumed to map to internal O-Cloud node cluster networks in the O-Cloud site in O-RAN.
- Transport networks enabling inter-site connectivity in ETSI NFV map to transport network in O-RAN.

Regarding the O-Cloud boundaries and network demarcation points, from ETSI NFV point of view the two-network management demarcation point alternatives described Annex E of ETSI GS NFV-SOL 005 [i.73] can be considered. The two demarcation points documented in ETSI GS NFV-SOL 005 [i.73] are:

- a first management boundary between NFVI-PoP network gateway (e.g. CE) and network provider (e.g. PE); and
- a second boundary between NFVI-PoPs network resources and the NFVI-PoP network gateway.

In all cases NFVO interfaces with the WIM for the management of WAN connectivity (i.e. transport network) for MSCS and the interfaces described in ETSI GS NFV-IFA 032 [i.35] can be applied irrelevant of the execution environment (VM or container based), as these concern to transport networks only.

Also aligned with the uniform network model approach according to O-RAN XTRP MGT [i.74], WIM can be a producer of TAPI and IETF specifications-based interfaces, exposing on the northbound the abstraction and model translation layer referenced by the O-RAN XTRP MGT [i.74]. However, to which O-RAN entity WIM will map is an open discussion point, but since ETSI NFV's framework enables two options of integrating multi-site network connectivity management (i.e. either WIM is part of NFV-MANO, or WIM is part of other OSS/BSS), reuse of WIM concepts and defined interfaces is feasible.

5.2.4.2.2.2 Solution SOL-D1-2 (Compute node as an O-Cloud gateway)

The basic assumption in SOL-D1-1 is that an NFVI-PoP network gateway maps to an O-Cloud gateway. In solution SOL-D1-2 the approach described in use case 13 in ETSI GR NFV-IFA 022 [i.83] is used as a baseline. In this approach there is no NFVI-PoP network gateway, rather a compute node can interact directly with a PE (i.e. is connected to the transport network). In that case the VNF in the compute node plays the role of a CE (with external CPs) consuming the end-to-end service provided by the Virtual Link and still L2 or L3 VPN services can be designed end-to-end. Different than the use case solution in the referenced ETSI GR NFV-IFA 022 [i.83], the present solution proposes to assign the role of CE to the compute node hosting the VNF. In such as case, CE configuration management is performed by VIM through interaction with the NFVO and still WIM is responsible for the management of the WAN. In O-RAN the O-Cloud nodes are managed by IMS. This solution considers a mapping of VIM/PIM functionalities to IMS regarding the management of CE network aspects.

5.2.4.2.3 Solutions for challenge D.2: Network management boundaries

5.2.4.2.3.1 Solution SOL-D2-1

In this solution, WIM is used to manage the MSCS for inter O-Cloud site connectivity and TN controllers are responsible for the actual TN network configuration following O-RAN WG9 specifications. WIM interacts with the TN controllers for the actual TN network provisioning.

Regarding architectural mappings, the solutions described in clause 5.2.1.2 consider WIM as part of O-Cloud. This means that, for a NFV-MANO-aware O-RAN system, WIM functionality can reside:

a) inside O-Cloud as part of NFV-MANO (when NFV-MANO is also providing equivalent functionality in the O-Cloud); or

b) inside O-Cloud but outside NFV-MANO; and

c) outside O-Cloud (and outside NFV-MANO).

The present solution is about considering WIM inside O-Cloud and inside NFV-MANO as a FB. This means that a single OSS could drive WIM operations through interactions with SMO.

NOTE: Interactions between IMS and TN management systems have not been yet articulated by O-RAN, according to the referenced O-RAN specifications.

5.2.4.2.3.2 Solution SOL-D2-2

In this solution, WIM resides inside O-Cloud but outside NFV-MANO. In this solution an OSS could trigger WIM operations without involving NFV-MANO functional blocks. This OSS (or part of it) could be the O-RAN defined SMO.

NOTE: Interactions between IMS and the TN management systems have not been articulated by O-RAN, according to the referenced O-RAN specifications, like also interactions of the additional OSS responsible for the TN with SMO.

5.2.4.2.4 Solutions for challenge D.3: Time synchronization

5.2.4.2.4.1 Solution SOL-D3-1

This solution is about enhancing information elements related to MSCS with time synchronization capabilities. For example, new attributes related to time synchronization could be defined in the *MscsProfile* information element of ETSI GS NFV-IFA 032 [i.35].

To achieve end-to-end synchronization all the nodes in the path are expected to be synchronized. This means that intra-site connectivity is also aware of the relevant time synchronization requirements. For example, actual configuration of PTP parameters of the TN intermediate nodes but also for the node hosting the CSE depend on the TN controller in effect. PTP parameters configuration of the intra-site network nodes are managed by VIM. Following this reasoning *VirtualLinkProfile* information element from ETSI GS NFV-IFA 011 [i.55] are expected to be augmented to define requirements related to time synchronization.

5.2.4.2.5 Solutions for challenge D.4: Transport Network Slicing

5.2.4.2.5.1 Solution SOL-D4-1

This solution is about TN slicing and relies on 3GPP management entities defined in ETSI TS 128 533 [i.77] and Solution #3D described in ETSI GR NFV-IFA 037 [i.15]. In an O-RAN environment the solution expects that a function or entity residing in SMO (or to an external OSS in case WIM is outside O-Cloud) keeps the state about mapping of MSCS VLs to Network Slice subnet instances.

5.2.4.2.6 Solutions for challenge D.5: Transport specific protocols

5.2.4.2.6.1 Overview

In principle for network provisioning, NFVO capabilities can be exploited to enable VLAN functionality defined in the VLD while relevant operations are already supported by the referenced ETSI NFV specifications. For example, in ETSI GS NFV-IFA 005 [i.39] *networkType* attribute of the *VirtualNetworkResourceInformation* information element to describe the virtualised network type and segmentation identifiers of the network (similarly *networkType* is part of the *L2ProtocolData* information element in ETSI GS NFV-IFA 014 [i.44]) and the *VirtualNetworkPort* information element in ETSI GS NFV-IFA 005 [i.39] encapsulates information of an instantiated virtual network port with the capability to express the type of port (trunk port, sub-port or normal).

Different methods can be considered regarding the way VLAN information (i.e. VIDs according to IEEE 802.1Q-2018 [i.63]) is distributed and enforced to the different VNFs. For O-Cloud networks, note that O-RU is expected to be deployed as a PNF. In the solutions described in the following, the case of managing and configuring VLAN information for virtualized functions (e.g. O-DUs) when deployed as VNFs is investigated. In all the solutions described VLAN configuration for O-RUs is made by OSS/SMO.

In O-RAN network provisioning is responsibility of IMS, while the configuration of network parameters for VNF deployments is responsibility of DMS.

5.2.4.2.6.2 Solution SOL-D5-1 (VLAN config based on ETSI GR NFV-EVE 022 options)

For network provisioning the solution considers method #C according to ETSI GR NFV-EVE 022 [i.59] where in that case VIM/CISM are used to allocate the necessary network resources and apply the VLAN configuration through interaction with the NFVI. For example, NFVO uses the Virtualised Network Resources Management Interface exposed by VIM according to ETSI GS NFV-IFA 005 [i.39], to pass the necessary information to VIM and VIM interacts with NFVI to perform the network resource provisioning.

This solution considers configuration method #B according to ETSI GR NFV-EVE 022 [i.59] to configure the VLAN IDs to be used. According to method #B, a VNF instance receives configuration data from the VNFM in charge of managing its lifecycle. The configuration data values can be originated from the VNFM can be also determined by the NFVO or received from the OSS/BSS. In that case OSS can tune VLAN information end-to-end.

Method #A according to ETSI GR NFV-EVE 022 [i.59] can be also used for dynamic scenarios, where the VLAN configuration data values can be configured in the VNF either from OSS/BSS directly or via the EM. To apply method #A network resources need to be pre-provisioned.

In this solution, method #C supports IMS related functionality, while method #A and method #B support DMS related functionality. Aspects like VLAN ids selection from VLAN pools is similar for both O-RAN operations performed by DMS and NFV operations. Note however that all the different methods described in ETSI GR NFV-EVE 022 [i.59] are about management of the overlay network and not the underlay network.

5.2.4.2.6.3 Solution SOL-D5-2 (VLAN config based on VNF generic OAM functions)

In this solution VLAN configuration is made through the Network Configuration Manager VNF generic OAM function as specified in ETSI GS NFV-IFA 049 [i.80]. OSS is the entity responsible to convey VLAN configuration information to the Network Configuration Manager, which in turn is responsible to convey the configuration to the relevant O-Cloud VNF (e.g. O-DU). In this solution, the Network Configuration Manager mainly supports DMS related functionality. If the configuration has been provided via the O2 to the DMS, then, it supports DMS related configuration. If the configuration has been provided via the O1 interface the configuration is related to the VNF application. The case of supporting IMS related functionality is also not excluded. For example, the Network Configuration Manager can be used to support network provisioning and also configuration of the underlay network (e.g. through interaction with PIM, which is specified in ETSI GS NFV-IFA 053 [i.82]).

5.2.4.2.6.4 Solution SOL-D5-3 (VLAN config based on VNF generic OAM functions plus ETSI GR NFV-EVE 022 [i.59] options)

According to this solution Network configuration manager VNF generic OAM function can be used as described in ETSI GR NFV-EVE 019 [i.34] and can be incorporated in a solution where configuration methods described in ETSI GR NFV-EVE 022 [i.59] can be used. For example, in the case of configuration method #B, when Network configuration manager VNF generic OAM function is used, the following configuration paths are possible a) (OSS/EM or NFV) to VNFM to "Network configuration manager" to VNF and b) (OSS/EM or NFV) to "Network configuration manager" to VNFM to VNF. This solution can support both the dynamic and the network pre-provisioning cases.

5.2.4.2.6.5 Solution SOL-D5-4 (VLAN-ID information in VNFD)

This solution considers that VLAN-ID information is carried in the *segmentationId* attribute of the L2ProtocolData information element according to ETSI GS NFV-IFA 011 [i.55]. Global VLAN information knowledge resides in OSS and this solution is not able to cope with dynamic provisioning cases.

5.2.4.3 Gap analysis

Although from ETSI NFV point of view WIM functionality can cover MSCS management, architectural mapping between O-RAN entities and ETSI NFV-defined WIM is expected to be further elaborated, which however is not considered as a gap in the referenced ETSI NFV specifications.

