5G-SOLUTIONS for European Citizens

D1.2A Cross-domain Service Orchestration and Management Challenges Analysis (v1.0)

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[1] According to 5G Solutions Quality Assurance Process:

1 month after the Task started: Deliverable outline and structure
3 months before Deliverable's Due Date: 50% should be complete
2 months before Deliverable's Due Date: 80% should be complete
1 months before Deliverable's Due Date: close to 100%. At this stage it sent for review by 2 peer reviewers
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Glossary of Acronyms

Abbreviation / Term	Description
3GPP	3rd Generation Partnership Project
5G	Fifth Generation
5GEx	5G Exchange
API	Application Programming Interface
ASQ	Assured Service Quality
B2B	Business to Business
BSS	Business Support Systems
C2B	Customer to Business
CAPEX	Capital Expenditure
CBAM	CloudBand Application Manager
CBND	CloudBand Network Director
CEE	Cloud Execution Environment
CN	Core Network
CSC	Customer Service Centre
CSMF	Communication Service Management Function
CUPS	Control User Plane Separation
DC	Data Center
E2E	End-to-End
eMBB	Enhanced Mobile Broadband
EMS	Element Management System
eMTC	Enhanced Machine Type Communication
ENM	Ericsson Network Manager
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FhG	Fraunhofer Group
G-VNFM	Generic VNFM
HSS	Home Subscriber Server
IoT	Internet of Things
IP	Internet Protocol
ISG	Industry Specification Group
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LCM	Life Cycle Management
LL	Living Lab
LTE	Long Term Evolution
M2M	Machine to Machine
MANO	Management and Network Orchestration
MdO	Multi-domain Orchestration
MDSO	Multi-domain Service Orchestrator

MEC	Multi-access Edge Computing
MioT	Massive Internet of Things
MME	Mobility Management Entity
MPLS	Multi Protocol Label Switching
NB	Narrowband
NBI	North Bound Interface
NCIR	Nokia Cloud Infrastructure Real-time
NEI	Network Element Interface
NF	Network Function
NFV	Network Function Virtualisation
NFVIaas	NFV Infrastructure as a Service
NFVO	NFV Orchestrator
NS	Network Service
NSA	Non-standalone
NSaaS	Network Security as a Service
NSD	Network Service Descriptor
NSG	Network Service Graph
NSI	Network Service Interface
NSMF	Network Slice Management Function
NSSI	Network Slice Subnet Instance
NSSMF	Network Slice Subnet Management Function
NST	Network Slice Template
ONAP	Open Networking Automation Platform
OPEX	Operational Expenditure
OSM	Open Source MANO
OSS	Operations Support Systems
PCRF	Policy and Charging Rules Function
PGW	Public Gateway
PNF	Physical Network Functions
PoP	Point of Presence
QoE	Quality of Experience
RAN	Radio Access Network
REST	Representational state transfer
SBA	Service Based Architecture
SDN	Software Defined Network
SDR	Software Defined Radio
SFC	Service Function Chain
SGW	Serving Gateway
SIM	Subscriber Identity Module
SLA	Service Level Agreement
SOM	Service Order Management
SON	Self-organizing Network

SP	Service Provider
SRS	Software Radio System
SST	Slice/Service Type
TOSCA	Topology and Orchestration Specification for Cloud Applications
TR	Technical Report
UC	Use Case
UDR	Unified Data Repository
UE	User Equipment
uRLLC	Ultra Reliable Low Latency Communication
VACS	Value added Connectivity as a Service
VIM	Virtualised Infrastructure Manager
VNF	Virtual Network Function
VNFaaS	VNF as a Service
VNFM	Virtual Network Virtualisation Manager
VPN	Virtual Private Network
WAN	Wide Area Network
WP	Work Package
XML	Extensible Markup Language

1 Executive summary

The 5G-PPP vision towards the next-generation networks & services, offering ubiquitous and performant access in line with the different service needs, comes with a set of requirements that span across the infrastructure and management domains, including performance, dynamicity, and programmability. In this context, management and orchestration become very important features for enabling the correct support for verticals. Different classes of 5G services must be orchestrated on top of 5G infrastructures that come with different capabilities and different exported network functions, while considering concepts such as virtualization and software driven, programmable capabilities. Rather than setting up and managing services in network domains separately and manually, the expectation of 5G networks is that cross-domain E2E services will be provisioned, deployed, managed, and retired in a DevOps manner, with minimal manual intervention. In addition, where slicing capabilities are exposed by network domains, those E2E services will be deployable on network slices and managed accordingly.