The following gaps have been identified regarding the realization of NFV-MANO solutions supporting O-RAN transport network management. These gaps are relevant to the challenges described in clause 5.2.4.1.4 and solutions described in clause 5.2.4.2.

Gap#D.1: connection points and connectivity service endpoints specification are missing attributes related to time synchronization. Relevant requirements in descriptors could also be specified in ETSI GS NFV-IFA 011 [i.55].

5.2.4.4 Evaluation and concluding remark

Table 5.2.4.4-1 provides pros/cons analysis of the solutions described for this key issue.

Table 5.2.4.4-1: Solutions evaluation for Key Issue D

Challenge	Solution	Pros	Cons	Additional considerations/remarks
D.1	SOL-D1-1	- ETSI NFV specifications are reusable by adopting demarcation points as defined in ETSI GS NFV-SOL 005 [i.73]. - Clear positioning and demarcation of the O-Cloud site network gateway is possible, thus facilitating clear network management boundaries.	- Solution depended on the concept of MSCS. Not easy to adapt to cases where more fine-grained TN control and management are expected.	- As Multi-site overlay operations in O-RAN are not well defined, is not clear how L2VPN and L3VPN will operate when considering NFV control of the network gateways.
	SOL-D1-2	- Clear network demarcation from NFV side. NFVO is responsible for CE configuration through VIM. - No need to maintain a NFVI-PoP gateway to interface the WAN.	- Every Compute node needs to terminate the tunnelling endpoints - Complicated management in case the role of CE is assigned to compute nodes but some still interact with the WAN through a NFVI-PoP network gateway.	
D.2	SOL-D2-1 (WIM in NFV-MANO)	- Simplicity of design on OSS/SMO level - Clear demarcation of higher orchestration layer (SMO) and lower infrastructure/resource orchestration for transport networking, i.e. WIM is part of O-Cloud. - Well defined multi-site connectivity interfaces (from ETSI GS NFV-IFA 032 [i.35]) can be leveraged for interacting SMO and O-Cloud transport networking. - Fully dynamic transport network provisioning can be realized based on end-to-end vRAN deployment requirements.	- Difficult management in the case of O-Cloud federations and interdomain NFV-MANO.	- Annex E of ETSI GS NFV-SOL 005 [i.73] provides additional information about the different network gateway management models. However, a detailed pros and cons analysis has not been performed in the ETSI GS NFV-SOL 005 [i.73].
	SOL-D2-2 (WIM outside NFV-MANO)	- Easier to incorporate third party TN providers - Clear demarcation of higher orchestration layer (SMO) and lower infrastructure/resource orchestration for transport networking, i.e. WIM is part of O-Cloud.	- Additional OSS Interactions in case there is a dedicated different TN OSS, i.e. only pre-provisioning interactions are considered, thus lacking other network fulfilment and provisioning coordination. - Integration focus is more on "transport network pre-provisioning".	

Challenge	Solution	Pros	Cons	Additional considerations/remarks
D.3	SOL-D3-1	- Simplicity of implementation, only new attributes are considered to extend existing information elements.	- None identified.	
D.4	SOL-D4-1	- No extensions are needed for relevant ETSI NFV specifications.	- Not able to manage TN parameters on per slice basis at a high granular level (e.g. related to physical layer, MAC scheduling, etc.).	- Undefined control/ management entity) responsible of the mapping of MSCS VLs to Network Slice subnet instances.
D.5	SOL-D5-1	- Applies to both pre-provisioning and dynamic provisioning cases.	- None identified.	- See note 1.
	SOL-D5-2	- Applies to both pre-provisioning and dynamic provisioning cases.	- None identified.	- Network configuration manager can holistically configure all network connectivity aspects of the VNF dynamically, and not only about VLAN configuration. - See note 2.
	SOL-D5-3	- Applies to both pre-provisioning and dynamic provisioning cases.	- None identified.	- Network configuration manager can holistically configure all network connectivity aspects of the VNF dynamically, and not only about VLAN configuration. - See notes 1 and 2.
	SOL-D5-4	- No extensions are needed in ETSI NFV specifications	- Only applies to pre-provisioning case, not applicable to dynamic scenarios. - To accommodate for the possible VLAN ranges limitation in actual network deployments, VNFD would have to be specialized for specific deployments.	
NOTE 1: Extensions might be expected in ETSI NFV specifications to realize the configuration methods proposed by ETSI GR NFV-EVE 022 [i.59] and the closure of technical gaps identified therein. NOTE 2: VNF generic OAM functions framework specification and interfaces definition are part of ETSI GR NFV-IFA 049 [i.80] ongoing work item in Release 4.				

The evaluation analysis presented is based on the modelling assumption that transport network is part of the O-RAN O-Cloud and can be managed by OSS/SMO. For example, to address challenge D.2 two alternative solutions have been proposed based on the different models defined in ETSI GS NFV-SOL 005 [i.73] related to whether WIM is considered part of NFV-MANO or not. In case the transport network is not part of O-Cloud then the proposed solutions are still applicable however further investigation is necessary on how the concept of MSCS can be applied and how NFV-MANO related operations can be applied on the NFVI-PoP network gateways.

6 Recommendations

6.1 Overview

The present clause documents recommendations about potential enhancements, changes, or clarifications to existing ETSI NFV specifications. The recommendations are derived based on the analysis performed on the profiling of NFV against for the support of vRAN deployments, their characteristics and relevant other organization specifications on a per key issue basis, as described in clause 5.

The recommendations are categorized and elaborated as follows:

- recommendations for solutions (refer to clause 6.2);
- recommendations for architecture and framework aspects (refer to clause 6.3);
- recommendations for functional aspects (refer to clause 6.4);
- recommendations for descriptors and other information/data model artefacts (refer to clause 6.5);
- recommendations for interfaces and associated information/data model (refer to clause 6.6); and
- recommendations related to cross organization collaboration (refer to clause 6.7).

6.2 Recommendations for solutions

For some of the challenges described in clause 5 there is a single solution provided in the corresponding sub-clause. In this case, the only solution will be recommended for further investigation, without further analysis. In the case where multiple solutions are described to address a single challenge, the recommendations are based on the evaluation analysis provided, considering compatibility aspects with the referenced external organization specifications, e.g. the O-RAN framework.

Table 6.2-1 provides recommendations for the solutions to be further considered for normative work.

Table 6.2-1: Recommendations for the solutions

Challenge	Solution Identifier	Description	Recommended	Comment
A.1: Architectural Mappings	SOL-A1-1	VNFM in SMO	NO	Solution details are in clause 5.2.1.2.2.1 and evaluation in clause 5.2.1.4.
	SOL-A1-2	VNFM in O-Cloud	YES	Aligned with O2dms interface [i.78] and ETSI NFV profile. Solution details are in clause 5.2.1.2.2.2 and evaluation in clause 5.2.1.4.
A.3: Physical Infrastructure Management	SOL-A3-1	Enhancing VIM	YES	Solution details are in clause 5.2.1.2.3.2 and evaluation in clause 5.2.1.4.
	SOL-A3-2	PIM in OSS	NO	Solution details are in clause 5.2.1.2.3.3 and evaluation in clause 5.2.1.4.
	SOL-A3-3	PIM outside OSS and outside NFV-MANO	NO	Solution details are in clause 5.2.1.2.3.4 and evaluation in clause 5.2.1.4.
	SOL-A3-4	PIM inside NFV-MANO	YES	Solution details are in clause 5.2.1.2.3.5 and evaluation in clause 5.2.1.4.
	SOL-A3-5	PIM in NFVI	NO	Solution details are in clause 5.2.1.2.3.6 and evaluation in clause 5.2.1.4.
B.1: Virtual accelerator model	SOL-B1-1	New virtual accelerator model	YES	Only one solution. Solution details are in clause 5.2.2.2.2.1 and evaluation in clause 5.2.2.4.
B.2: Virtual accel. Management	SOL-B2-1	Virtual accelerator management aligned with O-RAN	YES	Only one solution. Solution details are in clause 5.2.2.2.3.1 and evaluation in clause 5.2.2.4.
B.3: Virtual accel.	SOL-B3-1	Northbound based on the new EPD-based virtual accelerator model	YES	Aligns better with the O-RAN approach. Solution details are in clause 5.2.2.2.4.2 and evaluation in clause 5.2.2.4.

Challenge	Solution Identifier	Description	Recommended	Comment
northbound interface	SOL-B3-2	Northbound based on the virtual accelerator without EPD model extensions	NO	Solution details are in clause 5.2.2.2.4.3 and evaluation in clause 5.2.2.4.
C.1: ML modelling	SOL-C1-1	ML models in VNFD	NO	Solution details are in clause 5.2.3.2.2.1 and evaluation in clause 5.2.3.4.
	SOL-C1-2	ML models in VNF package	YES	Solution details are in clause 5.2.3.2.2.2 and evaluation in clause 5.2.3.4.
	SOL-C1-3	ML models in MDA	NO	Solution details are in clause 5.2.3.2.2.3 and evaluation in clause 5.2.3.4.
C.2: CRDs in NFV	SOL-C2-1	CRDs in NFV	YES	Only one solution. Solution details are in clause 5.2.3.2.3.1 and evaluation in clause 5.2.3.4.
C.3: VNF dependencies	SOL-C3-1	Partial packaging	YES	Solution details are in clause 5.2.3.2.4.1 and evaluation in clause 5.2.3.4.
	SOL-C3-2	Common VNFs	YES	Solution details are in clause 5.2.3.2.4.2 and evaluation in clause 5.2.3.4.
	SOL-C3-3	VNF Bundle	YES	Solution details are in clause 5.2.3.2.4.3 and evaluation in clause 5.2.3.4. See note 3.
	SOL-C3-4	Normal VNFs	YES	Solution details are in clause 5.2.3.2.4.4 and evaluation in clause 5.2.3.4.
D.1: Network demarcation points	SOL-D1-1	Demarcation points described in Annex E of ETSI GS NFV-SOL 005 [i.73]	YES	Solution details are in clause 5.2.4.2.2.1 and evaluation in clause 5.2.4.4.
	SOL-D1-2	Compute nodes as CEs	YES	Solution details are in clause 5.2.4.2.2.2 and evaluation in clause 5.2.4.4. It is recommended in the case of small footprint deployments of compute nodes directly connected to transport.
D2: management boundaries	SOL-D2-1	WIM inside O-Cloud and inside NFV-MANO	YES	Solution details are in clause 5.2.4.2.3.1 and evaluation in clause 5.2.4.4.
	SOL-D2-2	WIM inside O-Cloud but outside NFV-MANO	YES	Solution details are in clause 5.2.4.2.3.2 and evaluation in clause 5.2.4.4. See note 1.
D.3: Time synchronization	SOL-D3-1	Enhancing information elements related to MSCS with time synchronization capabilities	YES	Only one solution. Solution details are in clause 5.2.4.2.4.1 and evaluation in clause 5.2.4.4.
D.4: Transport network slicing	SOL-D4-1	Considers solution #3D described in ETSI GR NFV-IFA 037 [i.15]	YES	Only one solution. Solution details are in clause 5.2.4.2.5.1 and evaluation in clause 5.2.4.4.
D.5: RAN protocol operations	SOL-D5-1	VLAN config based on ETSI GR NFV-EVE 022 [i.59]	YES	Solution details are in clause 5.2.4.2.6.2 and evaluation in clause 5.2.4.4. See note 2.
	SOL-D5-2	VLAN config based on VNF generic OAM functions	YES	Solution details are in clause 5.2.4.2.6.3 and evaluation in clause 5.2.4.4. See note 2.
	SOL-D5-3	VLAN config based on VNF generic OAM functions plus ETSI GR NFV-EVE 022 [i.59].	YES	Solution details are in clause 5.2.4.2.6.4 and evaluation in clause 5.2.4.4. See note 2.
	SOL-D5-4	VLAN-ID information in VNFD.	NO	Solution details are in clause 5.2.4.2.6.4 and evaluation in clause 5.2.4.4.