5G-SOLUTIONS is an ICT-19 H2020 project that proposes to address issues related to the correct support of 5G verticals on top of 5G platforms and also validating KPIs for the respective verticals. Our proposed use cases will be deployed on two ICT-17 frameworks, namely 5G EVE and 5G-VINNI. This current deliverable is part of the first set of deliverables and has as its main focus the analysis of challenges for orchestration for the 5G-SOLUTIONS Use Cases.

With this focus in mind, this deliverable brings together the following aspects: (1) existing standards and solutions in the area of service orchestration, (2) orchestration solutions in the underlying ICT-17 platforms, (3) Use Case requirements for orchestration support.

Based on these three aspects, we present our initial understanding and planning for the integration between 5G-SOLUTIONS and the ICT-17 platforms, including boundaries and planned integration strategy. In addition, we also describe our planned innovation in the area of orchestration optimization based on Machine Learning techniques, including predictive slicing and optimisations based on correlations between vertical industry requirements and telecom network data.

It is worth mentioning that this deliverable presents our initial plans in these areas, based on the discussions during the first five months of the project, and will be expanded as our understanding of Use Case requirements and synergies of technologies evolves.

The key achievements presented in this deliverable are:

- Exploration of related 5G orchestration concepts both in standards and in existing implementations;
- Presentation of underlying 5G platforms, especially in terms of capabilities and their existing support for orchestration;
- Initial understanding of the challenges for the 5G-SOLUTIONS orchestration, boundaries between the underlying 5G platforms and 5G-SOLUTIONS for orchestration purposes, as well as integration points. This includes the analysis of Use Case platform deployments and our own classification of Use Cases based on the support for orchestration required in 5G-SOLUTIONS;
- Innovation themes planned in terms of ML-based techniques for supporting optimisations of 5G service orchestration.

2 Introduction

The main purpose of this deliverable is to summarise the results of the work conducted in Task 1.2 during the first 5 months of the project. The major focus is on the 5G-SOLUTIONS service orchestration challenges to support the vertical Use Cases described in deliverable D1.1. Since 5G-SOLUTIONS relies on deployments on top of platforms developed during ICT-17 projects, this deliverable is also the first deliverable to present these platforms in terms of capabilities, support for 5G verticals, as well as orchestration solutions. In particular, we present 5G-EVE (Italy), 5G-VINNI (Greece) and 5G-VINNI (Norway), including their features that are relevant to orchestration and management, as well as to the integration with 5G-SOLUTIONS.

The Use Cases described in deliverable D1.1 have been analysed with respect to their plans in terms of deployment on the ICT-17 platforms, as well as in terms of orchestration requirements support needed from 5G-SOLUTIOS. We have created a taxonomy taking into account the level of support needed to orchestrate these Use Cases. Bringing together the Use Case taxonomy with the ICT-17 platforms features analysis, we have developed our initial understanding of the boundaries and integration points between the ICT-17 platforms 5G EVE ad 5G-VINNI and the service orchestration solution in 5G-SOLUTIONS.

The core sub-tasks of Task 1.2, as presented in this deliverable, are:

- Understanding existing solutions in the area of orchestration, including standards and related work, as well as challenges to implementing multi-domain orchestration;
- Describing the underlying platforms (5G EVE and 5G-VINNI) capabilities and features, support for ICT-19 projects, as well as their orchestration solutions (existing and planned);
- Analysing planned deployments for the 5G-SOLUTIONS Use Cases and their support for orchestration in 5G-SOLUTIONS;
- Describing challenges to developing the 5G-SOLUTIONS service orchestration;
- Presenting our initial understanding and plans for integration between 5G-SOLUTIONS and the ICT-17 platforms, as well as boundaries in terms of orchestration;
- Describing our initial starting point for service orchestration in 5G-SOLUTIONS, namely the Nokia orchestrator CBND, as well as mechanism for extending the Nokia orchestrator into a multi-domain orchestrator that interacts with the underlying platforms

This deliverable is a starting point in developing our service orchestration in 5G-SOLUTIONS. As such, it serves as a reference point for other Tasks and WPs in 5G-SOLUTIONS, and it will be extended in its next version. At the same time, we believe it is a good reference point for people external to 5G-SOLUTIONS, to understand the main challenges towards 5G vertical industry support, especially in the context of H2020 projects roadmap.