NOTE 1: This solution does not differ much from the case when the WIM is considered to be part of the OSS/BSS as per clause G.2.2 of ETSI GS NFV-IFA 010 [i.32], which is also supported by the current NFV-MANO architecture.

NOTE 2: The VNF generic OAM functions framework is compatible with the three baseline configuration methods described in ETSI GR NFV-EVE 022 [i.59], so any combination of these would be feasible.

NOTE 3: A comprehensive set of recommendations to define normative requirements, which support this solution, is provided in ETSI GR NFV-IFA 044 [i.71].

6.3 Recommendations related to the NFV architectural framework

The present clause provides recommendations related to possible enhancements to the NFV architectural framework, potential new functions, and their interaction with the NFV-MANO entities.

Table 6.3-1 provides the recommendations related to the NFV architectural framework.

Table 6.3-1: Recommendations related to the NFV architectural framework

Identifier	Recommendation description	Comments
vran.arch.001	It is recommended that a requirement be specified for the NFV architectural framework to support interactions between NFV-MANO entities with a Physical Infrastructure Management (PIM) function. See note.	
NOTE: Example NFV-MANO entities who could potentially interact with PIM are VIM, CCM, CISM and NFVO. Interactions between CISM and PIM are possible (e.g. for storage management and provisioning).		

6.4 Recommendations related to functional aspects

The present clause provides recommendations related to functional aspects of the different NFV-MANO entities like functions and functional blocks.

Table 6.4-1 provides the recommendations related to functional aspects.

Table 6.4-1: Recommendations related to functional aspects

Identifier	Recommendation description	Comments
vran.func.001	It is recommended that a requirement be specified for the VIM to be able to consume physical resources management from PIM.	See clause 5.2.1.2.3 regarding solutions related to Physical Infrastructure management. The present document does not analyse whether CISM can consume PIM functionality regarding physical resource management, for example, related to physical resource performance metrics and faults.
vran.func.002	It is recommended that a requirement be specified for the CCM to be able to consume physical resources management from PIM.	
vran.func.003	It is recommended that a requirement be specified for the NFVO to be able to consume physical resources management and physical infrastructure inventory information from PIM.	
vran.func.004	It is recommended that a requirement be specified for VIM to be able to support and manage virtualised resources for VM-based deployments considering requirements related to acceleration resources and virtual accelerator abstraction. See note 1.	See clause 5.2.2 regarding an analysis of the virtual accelerator concept and solutions related to management and functionality exposure. Virtual acceleration abstraction enables a common way to offer acceleration resources to deployments regardless of the mode of deployment, i.e. VM-based or container-based.
vran.func.005	It is recommended that a requirement be specified for CISM to be able to support and manage containerized workloads for OS container-based deployments considering requirements related to acceleration resources and virtual accelerator abstraction. See note 1.	
vran.func.006	It is recommended that a requirement be specified for CCM to be able to manage CIS clusters considering requirements related to acceleration resource and virtual acceleration abstraction. See note 1.	
vran.func.007	It is recommended that a requirement be specified for VIM to be able to configure accelerator resources and virtual accelerator abstraction on the NFVI. See note 2.	
vran.func.008	It is recommended that a requirement be specified for CCM to be able to configure accelerator resources and virtual accelerator abstraction on CIS clusters. See note 2.	
vran.func.009	It is recommended that a requirement be specified for the NFVO to be able to manage partial VNF packaging.	See clause 5.2.3.2.4.1 about solution SOL-C3-1 and Gap#3.3 in clause 5.2.3.3 regarding partial packaging support in NFV.
NOTE 1: VIM, CISM and CCM can be aware of the acceleration resources available for deployment and abstractions that are supported by these resources. Acceleration resources management and accelerator abstraction management responsibilities between VIM, CISM and CCM could leverage AAL Management API defined by O-RAN as described in clause 5.2.2.1.3. NOTE 2: Acceleration resources configuration and accelerator abstraction configuration responsibilities between VIM, CISM and CCM could leverage the AAL Management API defined by O-RAN (see clause 5.2.2.1.3). For instance, CCM could interact with the Accelerator HW manager defined by O-RAN specifications to support the configuration of accelerator resources and to support such abstractions.		

6.5 Recommendations related to NFV descriptors and other artifacts

The present clause provides recommendations related to descriptors and other artifacts.

Table 6.5-1 provides the recommendations related to descriptors and other artifacts.

Table 6.5-1: Recommendations related to descriptors and other artifacts

Identifier	Recommendation description	Comments
vran.descr.001	It is recommended that a requirement be specified to be able to support the description of virtual accelerator abstraction in ETSI GS NFV-IFA 011 [i.55] in a common way for both VM-based and containerized deployments.	See solution SOL-B1-1 under clause 5.2.2.2.2.1 and Gap#2.1 in clause 5.2.2.3. This requirement is not intended to replace existing requirements on acceleration resources.
vran.descr.002	It is recommended that a requirement be specified to be able to support that a VNF Package contains only parts (VNFC) of the software of a VNF or artifacts necessary for the management of the VNF (partial packaging).	Partial VNF Packages would then have a reference to VNF Package versions to where they are applicable while independent VNFC updates and upgrades or lifecycle of management artifacts are possible. See solution SOL-C3-1 in clause 5.2.3.2.4.1. Impacts in versioning management are expected to be considered in future standardization work.
vran.descr.003	It is recommended that a requirement be specified to be able to support time synchronization attributes in the relevant endpoint descriptors. See note.	See discussion under Gap and solution SOL-D3-1 in clause 5.2.4.2.4.1.
NOTE: Examples include potential extensions of ETSI GS NFV-IFA 011 [i.55] attributes, MSCS endpoint data in ETSI GS NFV-IFA 032 [i.35] and new attribute for the CCDs regarding the CIS Cluster Networks to support time-synchronization capabilities, according to ETSI GS NFV-IFA 036 [i.52].		

6.6 Recommendations related to interfaces and information model

The present clause provides recommendations related to interfaces and information model associated to interfaces. Table 6.6-1 provides the recommendations related to interfaces and information models.

Table 6.6-1: Recommendations related to interfaces and information models

Identifier	Recommendation description	Comments
vran.inter.001	It is recommended that a requirement be specified for the VIM to be able to consume standard interfaces exposed by PIM regarding physical resources management.	See clause 5.2.1.2.3 regarding solutions related to Physical Infrastructure management. These recommendations make no assumption on the form of the standard interface which is left for future specification.
vran.inter.002	It is recommended that a requirement be specified for the CCM to be able to consume standard interfaces exposed by PIM regarding physical resources management.	
vran.inter.003	It is recommended that a requirement be specified for the NFVO to be able to consume standard interfaces exposed by PIM regarding physical resources management.	
vran.inter.004	It is recommended that a requirement be specified for the interfaces exposed over Nf-vi reference point to be able to support and manage virtualised resources for VM-based deployments considering requirements related to acceleration resources and virtual accelerator abstraction.	
vran.inter.005	It is recommended that a requirement be specified for the interface exposed by CISM to consider requirements related to acceleration resources and virtual accelerator abstraction when managing containerized workloads for OS container-based deployments.	
vran.inter.006	It is recommended that a requirement be specified to extend the endpoint information models to support time synchronization (e.g. metadata attribute from *VirtualNetworkPortData* information element in ETSI GS NFV-IFA 005 [i.39] can be used to carry synchronization data or a new attribute could be defined).	Example information is related to enabling PTP functionality on the port level.

6.7 Recommendations related to cross organization collaboration

Based on the analysis performed in clause 5 of the present document the following areas have been identified and are recommended for further potential collaboration between ETSI-NFV and O-RAN alliance:

1) Architectural mapping of the different NFV-MANO entities to the O-RAN architecture. See clause 5.2.1 for an architectural mappings analysis of the different NFV-MANO entities to the O-RAN architecture.

2) Requirements specification regarding physical infrastructure management applicable for both architectural frameworks. PIM functionality is not currently supported by NFV-MANO. See clause 5.2.1.2.3 for solutions regarding physical infrastructure management in NFV.

3) Definition of a compatible acceleration abstraction management applicable for both architectural frameworks. See clause 5.2.2 for an analysis of acceleration abstraction support.

4) Discussion on VNF descriptors and packaging to maximize the portability of VNF between the two architectural frameworks. See clause 5.2.3 for an analysis of VNF descriptors and packaging challenges.

5) Definition of requirements or on reusing existing specifications to define the O-Cloud network boundaries and network demarcations points. See clause 5.2.4.2.2.1 (solution SOL-D1-1) and clause 5.2.4.2.3 (solutions SOL-D2-1 and SOL-D2-2) for network demarcation points and network management boundaries respectively.

The analysis presented depends on current state of development of the O2ims and O2dms interfaces at the time of publication of the present document. Depending on the architectural mapping solution selected, further analysis is expected since IMS and DMS boundaries have not been precisely articulated. Since there is lack of IMS and DMS implementations complying with O-RAN specifications (because standards are still under development in O-RAN), more collaboration is expected between the different SDOs. Similarly internal functionality breakdown inside the SMO is under discussion and functionality boundaries between concrete entities inside the SMO are still to be defined.