2.1 Mapping to Project Outputs

This section maps the 5G-Solutions Grant Agreement commitments, both within the formal Deliverable and the Task descriptions, against the project's respective outputs and work performed.

Sets the stage for Objective 2, builds onto the work on T1.1 and bridges the verticals point of view with the platforms point of view.

Table 2-1: Adherence to 5G-SOLUTIONS GA Deliverable & Tasks Descriptions

Project GA Component Title	Project GA Component Outline	Respective Document Sections(s)	Justification
TASKS			
Task 1.2: Analysis of challenges and requirements for 5G E2E multi, concurrent and cross-domain service management and orchestration including interaction with ICT-17 facilities	*The evolution of NFV is faced with the reality that the initial MANO architecture is not adequate to address the service providers' underlying requirement to instil the agility of DevOps principles. Rather than setting up and managing services in network domains separately and manually, the expectation on 5G networks is that cross- domain E2E services will be provisioned, deployed, managed, and retired in a DevOps manner, with minimal manual intervention. In addition, where slicing capabilities are exposed by network domains, those E2E services will be deployable on network slices. We will also explore the integrity of OSS features being kept under cross data correlation from low level virtualisation and the vertical industry requirement, which is agnostic of the underlying telecom infrastructure. The core focus of Task 1.2 is to explore the above challenges in the context of a framework that aligns with industry standards, yet is innovative and provides leadership beyond what is included today in current approaches.*	*Sections 3 - 7*	*Section 4 presents the UC deployment plans, that will influence the need for orchestration support. Section 5, following the SoA analysis of Section 3, includes an analysis of the current state of orchestration in the underlying ICT-17 platforms. Section 6 brings together the verticals point of view, through their expressed orchestration support requirements with the underlying platforms solutions, combined with the Nokia CBND proposed starting point. Section 7 presents initial plans for ML-based optimisations for service management and orchestration.*
	End-to-end service provisioning with slicing capabilities: *In this sub-task, we shall design how to leverage the NOKIA orchestrator to support end-to-end inter-domain lifecycle management. We will make use of the*	*Section 6*	*Section 6 presents our initial investigation in terms of using the NOKIA orchestrator for end-to-end lifecycle*

	*available plugin interfaces to extend the functionality to allow management of closed loop services for network slicing. In addition, the plugins implementing the interfaces towards the network domain orchestrators will be designed to allow configuration and monitoring of the virtual and physical resources that are providing the network slices that the end-to-end services are running on. We will also investigate the issue of monitoring the verticals SLAs and analyse the data coming from the verticals to allow for efficient orchestration of the end-to-end services. The interaction and integration with the ICT-17 facilities (south-bound to 5G-SOLUTIONS) will also be accommodated, as well as north-bound to customer facing systems or portal*s.		*orchestration, as well as the possible integration points with the underlying ICT-17 platforms.*
	Proposed solutions of slicing issues between core and access in 5G mobile networks: *The radio and core networks differ in the manner in which they implement slicing and in which such slices are configured. We will examine how services using network slices across the RAN and core networks can be provisioned and managed transparently. We will investigate how common slices can be created across the two domains, and how traffic can be routed and shaped between these slice fragments whilst preserving a common view of the end to end slide. In addition, we will investigate how services running across slices can be optimised using predictive optimisation - we will try to understand how common slicing patterns can be predicted, in an effort to formulate a set of training patterns that can be used to train predictive and proactive configuration changes.*	*Sections 6&7*	*Section 6 discusses the Nokia CBND orchestrator capabilities for end-to-end orchestration and our initial plans on extending these capabilities. Section 7 presents our initial plans in terms of automated optimisations to end-to-end orchestration, as well as requirements on the experiments data for implementing the proposed methods.*
DELIVERABLE			

<table>
<tr><td colspan="4"><u>D1.2A: Cross-domain orchestration and management challenges analysis v1.0</u>
Interim (v1.0) report defining the management of the life cycle of services running across different 5G mobile networks including solutions for slicing and virtualisation beyond MANO</td></tr>
<tr><td colspan="4">PROJECT OBJECTIVE</td></tr>
<tr><td>Objective 2:
Technology development and readiness</td><td>To analyse key challenges for performing multi and cross-domain service provisioning leveraging slicing and virtualisation technologies</td><td>Sections 3-7</td><td>Key challenged in end-to-end and multi-domain orchestration in the context of virtualization and slicing are presented in Section 3. Challenges related to integration with the ICT-17 platforms are presented in Section 6, following the description of ICT-17 platforms orchestration solution in Section 5. Sections 4 and 6 bridge the network point of view with the Use Case point of view, while Section 7 presents benefits to adopting ML-based techniques for optimisations and proposes directions of research in this area.</td></tr>
</table>