Although in NFV well-defined descriptors and packaging are used, in O-RAN Alliance a relevant discussion still undergoes. Collaboration between the two organizations on this field is expected to maximize the benefits of NFV framework for relevant O-RAN areas that are leveraging ETSI-NFV specifications.

7 Conclusion

The present document analysed the NFV framework to determine how it can support virtualised RAN (vRAN) use cases. A number of key issues were identified, and relevant challenges were described when analysing the ETSI-NFV framework to support the O-RAN intended functionality. These key issues are about architectural mappings (clause 5.2.1), acceleration abstractions (clause 5.2.2), descriptors and packaging (clause 5.2.3) and transport network management when for example considering network demarcation points (clause 5.2.4). For each challenge identified under each key issue, a set of solutions was described together with a gap analysis in the NFV framework regarding the feasibility of each solution.

The present document also provides a set of recommendations for enhancements to the NFV architectural framework functionality, descriptors and interfaces aiming to provide further support for vRAN use cases. Future specification work is expected to consider the recommendations and potential enhancements in a subsequent normative specification phase.

Each solution proposed was described considering that the functionality of the different O-RAN elements, like DMS, IMS and SMO have not yet been fully delineated by the O-RAN technical specifications. In this regard close collaboration between ETSI NFV and O-RAN Alliance is expected to unleash the potential of NFV-MANO solutions in the field of virtualised RAN.

Annex A: Virtualised RAN Use Cases

A.1 Introduction

The aim of this clause is to analyse use cases provided by other SDOs regarding RAN cloudification. A technical assessment is provided regarding the relationship with the NFV-MANO framework like also the technical challenges when all or parts of RAN NFs are deployed as VNFs, using VIM or CISM based solutions.

In this annex the focus is on NF virtualisation and NFV management and orchestration aspects. Application-level operations and optimizations are considered out of scope of the present analysis and will be succinctly described only in case they drive requirements (e.g. like the need for hardware or software acceleration).

In the following analysis references are provided only for NFV-EVE (stage 0) and NFV-IFA (stages 1 and 2) like also NFV-REL and NFV-TST, as NFV-SOL relevant reports and specifications can be easily deduced.

NOTE: All the descriptions of O-RAN Use cases were adapted and summarized based on the original description provided in the related specification. For the original and accurate description of the relevant use case, refer to the O-RAN specification.

A.2 Use cases from O-RAN WG1

The following use cases have been introduced in O-RAN WG1 "Use Cases Analysis Report" [i.47].

Table A.2-1: O-RAN WG1 Use Cases Analysis

Source	Use Case
[i.47]-UC1 and UC2	**UC1 Title:** Context-Based Dynamic HO Management for V2X **Short description:** This use case is about optimizing handover decision making for moving vehicles in V2X applications by introducing AI/ML assisted decision making in the Near-RT RIC. This functionality is performed by an xAPP running in the Near-RT RIC, applying long-term analytics by using AI/ML algorithms and real-time optimization which is offered by trained ML model. Near-RT RIC monitors UE specific real-time mobility context based on V2X data. **UC2 Title:** Flight Path Based Dynamic UAV Radio Resource Allocation. **Short Description:** This use case is targeting UAV mobility handling, adjusting radio resource allocation policies, reducing unnecessary handover and improving radio resource utilization for UAV. The Near-RT RIC supports deployment and execution of AI/ML models, constructed/trained in the Non-RT RIC. **Relevance to NFV:** Minimum according to the description. However, deploying Near-RT as a VNF with real-time characteristics is related to issues like the ones described in ETSI GR NFV-EVE 017 [i.16]. **Potential key issues for NFV:** See Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF.

Source	Use Case
[i.47]-UC3	**UC3 Title:** Radio Resource Allocation for UAV Application Scenario **Short Description:** Besides UAVs this use case also considers UAV operational terminals and moving UAV Control Vehicles. UAV Control Vehicle deploy network equipment, including O-CU, O-DU, the Non-RT RIC, the Near RT RIC function modules and the Application Server. In deployment option A, O-CU, O-DU and Near-RT RIC are deployed on the Control Vehicle, Non-RT RIC and core network are deployed on the central cloud. In option B, all modules, including the gNB, Near-RT RIC, Non-RT RIC and the necessary core network function modules, are deployed in the Control Vehicle. **Relevance to NFV:** Minimum according to the description. ETSI GS NFV-IFA 032 [i.35] is about Multi-Site Connectivity Services and considering a VNF-based deployment of the DU/CUs NFs under option A, additional issues are related to connectivity aspects (CPs, SAPs) because of the moving nature of the Control Vehicle. **Potential key issues for NFV:** See Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF. Requirements regarding preserving IP addressing or FQDN for moving VNFs can be deduced, for example by building a local network inside the moving vehicle.
[i.47]-UC4	**UC4 Title:** QoE Optimization **Short Description:** The goal of this use case is to improve the way congested cells are detected and automatically allocate resources based on the end user experience. The solution introduces a "User RAN Policy", hosted at the Non-RT RIC or Near-RT RIC. The User RAN Policy will be instantiated as an rApp or xApp which will apply the operator's desired QoE configuration for specific user, slice or 5QI flow types on the network. **Relevance to NFV:** Minimum according to the description. In case of NFV-based orchestration and management, QoS and QoE preservation besides pure RAN configuration aspects is also relevant to scaling out/up decision making and VNF LCM. Scaling out/up functionality is already provided by ETSI NFV for both VIM, CISM based solutions. **Potential key issues for NFV:** See Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF. Auto-scaling is based on VNF indicators supplied by the VNF or the EM, or from performance/fault notifications received from the VIM/CISM about virtualised resources used by the VNF. In O-RAN, EM functionality is supported by functions residing in the SMO. However how this functionality can be mapped for example to VNFM, EM and VNF generic OAM functions reported in ETSI GR NFV-EVE 019 [i.34] is an open discussion.
[i.47]-UC5	**UC5 Title:** Traffic Steering **Short Description:** Traffic steering allows, using the A1 interface, to flexibly configure optimization policies and utilize the appropriate performance criteria to proactively manage user traffic across different access technologies (like NR, LTE and Wi-Fi). Traffic management policies are sent over the A1 interface from Non-RT RIC to Near RT-RIC, who uses the policies when enforcing the radio resource control. **Relevance to NFV:** Clause 5.10 of ETSI GR NFV-IFA 037 [i.15] describes the support of NFV for convergent access (3GPP and non-3GPP), where different virtualised gateway systems are used to connect the different access networks to the 5GCN. ETSI GR NFV-IFA 037 [i.15] also reports about usage of VL for connectivity matters, traffic routing/balancing. **Potential key issues for NFV:** See Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF. Gap#3.1 described in clause 5.4.4 of ETSI GR NFV-IFA 037 [i.15] also applies regarding L2 connectivity aspects.
[i.47]-UC6	**UC6 Title:** Massive MIMO Beamforming Optimization **Short Description:** The objective of this use case is to allow the operator to flexibly configure Massive MIMO system parameters by means of policies, configuration, or machine learning techniques. In this use case three optimization loops for massive MIMO Beam Forming are proposed: 1) an outer, Non-RT loop Massive MIMO Grid of Beams Beam Forming Optimization; 2) an inner, Near-RT loop Massive MIMO Beam-based Mobility Robustness Optimization; and 3) an inner, Near-RT loop Massive MIMO Beam Selection Optimization. Non-RT RIC is used for model training and Near RT RIC for model Inference and decision making. **Relevance to NFV:** Minimum according to the description. **Potential key issues for NFV:** See Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF.

Source	Use Case
[i.47]-UC7	**UC7 Title:** RAN Sharing **Short Description:** two operators A and B, share the same RAN infrastructure, while keeping the core network independent. Operator A owns site A and shares the O-RU (Low PHY Layer) with Operator B. Site A hosts VNF instances (O-DU and O-CU) of Operator B where the computing resources of the site A are shared among multiple VNFs, belonging to the operator A and B respectively. In site A operator A can directly control its VNFs, and Operator B controls its VNFs in a remote manner. It is assumed that Operator B can monitor and control the remote resources via the RIC node deployed in another site B. In the proposed architecture, the RICs are not shared and kept independent at the site A and B respectively. Implementation challenges: a) a common interface is expected to control and coordinate the usage of shared resources; and b) an orchestrator is expected to communicate effectively with the shared nodes. Need for a new interface between the Service & Orchestration Framework of the two sites and by enabling the Operator B to directly orchestrate its VNFs deployed in site A via "remote O1 & O2" interfaces. Regarding the control plane, it is assumed that Operator A can control only the shared physical resources, while Operator B can handle only the virtual resources that belong to it. This use case proposes an extension of the E2 interface in order to support the remote control of shared resources. **Relevance to NFV:** Use case is relevant to ETSI GR NFV-EVE 018 [i.33] study which describes the different sharing models between multiple tenants, operating over shared virtualised and physical infrastructure. Composition of NS across multiple administrative domains is in ETSI GS NFV-IFA 030 [i.36] where interfaces on the Or-Or reference point are specified. ETSI GR NFV-IFA 028 [i.37] is about interactions between NFV-MANO stacks belonging to different administrative domains. VIM supports grouping sets of virtualised resources into a "virtualised resource group" as specified in ETSI GS NFV-IFA 005 [i.39] and ETSI GS NFV-IFA 006 [i.40]. Based on these findings' connectivity can be enabled for E2 operations over multi-site environments, like also NS and VNF LCM can be applied over multidomain environments and communication between NFVOs belonging to different tenants. **Potential key issues for NFV:** Mapping of SMO functionality to NFVO and normative provisions based on recommendations derived from the ETSI GR NFV-EVE 018 [i.33].
[i.47]-UC8 and UC9	**UC8 Title:** QoS Based Resource Optimization **Short Description:** The desired default RAN behaviour for slices is configured over O1. For example, the ratio of physical resources (PRBs) reserved for a slice is configured at slice creation over O1. The performance of a RAN slice will continuously be monitored by SMO. When SMO detects a situation when RAN goals cannot be fulfilled, Non-RT RIC can use A1 policies to improve the situation. A motivating example is provided for an emergency network slice. The Non-RT RIC will evaluate how to ensure higher bandwidth for the feed selected by Emergency Control Command and lower for other feeds. The Non-RT RIC updates the policy for the associated UEs for this slice in the associated Near-RT RIC over the A1 interface. Near-RT RIC enforces the modified QoS target for the associated UEs over the E2 interface to fulfil the request. **UC9 Title:** RAN Slice SLA Assurance **Short Description:** Non-RT RIC and Near-RT RIC can fine-tune RAN behaviour to assure RAN slice SLAs dynamically. Non-RT RIC monitors long-term trends and patterns for RAN slice subnets' performance, and employs AI/ML methods to perform corrective actions through SMO (e.g. reconfiguration via O1) or via creation of A1 policies. Non-RT RIC can also construct/train relevant AI/ML models that will be deployed at Near-RT RIC. A1 policies possibly include scope identifiers (e.g. S-NSSAI) and statements such as KPI targets. On the other hand, Near-RT RIC enables optimized RAN actions through execution of deployed AI/ML models in near-real-time by considering both O1 1 configuration (e.g. static RRM policies) and received A1 policies, as well as received slice specific E2 measurements. **Relevance to NFV:** clause 5.4 of ETSI GR NFV-IFA 037 [i.15] profiles the different NFV capabilities to support 3GPP Network Slicing. ETSI GR NFV-IFA 024 [i.41] describes the touchpoints between the 3GPP's management model and the ETSI NFV information model. ETSI GR NFV-IFA 023 [i.42] and ETSI GR NFV-IFA 042 [i.43] report about policy management in NFV. **Potential key issues for NFV:** see Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF. Mechanisms to enable slice aware NFV policy management could be established. From a deployment point of view, correlation between end-to-end slice QoS and slice aware VNF and resource performance indicators can be expected, however this is out of NFV work scope. In addition, a VNF can be also shared under slicing and different models apply. Transport Network slicing relationship with NFV WIM has not been investigated enough.