2.2 Deliverable Overview and Structure

This deliverable is organized as follows:

- Section 3 discusses the concepts supporting service orchestration in 5G, as they appear in the standards, as well as introducing existing implementations in this area;
- Section 4 presents the 5G-SOLUTIONS Use Cases' plans for deployment on top of the ICT-17 platforms 5G EVE and 5G-VINNI Greece and 5G-VINNI Norway;
- Section 5 introduces the ICT-17 underlying platforms, with their capabilities, support for 5G verticals and plans for orchestration;
- Section 6 discusses the challenges for service orchestration in 5G-SOLUTIONS, as well as our initial understanding of boundaries and integration points between 5G-SOLUTIONS and the ICT-17 platforms and our starting point for 5G-SOLUTIONS orchestration, the Nokia CBND orchestration solution;

- Section 7 presents the initial plans in terms of service and orchestration optimisations based on Machine Learning techniques;
- Section 8 summarizes the work done in Task 1.2 and presents our conclusions, as well as plans for extensions for the next version of the deliverable.

3 Multi-Domain Service Orchestration & Management

Service orchestration is the execution of the operational and functional processes involved in designing, creating, and delivering an end-to-end service.

Traditionally, these processes were handled by domain-specific, siloed operational support systems and tools built for static environments. 5G systems, though, come with a different architectural view. 3GPP defines in TS 23.501 [1] the 5G architecture as a Service Based Architecture (SBA). In the SBA, the system functionality is achieved by a set of Network Functions (NFs) that provide services to other authorized NFs to access their services. The SBA aims to decouple end-user services from the basic network and the platform infrastructure, in order to speed up the network deployment and thus the service delivery. This creates a more dynamic environment, in which the different NFs must be orchestrated. In parallel to this, the introduction of software driven capabilities and virtualization means that service orchestration must take into account a much more dynamic and complex service provider environment.

This section elaborates on the main concepts and components involved in service orchestration, including network slicing and NFV orchestration as defined by today's standards bodies, as well as application-level end-to-end service orchestration. A final subsection details existing work in these directions, both in the industry and in research projects.

3.1 Network Function Virtualisation (NFV) Management & Orchestration

NFV technology was initiated in 2012 by ETSI NFV ISG, allowing for network services to be provided in virtual machines working in a cloud infrastructure, where each virtual machine can provide a different function (e.g., load balancing, deep packet inspection, firewall, etc.) This technology comes with the main advantages of:

- Flexibility in the allocation of NFVs in general-purpose hardware;
- Rapid implementation and deployment of new network services;
- Support for multiple versions of services and multi-tenancy scenarios;
- Reduction of CAPEX & OPEX through efficient energy usage and automation of operational processes.

However, this technology also introduces a lot of dynamicity, which adds a new layer of complexity to the management and orchestration of network services.

3.1.1 NFV MANO

ETSI defined a standard approach to management and orchestration of NFVs, the NFV MANO. The main focus of NFV MANO is to allow flexible onboarding, simplifying the rapid spin-up and lifecycle management of virtual network components.

Figure **3-1** Illustrates the architecture of NFV MANO and its interfaces. As can be seen, the MANO framework consists of three main blocks:

- **NFV Orchestrator**, responsible for onboarding of network services and VNF packages; network service lifecycle management; validation and authorization of NFV infrastructure (NFVI) resource requests, as well as monitoring of NFVI for operation & performance monitoring purposes;
- **VNF Manager**, whose main role is to oversee the lifecycle management of VNF instances;
- **Virtualized Infrastructure Manager (VIM)**, which controls and manages the interaction of VNFs with the NFVI resources (e.g., resource allocation, deallocation, inventory, etc.).