Source	Use Case
[i.47]-UC10	**UC10 Title:** Multi-vendor Slices **Short Description:** This use case enables multiple slices with functions provided by multiplevendors. For example, slice-1 is composed of vO-DU(s) and vO-CU(s) provided by vendor B, and slice-2 is composed of vO-DU(s) and vO-CU-UP(s) provided by vendor C. An additional application of multi-vendor slices use case is RAN sharing where, operator A has a pair of vO-DU and vO-CU from vendor A, and operator B has a different pair of vO-DU and vO-CU from vendor B, and O-RU is shared among these two operators. Coordination between vO-DU/vO-CUs is key since radio resources are expected to be assigned properly and without any conflicts. Possible cases are: 1) loose coordination through O1//A1 interface; 2) moderate coordination through E2/X2/F1 interface; and 3) tight coordination through a new interface between vO-DUs. **Relevance to NFV:** Clause 5.4 of ETSI GR NFV-IFA 037 [i.15] profiles the different NFV capabilities to support 3GPP Network Slicing. For the RAN sharing model ETSI GR NFV-EVE 018 [i.33] is also relevant. **Potential key issues for NFV:** None additional, see also UC7, UC8 and UC9.
[i.47]-UC11	**UC11 Title:** Dynamic Spectrum Sharing (DSS) **Short Description:** DSS enables 4G and 5G UEs to operate over the same spectrum identified as X (typically low band), while 5G itself could operate on new bands Y (typically high band) not used by current 4G deployment. The DSS over RIC can be realized as multiple applications. One possible logical breakdown is as a resource management application (DSS-App) managing the shared spectrum resource, and another application (RAT-App) to configure, control and monitor DSS rules in the CU/DU corresponding to the LTE (RAT-App-4G) and 5G (RAT-App-5G) cells. The main functionality of Non-RT RAT-App is to translate the global DSS policies from Non-RT DSS-App to RAT specific policies to the RAT-App in the Near-RT RIC over A1. The main functionalities of the Near-RT DSS-App include policy translation between Non-RT DSS-App to RAT specific configuration to the Near-RT RAT-App. Furthermore, it is actively involved in closed-loop decision using the KPIs from the RAN. The main functionality of Near-RT RAT-App is to perform RAT specific configuration, control and data subscription over E2 interface with RAN (CU/DU components). **Relevance to NFV:** ETSI GR NFV-EVE 017 [i.16] reports about real time/ultra-low latency aspects in NFV-MANO. ETSI GR NFV-EVE 017 [i.16] investigates different delay points within an NFV deployment (e.g. VNF Delay, Virtual Link Delay), which are important to consider when designing low latency closed-loop control mechanisms. **Potential key issues for NFV:** See Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF. DSS synchronizes the MAC schedulers to avoid scheduling interference, this presumes time synchronization between the deployed VNFs (hosting Near-RT RIC). Operational requirements for 10 ms-1 s control loop latency are recommended to be supported by the hardware, virtualisation stack and the relevant network operations.
[i.47]-UC12	**UC12 Title:** NSSI Resource Allocation Optimization **Short Description:** This use case is about NSSI resource allocation optimization on the Non-RT RIC, and consists of the following steps: 1) monitor the radio network(s) by collecting data via the O1 interface, including performance measurements such as DL PRB used for data traffic, number of PDU Sessions requested to setup, etc.; 2) analyse the data to train the AI/ML model, and then determine the actions needed to add or reduce the resources for the NSSI at the given time, and location; 3) execute the actions to reallocate the NSSI resources by a) re-configuring the NSSI attributes via the O1 interface and b) updating the cloud resources via the O2 interface. **Relevance to NFV:** Clause 5.4 of ETSI GR NFV-IFA 037 [i.15] profiles the different NFV capabilities to support 3GPP Network Slicing. **Potential key issues for NFV:** None additional.

<table>
<tr><th>Source</th><th>Use Case</th></tr>
<tr><td>[i.47]-UC13 to UC15</td><td>UC13 Title: Local Indoor Positioning in RAN

Short Description: This use case focuses on indoor environments, where the positioning function regarding UE location, can be deployed as a positioning xApp in the Near-RT RIC. The positioning xApp computes the UE location and optional velocity based on the positioning measurement obtained via the E2 interface. Non-RT RIC can also be leveraged to provide the AI/ML model if machine learning based algorithm is selected for the positioning. Then, the trained positioning/ML model can be deployed to Near-RT RIC for real-time positioning inference. The E2 nodes are expected to provide positioning measurements to Near-RT RIC as required. The positioning xApp in Near-RT RIC can pass the positioning results to the SMO for further exposure.

UC14 Title: Massive MIMO SU/MU-MIMO Grouping Optimization.

Short Description: This use case is about adapting appropriate transmission methods (e.g. SU-MIMO, MU-MIMO) for each user.
Solution 1: When the optimization objective fails, SMO triggers the AI/ML model re-training, data analytics and optimization in Non-RT RIC. The Non-RT RIC uses the trained AI/ML model to decide the UE list for SU-MIMO group and MU-MIMO group by inferring the mobility, traffic model of each user. The Near-RT RIC retrieves SU/MU-MIMO grouping, and related RRC configurations from non-RT RIC. Moreover, it can send the configurations to E2 nodes. The RAN Nodes send proper RRC configuration accordingly for UE in both SU-MIMO and MU-MIMO groups, do SU-MIMO scheduling for UE in SU-MIMO group, and do SU-MIMO or MU-MIMO scheduling for UE in MU-MIMO group dynamically. The RAN nodes collect and report the performance measurement to SMO related to SU- MIMO and MU-MIMO spectral efficiency.
Solution 2: AI/ML model re-training, data analytics and optimization are performed in Non-RT RIC. Near-RT RIC provides the mobility and the traffic model prediction result over E2 interface. The E2 node makes final decision on SU/MU-MIMO grouping. E2 nodes can support the advanced MAC scheduling algorithms that decide to do SU-MIMO or MU-MIMO transmission for each user considering the user mobility and traffic model prediction.

Title: O-RAN Signalling Storm Protection
Short Description: This use case is about protecting the network from UE originated signalling storms. An xApp can be built with two main functionalities: a DDoS detection capability and a DDoS mitigation capability. The DDoS detection capability has two parts: the near real time detection, which takes place in a RIC xApp and a non-real time detection, which takes place at the SMO and relies on enrichment data originated in external system (e.g. 5G Core or OAM system). The DDoS Mitigation xApp can decide for each attach request if it can be accepted or rejected, or it can update an appropriate E2 policy when a UE is determined to be suspect. The mitigation functionality can support a set of actions, depending on the policy applied. These actions can be applied to a single UE, or a set of UEs.

Relevance to NFV: Minimum according to the description.

Potential key issues for NFV: See Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF.</td></tr>
<tr><td>[i.47]-UC16</td><td>UC16 Title: Congestion Prediction & Management

Short Description: In the CPM (Congestion Prediction & Management) architecture proposed, E2 node statistics are collected by the data collector of SMO over the O1 interface. After pre-processing data is shared with Non-RT RIC using a data sharing entity. Non-RT RIC will invoke the corresponding training model/application in an AI server inside or outside SMO. Machine learning models, can be used to learn and predict the future traffic. CPM rApp in Non-RT RIC will form the inference. Two options to mitigate cell congestion are:
a) option a: CPM rApp in Non-RT RIC transfers the inference to the CPM xApp in Near-RT RIC through A1 interface. Near-RT RIC can decide the mitigation solutions over E2 interface like switching to dual connectivity mode; and
b) option b: Non-RT RIC can directly mitigate the congestion with the help of O1 interface.
Some of the mitigation solutions can be switching to higher order MIMO or switching some of the users to Wi-Fi. The E2 nodes feedback can be sent to Non-RT RIC through O1 interface.

Relevance to NFV: Inference logic may consider O-Cloud reports for VNF-based deployments, besides UE related performance metrics analysis. VNF generic OAM can be also exploited as defined in ETSI GR NFV-EVE 019 [i.34].

Potential key issues for NFV: See Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF. Ensure enough naming and identification information is made available to ensure proper correlation between application and resource management views.</td></tr>
</table>

Source	Use Case
[i.47]-UC17	**UC17 Title:** Industrial IoT Optimization **Short Description:** Key features as below have been supported for IIoT in 5G system, such as data duplication and multi-connectivity enhancement, Time Sensitive Networking, and different prioritized transmission multiplexing. Based on O-RAN architecture some of these features can be optimized, e.g. PDCP duplication, Ethernet Header Compression (EHC). **Relevance to NFV:** ETSI GR NFV-EVE 017 [i.16] reports about real time NFV-MANO. **Potential key issues for NFV:** see Table A.3-3 for a discussion about deploying Near-RT RIC as a VNF. How data duplication and multi-connectivity concepts driven from an application can affect VNF operation and NS deployment are expected to be investigated. Operational requirements for time synchronization are expected to be supported by the hardware, virtualisation stack and the relevant network operations.
[i.47]-UC18	**UC18 Title:** BBU Pooling to achieve RAN Elasticity **Short Description:** This use case investigates scenarios where both O-CUs and O-DUs can be pooled, focusing on O-DU pooling. The O-DU resources for multiple cell sites are pooled at a single centralized location (the O-DU Pool). The Cloud Access Switch (CAS) at the O-DU Pool aggregates traffic from the multiple Front Haul gateways and routes it to the appropriate O-DU blade based on the load balancing requirement. The following classes of O-DU pooling have been defined: 1) Class 0: an O-RU is assigned to a single specific O-DU statically, and the traffic from the O-RU is not split into subsets that could be assigned to different O-DUs. With Class 0 pooling, re-assigning an O-RU to connect to a different DU would imply significant effort and is performed very infrequently during specific maintenance windows. 2) Class 1: n O-RUs are initially assigned to a single O-DU during a specific period of time, but the O-RUs can be re-assigned to different O-DU at any point of time via orchestration procedures with the help of SMO. This automated re-assignment can be triggered outside maintenance windows, based on various performance criterion or for load balancing. Like with Class 0 pooling, the traffic from the O-RU is not split into subsets that could be assigned to different O-DUs. 3) Class 2 pooling: n O-RUs are assigned to m O-DUs, and subsets of traffic from one O-RU are dynamically distributed (and load-balanced) across the O-DU resources within the O-DU pool using a cluster aware scheduler. Both Class 1 and Class 2 Pooling are enabled by the O-RAN Open Fronthaul with LLS 7 (option 7-2x split). **Relevance to NFV:** Different pooling models can be realized in a form of a policy (ETSI GR NFV-IFA 023 [i.42] and ETSI GR NFV-IFA 042 [i.43]). VLs are part of the NSD according to ETSI GS NFV-IFA 014 [i.44] which enable the designer of the network to provide requirements about the connectivity between constituents of the NS. Load balancing between distributed VNFCs is described in ETSI GR NFV-IFA 029 [i.49]. **Potential key issues for NFV:** enhance load balancing (e.g. VL capabilities or NFP) by incorporating cluster aware scheduler tuned by NFV-MANO to support Class 2 pooling for the case of VIM managed resources. Virtual CP concepts associated to container-based deployments supported by CISM can natively support this functionality.

The following Use Cases have been introduced by O-RAN WG1 "O-RAN Operations and Maintenance Architecture" [i.48].

Table A.2-2: ORAN WG1-OAM Use Cases Analysis

Source	Multi-vendor network provisioning in a mixed PNF/VNF environment
[i.48]-UC19	**UC19 Title:** O-RAN Service Provisioning **Description:** This use case assumes that the network elements are deployed based on an example Network Design using VNFs for centralized functions and PNFs for functions closer to the customer, so that the sequence calls for deployment of VNFs for the Near-RT RIC, O-CU-CP and O-CU-UP first followed by PNFs for the O-DU and O-RU. Note: RF functions are expected to always be realized as PNFs but the O-DU can be realized as a PNF or VNF; PNF is used as an example to illustrate the associated OAM flows. **Relevance to NFV:** as the use case is broad in scope, is relevant to all NFV-MANO FBs and operations. **Potential key issues for NFV:** None specific, NFV-MANO can support the intended functionality for virtualised NFs. However, mapping between the different NFV-MANO FBs and O-RAN management entities is a more general issue to be further analysed.
[i.48]-UC20	**UC20 Title:** O-RAN Measurement Data Collection **Description:** The use case focuses on the Non-RT RIC measurement data collection and consumption, the SMO can generate the Performance Management Job and perform the Performance Management Job control operations accordingly. The SMO can support the measurement data consumption by the Non-RT RIC. Specifications for collecting infrastructure measurements do not yet exist in O-RAN. **Relevance to NFV:** ETSI GS NFV-IFA 027 [i.45] specifies performance measurements that are exposed on various NFV-MANO reference points. ETSI GS NFV-TST 008 [i.46] specifies NFVI performance metrics reported to VIM. Application related performance monitoring metrics can be also collected by the VNF Metrics Aggregator VNF Generic OAM function according to ETSI GR NFV-EVE 019 [i.34]. **Potential key issues for NFV:** Mapping the different NFV-MANO FBs and O-RAN management entities is a more general issue to be further analysed.

A.3 Use cases from O-RAN WG6

The following use cases have been introduced by O-RAN WG6 in "Orchestration Use Cases and Requirements for O-RAN Virtualised RAN" [i.50].

Table A.3-1: ORAN WG6 Basic Use Cases Analysis

Source	O-Cloud Basic Use Cases
[i.50]-UC1	**UC1 Title:** O-Cloud Pre-Deployment Processing Use Case **Description:** The goal of this use case is to add an O-Cloud in SMO. The O-Cloud needs to be created before the SMO can interface with it. The Cloud Installation Project Manager issues a "service request" to the SMO to update its Inventory with the new O-Cloud. The Cloud Installation Project Manager also registers to the SMO the basic software for the O-Cloud. SMO generates O-Cloud ID, and creates an inventory record with the O-Cloud ID. **Relevance to NFV:** Use case concerns to management of infrastructure and their management system, and ETSI GS NFV-IFA 031 [i.51] is about NFV-MANO management, ETSI GR NFV-IFA 029 [i.49] is about PaaS, ETSI GS NFV-IFA 036 [i.52] concerns to management of Container Infrastructure Service (CIS) clusters. **Potential key issues for NFV:** Depending on the architectural mapping of SMO and O-Cloud to NFV-MANO FBs, interfaces specified by ETSI GS NFV-IFA 031 [i.51] can be exploited. However, in ETSI GS NFV-IFA 031 [i.51] there is no notion of lifecycle management of NFV-MANO entities or equivalents, instantiation workflows of the different entities of an NFV-MANO aware SMO/O-Cloud system are for further study.

Source	O-Cloud Basic Use Cases
[i.50]-UC2	**UC2 Title:** O-Cloud Platform Software Installation Use Case **Description:** The Use Case describes the deployment of the O-Cloud and installation of O-Cloud Platform Software on an O-Cloud Node. After the SMO is notified about new hardware on O-Cloud Nodes he loads O-Cloud Platform Software on the O-Cloud Node. During activation of the O-Cloud Nodes, the O-Cloud Management Plane activates IMS, and notifies the SMO of its availability. The IMS loads necessary basic software for O-Cloud onto the other O-Cloud Nodes and configures and activates one or more DMSs. **Relevance to NFV:** Hardware resources are part of NFVI and are discoverable/managed by VIM over Nf-Vi reference point. Resources reservation (e.g. Compute Host Reservation Management Interface) is part of Or-Vi defined in ETSI GS NFV-IFA 005 [i.39]. ETSI GS NFV-IFA 036 [i.52] concerns to management of container infrastructure service clusters. **Potential key issues for NFV:** The use case highlight specific OAM functionalities performed on "hardware", and "hardware management", and more specifically about software management for hardware aspects, which are not however addressed by ETSI NFV specifications. In addition, mapping of IMS functionality to NFVI/VIM/CISM operations, mapping of FOCOM functionality to NFVO and alignment of O2ims interface with Or-Vi are to be further analysed.
[i.50]-UC3	**UC3 Title:** O-Cloud Registration and Initialization Use Case **Description:** This Use Case describes the sequence for registration and initialization of the newly deployed O-Cloud. IMS initiates the O2 O-Cloud Registration Process using O2oam and O2ims services. The SMO queries the O-Cloud for its SW inventory, configures the O-Cloud using O2 and queries the O-Cloud for available DMS. For each DMS, SMO retrieves DMS capabilities using O-Cloud Inventory Update. **Relevance to NFV:** ETSI GS NFV-IFA 031 [i.51] about NFV-MANO management, which can be used for the registration aspects, and ETSI GS NFV-IFA 036 [i.52] about CIS cluster management, specifically concerning the aspects of registration and inventory of CIS cluster information. ETSI GS NFV-IFA 005 [i.39] specifies interfaces and operations related to information of consumable virtualised resources. It also specifies NFVI capacity management interfaces for capacity and usage reporting of physical resources. **Potential key issues for NFV:** Aspects of software management and inventory, beyond capacity information, of NFV-MANO and NFVI are not fully covered by ETSI NFV specifications. In addition, as DMS is closely related to VIM/CISM/CIR and VNFM operations, functionalities mapping and boundaries between them are to be further analysed.
[i.50]-UC4	**UC4 Title:** O-Cloud Inventory Update Use Case (DMS Example) **Description:** This Use Case describes the procedure for the SMO and O-Cloud to update inventory information about its type and current capabilities using O2 Infrastructure Inventory Services, including resource build configurations (also known as "flavours"), capacity, utilization and availability. **Relevance to NFV:** Capacity management services are handled by NFVO through Or-Vi reference point (ETSI GS NFV-IFA 005 [i.39]). **Potential key issues for NFV:** Similar to UC2.
[i.50]-UC5	**UC5 Title:** Hardware Infrastructure Scaling of O-Cloud Post Deployment **Description:** After the initial deployment of an O-Cloud, it may be necessary to scale up resources. In this use case, how the SMO will discover and manage a new O-Cloud Node that has been cabled and powered up to be part of an existing O-Cloud is examined. **Relevance to NFV:** Similar to UC2. **Potential key issues for NFV:** Similar to UC2.

Source	O-Cloud Basic Use Cases
[i.50]-UC6	**UC6 Title:** O-Cloud Platform Software Upgrade Use Case **Description:** It is examined how the SMO will upgrade a single O-Cloud. It is assumed that the software upgrade does not affect the IMS itself, and that the IMS can perform the software upgrade and migrating NF deployments from the affected O-Cloud Nodes without affecting active services. **Relevance to NFV:** Software upgrades are well investigated in ETSI GS NFV-IFA 011 [i.55]. Reliability considerations during software updates have been investigated by ETSI GS NFV-REL 006 [i.56] and ETSI GR NFV-REL 011 [i.38]. **Potential key issues for NFV:** interfaces for the software management of NFVI and NFV-MANO are unspecified. Functionality and requirements for the migration of VNF to support automatic migration strategies are also unspecified and are to be further analysed.

Table A.3-2: ORAN WG6 Network Function Basic Use Cases Analysis

Source	Network Function Basic Use Cases
[i.50]- UC7 to UC11	**UC7 Title:** Instantiate Network Function on O-Cloud **Description:** This Use Case is about instantiation of a Cloud-Native Network Function as a new deployment on an O-Cloud, and notification to the SMO once the instantiation of resources for the Network Function deployment has been completed. **UC8 Title:** Scale Out of NF. **Description:** This Use Case is about instantiating additional resources for NF deployments in order to expand the capacity of an NF. This results in horizontal elasticity and allows the NF to consume the resources it needs based on the level of demand based on network traffic. **UC9 Title:** Scale In of NF. **Description:** This Use Case describes how to delete NF deployments to reduce the capacity of an O-Cloud-based ME realizing an O-RAN NF, to improve efficiency. This supports horizontal elasticity and allows the NF to consume only the resources it needs based on the level of demand and network traffic. **UC10 Title:** Software Upgrade of NF. **Description:** This Use Case describes SMO-managed upgrade to the software of the Network Function. This covers the software deployment and its activation. Once activated the NF is configured by SMO similar to the NF deployment use case. **UC11 Title:** Terminate Network Function on O-Cloud. **Description:** This Use Case describes the termination of a Network Function on an O-Cloud, and notification to the SMO once the termination of resources for the Network Function deployment has been completed. **Relevance to NFV:** ETSI GS NFV-IFA 007 [i.53] and ETSI GS NFV-IFA 008 [i.54] cover all the functionality related to LCM of VNFs. Enhancements to support container-based solutions and the management of containerized workloads and MCIOs for VNFs have also been addressed. ETSI GR NFV-EVE 019 [i.34] studies also further enhancements to facilitate the management of VNFs using "VNF generic OAM" functions which can play a role as a consequence or during LCM procedures. **Potential key issues for NFV:** Mapping between NFV-MANO FBs and O-RAN entities is for further study.

Table A.3-3: ORAN WG6 Near-RT RIC/xAPP Use Cases Analysis

Source	Near-RT RIC/xAPP Use Cases
[i.50]- UC 12 and s13	**UC-12 Title:** Configure O-Cloud for Near-RT RIC. **Description:** This use case defines an optional procedure to configure a Kubernetes™ O-Cloud to support the Near-RT RIC function. The Near-RT RIC may require a Custom Resource to ensure proper lifecycle management of the near-RT RIC and its xAPPs. There are multiple ways to add a custom resource. For example, Custom Resource Definitions (CRD) is easy and requires no programming. Another possibility is to use API Aggregation. **UC-13 Title:** Deploy xAPP in Near-RT RIC. **Description:** xAPPs are developed independent of the near-RT RIC in which they execute. This Use case describes how an xAPP is instantiated and associated with a near-RT RIC. The LCM of xApp is performed by SMO and O-Cloud. According to the description, Near-RT RIC can be exposed as a CNF while a xAPP as a CNF Component (CNFC). SMO maps known RIC variables to xAPP variables to allow RIC and xAPP to interoperate. **Relevance to NFV:** ETSI GS NFV-IFA 011 [i.55] is about VNFD and VNF packaging specification, ETSI GS NFV-SOL 001 [i.60] provides stage 3 specification of TOSCA-based VNFDs. ETSI GR NFV-TST 006 [i.61] provides recommendations for partial VNF packaging, which are not however covered yet by all referred ETSI NFV specifications. The concept of custom resource definitions for containerized deployments has been considered by ETSI GS NFV-IFA 036 [i.52] in a conceptual level (see cluster enhancements, clauses 4.2.13 and C.2). Deploying near-RT as a VNF with real-time characteristics is related to issues like the ones described in ETSI GR NFV-EVE 017 [i.16] (for example usage of delay points). Different LCM cycles for each xAPP are expected to be also supported. For example, near-RT RIC could be deployed as a VNF Common Service according to ETSI GR NFV-IFA 029 [i.49] with a lifecycle independent from its consumers (the xAPPs exposed as consumer VNFs). The concept of VNF Bundles is described in ETSI GR NFV-IFA 044 [i.71]. **Potential key issues for NFV:** One key issue is related to the way new xAPPs could be onboarded to the NFV system and be associated with the near-RT RIC when both the near-RT RIC and the xApps are exposed as VNFs (or VNFCs). In case of bundling xAPPS with near-RT RIC, new xAPPS would imply an upgrade of the near-RT RIC VNF package; or alternatively, could be deployed using partial packaging, with references to the near-RT RIC VNF package to which they apply. However partial packaging is not yet supported by ETSI NFV specifications. The concept of Custom Resource Definitions (CRDs) for containerized deployments and API aggregation is discussed under the cluster enhancement features in ETSI GS NFV-IFA 036 [i.52], however standardization activity in ETSI NFV related to the specification of CRDs and the Aggregation API currently does not exist. Work on service mesh as defined in ETSI GR NFV-IFA 037 [i.15] and the mechanisms/solutions provided regarding the deployment of common platform functionality could be exploited regarding connecting near-RT RIC VNF and other components.

Table A.3-4: ORAN WG6 reconfiguration of VNFS Use Cases Analysis

Source	Reconfiguration of O-RAN Virtual Network Function(s)
[i.50]-UC14	**UC14 Title:** Reconfiguration of O-RAN Virtual Network Function(s). **Description:** This use case is about reconfiguration of O-RAN VNFs in order to affect the behaviour of the RAN. The trigger for reconfiguration could be any number of events such as non-real time traffic analysis by the Non-RT RIC, or input from non-RAN sources. In such cases the SMO will either be told or determine by its own analysis which VNFs need re-configuration, and in which order this is done. If a problem develops during re-configuration, then SMO may optionally invoke a fallback procedure. There may be a need for SMO to initially reroute traffic away from the affected VNFs and subsequently revert traffic to the original patterns. **Relevance to NFV:** VNF configuration interface over the Ve-Vnfm-vnf reference point, "VNF generic OAM" functions studied in ETSI GR NFV-EVE 019 [i.34], and "VNF configuration" currently under study in ETSI GR NFV-EVE 022 [i.59]. ETSI GR NFV-IFA 041 [i.57] analyses use cases and aspects regarding management data analytics. **Potential key issues for NFV:** While ETSI GR NFV-EVE 022 [i.59] studies the different VNF configuration options, and ETSI GR NFV-EVE 019 [i.34] provides additional solutions for VNF configuration using "VNF generic OAM" functions, how the VNF configuration procedures can jointly operate together with other procedures of orchestration and automation, and in particular, as a result of data analytics procedures, is to be further analysed.

Table A.3-5: ORAN WG6 Recovery Use Cases Analysis

Source	Recovery Use Cases
[i.50]-UC15 and UC16	**UC15 Title:** Network Function Deployment Level Reset Use Case. **Description:** When an O-RAN NF is experimenting some failure the SMO could request the O-Cloud platform to perform an NF Deployment level reset to fix the problem. The reset of an NF Deployment may be performed via different means depending on the type of resources conforming the NF Deployment (e.g. VM or container). For instance, both in VM-based and container-based NF Deployments, the capability to restart the VM or OS Container/Pod can be leveraged. This use case describes the procedure for the SMO to reset specific NF Deployments using the O2dms interface. **UC16 Title:** O-Cloud Node Level Reset Use Case. **Description:** When one or more O-RAN NF(s) is (are) experimenting some failure, and the error could not be fixed by using the O1 or O2dms interface services, the SMO could request the O-Cloud platform to perform an O-Cloud Node level reset to fix the problem. The reset of an O-Cloud Node may be performed via different means. For instance, the O-Cloud Node could be restarted (stop and start the node), or reallocating/replacing the O-Cloud Node to other O-Cloud infrastructure resources. This use case describes the procedure for the SMO to reset specific O-Cloud Nodes using the O2ims interface services. **Relevance to NFV:** ETSI GS NFV-IFA 007 [i.53] and ETSI GS NFV-IFA 008 [i.54] support operations for starting/stopping VNF instances. ETSI GS NFV-IFA 005 [i.39] and ETSI GS NFV-IFA 006 [i.40] offer operations for operating the state of virtualised resources, such as start/stop/reboot a VM; overall VIM and CISM operations are applied over the virtualised substrate for the case of exposing NFs as NFV-MANO managed VNFs. **Potential key issues for NFV:** management of hardware resources, which can include the operations needed for changing the operation state of NFVI resources is to be further analysed.

Table A.3-6: ORAN WG6 fault Use Cases Analysis

Source	Fault Use Cases
[i.50]-UC17 to UC19	**UC17 Title:** Alarm Subscription Use Case. **Description:** An alarm subscription allows for one or more consumers to receive alarm event notifications. This is accomplished by the potential subscriber(s) issuing a subscription to the publisher of alarm events. **UC18:** Title: Alarm Notification Use Case. **Description:** This use case supports Alarm Notification(s) by the alarm publisher (IMS). A condition occurs on an O-Cloud resource which causes the current alarm list to change. This triggers an evaluation of the alarm subscription criteria by the publisher (IMS). If deemed relevant by the subscription criteria, the alarm is sent to the subscription endpoint. **UC19 Title:** Alarm Query Use Case. **Description:** This use case supports Alarm Query (Alarm History) for O2ims. Alarm query allows for the SMO to query for specific kinds of alarms or groups of alarms based on the alarm query criteria. **Relevance to NFV:** ETSI NFV reference point specifications such as ETSI GS NFV-IFA 005 [i.39], ETSI GS NFV-IFA 007 [i.53], etc. define interfaces for fault management which include procedures related to alarm subscription, alarm notification, etc. regarding managed objects such as virtualised resources, VNF and NS. ETSI GS NFV-IFA 031 [i.51] defines fault management interfaces regarding the management of NFV-MANO. Ongoing work in ETSI GS NFV-IFA045 [i.58] aims at defining the information models for alarms and ETSI GR NFV-EVE 019 [i.34] is handling Notification Management and Logging management exploiting the concept of "VNF generic OAM functions". **Potential key issues for NFV:** Fault management of physical infrastructure in the NFVI is to be further analysed.

Annex B: Background information on Functional Splits

B.1 Introduction

The main idea behind the disaggregated RAN and functional splits concept is to decompose a single base-station into different entities, realized as network functions hosting parts of the overall functionality. These NFs can be deployed as VNFs, and the flexibility offered due to cloudification can be exploited to optimize the relevant procedures and lower costs.

The 5G RAN functions and the functional splits concept have been described in 3GPP TR 38.801 [i.6]. Detailed specification of the NG-RAN architecture and the different components for 5G are provided in ETSI TS 138 300 [i.7] and ETSI TS 138 401 [i.8].

According to ETSI TS 138 401 [i.8] the entities reassembling base station functionality are:

- Central Unit (CU): a logical node that includes the gNB functions excepting those functions allocated exclusively to the DU. CU controls the operation of DUs.
- Distributed Unit (DU): a logical node that includes, depending on the functional split option, a subset of the gNB functions. The operation of DU is controlled by the CU.

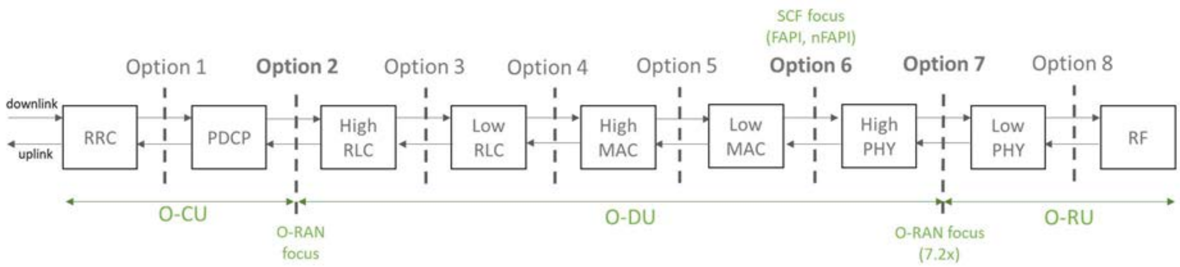

Figure B.1-1: Different Functional Split options (see Figure 11.1.1-1 in 3GPP TR 38.801 [i.6])

The referenced 3GPP specifications considers a DU and a Radio Unit (RU) as a single logical entity. A CU serves as an anchor between multiple DUs, while the interface between CU and DU is denoted as F1. A DU is the anchor point for one or multiple Radio Units (RUs) which (depending on the split) are responsible for Low-PHY and RF processing, like D/A and digital beamforming. Figure B.1-1 depicts the different split options and Table B.1-1 provides a short description of these split options according to 3GPP TR 38.801 [i.6].

Table B.1-1: Different split options description according to 3GPP TR 38.801 [i.6]

<table>
<tr><th>Option</th><th>Description</th><th>Note</th></tr>
<tr><td>Option 1</td><td>RRC is in the central unit. PDCP, RLC, MAC, physical layer and RF are in the distributed unit.</td><td rowspan="5">Splits 1 to 5 cover functionality reallocation above the MAC and have been considered as High Layer Splits (HLS).</td></tr>
<tr><td>Option 2</td><td>RRC, PDCP are in the central unit. RLC, MAC, physical layer and RF are in the distributed unit.</td></tr>
<tr><td>Option 3</td><td>Low RLC (partial function of RLC), MAC, physical layer and RF are in distributed unit. PDCP and high RLC (the other partial function of RLC) are in the central unit.</td></tr>
<tr><td>Option 4</td><td>MAC, physical layer and RF are in distributed unit. PDCP and RLC are in the central unit.</td></tr>
<tr><td>Option 5</td><td>RF, physical layer and parts of the MAC layer (e.g. HARQ) are in the distributed unit. Upper layer is in the central unit.</td></tr>
<tr><td>Option 6</td><td>Physical layer and RF are in the distributed unit. Upper layers are in the central unit.</td><td rowspan="3">Splits 6 to 8 are relevant to different splitting options below MAC and are considered as Low Layer Splits (LLS).</td></tr>
<tr><td>Option 7</td><td>Part of physical layer function and RF are in the distributed unit. Upper layers are in the central unit. Multiple realizations of this option are possible (split 7.3 splits High-PHY, only applies for downlink, split 7.2 between High-PHY and Low-PHY, split 7.1 splits Low-PHY).</td></tr>
<tr><td>Option 8</td><td>RF functionality is in the distributed unit and upper layer are in the central unit.</td></tr>
</table>

In principle a CU can host RAN functions above HLS and a DU can host RAN functions between LLS and HLS. RAN functions bellow LLS can be hosted by a RU. Compared to the description provided in the Table B.1-1 this refers to double splitting (one split option considered between a CU and a DU and another split option considered between a DU and a RU).

In O-RAN the corresponding entities are called O-CU, O-DU and O-RU respectively. In O-RAN split#2 is adopted between O-CU and O-DU while the focus stays on split#7.2 between O-DU and O-RU (fronthaul link). To lower bandwidth requirements and exploit the benefits of virtualisation, O-RAN further defined and developed split#7.2x in [i.70]. There are two variations named "Category A" and "Category B". In "Category A" O-RUs precoding in radio is not supported, while in "Category B" O-RUs precoding in radio is supported.

Finally, Small Cell Forum focus is on split#6. The FAPI interface between the MAC and the PHY is defined in SCF222 [i.25], while nFAPI is defined in SFC 225 [i.26] and it can be used for the MAC-PHY communication over the network.

Annex C: Change history

Date	Version	Information about changes
October 2021	0.0.1	Implementation of contributions NFVIFA(21)000751r1 and NFVIFA(21)000806r1 (approved at IFA#255)
January 2022	0.1.0	Implementation of contributions NFVIFA(21)0001032r2 (approved at IFA#265), NFVIFA(21)0001033r2 (approved at IFA#265), NFVIFA(21)0001034r3 (approved at IFA#268), NFVIFA(21)0001035r2 (approved at IFA#265) Additional rapporteur changes: Added informative references to IEEE1914.1 introduced by content in NFVIFA(21)0001033r2 and included an acronym fix
March 2022	0.2.0	Implementation of contributions: NFVIFA(21)0001069r1 (approved at IFA#270), NFVIFA(22)000037r1 (approved at IFA#272), NFVIFA(22)000038r1 (approved at IFA#272), NFVIFA(22)000140 (approved at IFA#275), NFVIFA(22)000141r1 (approved at IFA#275), NFVIFA(22)000142r1 (approved at IFA#275), NFVIFA(22)000143r1 (approved at IFA#275), NFVIFA(22)000144r2 (approved at IFA#277). Additional rapporteur changes updated references to Table A.3-3 and deleted relevant EN below Table A.2-1. Fixed hanging paragraph and headers numbering in section 5.2.1
May 2022	0.3.0	Implementation of contributions: NFVIFA(22)000251 (approved at IFA#280), NFVIFA(22)000260r1 (approved at IFA#280), NFVIFA(22)000261r3 (approved at IFA#280), NFVIFA(22)000306r1 (approved at IFA#284), NFVIFA(22)000307r1 (approved at IFA#284)
June 2022	0.4.0	Implementation of contributions: NFVIFA(22)000318 (approved IFA#285), NFVIFA(22)000319r2 (approved IFA#286),NFVIFA(22)000329 (approved IFA#286), NFVIFA(22)000356 (approved IFA#287), NFVIFA(22)000364 (approved IFA#288), NFVIFA(22)000368 (approved IFA#288), NFVIFA(22)000325r3 (approved IFA#288), NFVIFA(22)000365r1(approved IFA#288)
July 2022	0.5.0	Implementation of contributions: NFVIFA(22)000326r4 (approved IFA#291), NFVIFA(22)000416r1 (approved in IFA#292), NFVIFA(22)000417r2 (approved in IFA#292), NFVIFA(22)000420r3 (approved in IFA#292), NFVIFA(22)000369r4 (agreed in IFA#292), NFVIFA(22)000436 (agreed IFA#292)
August 2022	0.6.0	Implementation of contributions: NFVIFA(22)000470 (approved IFA#294), NFVIFA(22)000490r2 (approved in IFA#295), NFVIFA(22)000491r1 (approved in IFA#295), NFVIFA(22)000549 (approved in IFA#296), NFVIFA(22)000574 (agreed IFA#296)
September 2022	0.7.0	Implementation of contributions: NFVIFA(22)000581r1 (approved IFA#298), NFVIFA(22)000678r1 (approved IFA#301), NFVIFA(22)000679r3 (approved IFA#301), NFVIFA(22)000680 (approved IFA#301), NFVIFA(22)000681r2 (approved IFA#301), NFVIFA(22)000695r1 (approved IFA#301), NFVIFA(22)000682r1 (approved IFA#304), NFVIFA(22)000684r2 (approved IFA#303), NFVIFA(22)000685r1 (approved IFA#303), NFVIFA(22)000686r3 (approved IFA#303)
October 2022	0.8.0	Implementation of contributions: NFVIFA(22)000683r3 (approved IFA#305), NFVIFA(22)000749 (approved IFA#306) NFVIFA(22)000750 (approved IFA#306), NFVIFA(22)000751 (approved 3IFA#06) NFVIFA(22)000752r1 (approved in IFA#306), NFVIFA(22)000753r1 (approved in IFA#306), NFVIFA(22)000754 (approved IFA#306), NFVIFA(22)000764r2 (agreed IFA#306)
November 2022	0.9.0	Implementation of contributions: NFVIFA(22)000784 (approved ifa#308), NFVIFA(22)000787 (approved ifa#308), NFVIFA(22)000788 (approved ifa#308), NFVIFA(22)000789 (approved ifa#308), NFVIFA(22)000800 (approved ifa#308), NFVIFA(22)000809 (approved ifa#309), NFVIFA(22)000806 (approved ifa#309), NFVIFA(22)000823r2 (approved ifa#309) Additional rapporteur changes further editorial cleanup in Table 5.2.2.1.4-2
December 2022	0.10.0	Implementation of contributions: NFVIFA(22)000851 (approved ifa#312), NFVIFA(22)000865 (approved ifa#312) NFVIFA(22)000927r1 (approved IFA#313),NFVIFA(22)000928r1 (approved IFA#313), NFVIFA(22)000929r1 (approved IFA#313),NFVIFA(22)000930r1 (approved IFA#313), NFVIFA(22)000931 (approved IFA#313), NFVIFA(22)000932 (approved IFA#313), NFVIFA(22)000933 (approved IFA#313),NFVIFA(22)000934 (approved IFA#313), NFVIFA(22)000935 (approved IFA#313),NFVIFA(22)000941 (approved IFA#313) NFVIFA(22)000960 (approved IFA#315). Rapporteur action: deleted clause 6.8 because it was empty with no content.

Date	Version	Information about changes
June 2024	V5.1.2	Initial ed521 draft version created from published version 5.1.1.
September 2024	V5.1.3	Implementation of contributions: - NFVIFA(24)000509r1_IFA046ed521_vlan_configuration_methods - NFVIFA(24)000510_IFA046ed521 NFVI gateway mapping to O-Cloud gateway - NFVIFA(24)000513r1_FEAT27_IFA046_descriptors_updates - NFVIFA(24)000515r1_FEAT27_IFA046_cluster_descriptors

History

Document history		
V5.1.1	May 2023	Publication
V5.2.1	December 2024	Publication