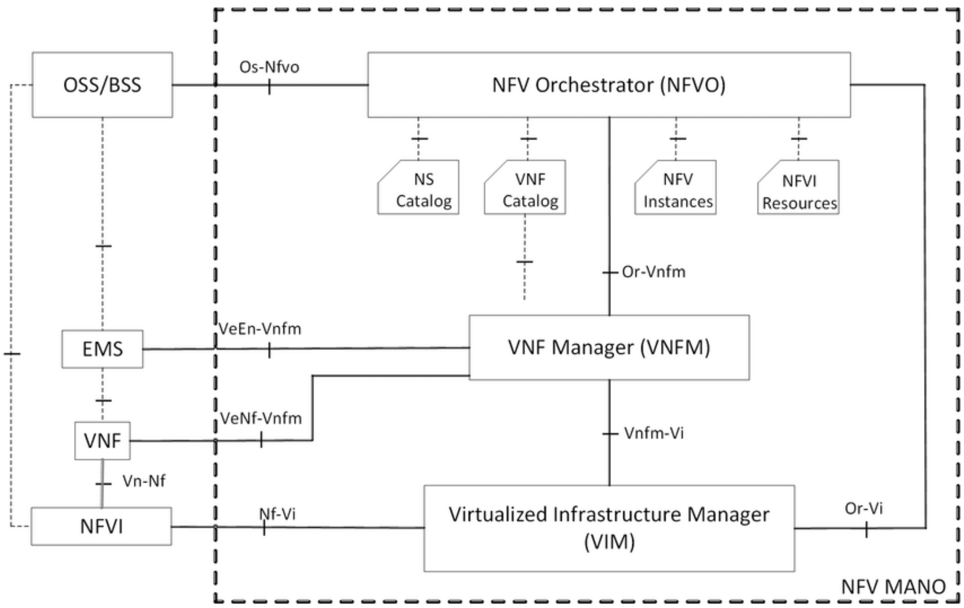

Figure 3-1: The NFV MANO architectural framework [2]

As pointed out by ETSI [3] , NFV MANO is VNF application and Network Service function agnostic (i.e., what relates directly to what the VNF application / Network Service does is out of scope for NFV MANO).

Hence, ETSI NFV does not address:

- Application-aware Network Service configuration and management,
- VNF application layer configuration and management.

Examples of reference open-source implementations of NFV MANO are:

1) **OSM (Open Source MANO):** [4] is an ETSI-hosted, open source project that is developing an NFV MANO platform aligned with the ETSI NFV information models and that meets the requirements of production for NFV networks. One of its main goals is to promote the integration between standardisation and open source initiatives. The OSM architecture has a clear split of orchestration functions between resource and service orchestrators. In its third release, it

integrates open source software initiatives such as Riftware as network service orchestrator and GUI, OpenMANO as resource orchestrator (NFVO), and Juju 5 server as configuration manager (G-VNFM). The resource orchestrator supports both cloud and SDN environments. The service orchestrator can provide VNF and NS lifecycle management and consumes open information and/or data models, such as YANG. The MANO architecture covers only a single administrative domain.

2) **OpenBaton**: [5] is an open source reference implementation of the NFVO based on the ETSI NFV MANO specification and the TOSCA [6] standard. It comprises of an easily extensible platform for supporting new functionalities and existing platforms. Some of the most important features and components are the NFVO following ETSI MANO specification, a generic VNFM to deploy Juju charms or OpenBaton VNF packages, a marketplace integrated within the Open Baton dashboard, a driver mechanism supporting different types of VIMs without having to re-write anything in the orchestration logic, and an event engine for the dispatching of lifecycle events execution.
3) **Tacker**: [7] is an official OpenStack project started in 2016, building a generic VNFM and NFVO to deploy and operate Network Services and VNFs on a cloud/NFV infrastructure platform such as OpenStack. It is based on the ETSI MANO architectural framework and provides a functional stack to orchestrate E2E network services using VNFs. Tacker also performs mapping to service function chain (SFC) and supports auto scaling and TOSCA NFV profile using heat-translator. Tacker’s components are directly integrated into OpenStack and thus, provide limited interoperability with other VIMs. Taker also combines the NFVO and VNFM into a single element and it works in single domain environments, offering limited design flexibility.

There are also other choices for orchestrators that are not necessarily aligned with NFV MANO. One of these is ONAP. As a key contributor in the Service and Network Orchestration area, **ONAP** [8] is a platform for real-time, policy-driven orchestration and automation of PNFs and VNFs that will enable rapid automation of new services and support complete lifecycle management. ONAP was introduced to address the rising need for a common automation platform for telecommunication, cable, and cloud service providers, leverage existing investments to deliver differentiated network services on demand and keep up with the scale and cost of manual changes required to implement new service offerings.

ONAP decouples details of specific services and technologies from the common information models, core orchestration platform, and generic management engines. It also leverages cloud-native technologies including Kubernetes to manage and rapidly deploy ONAP platform and related components.

Many components of the ONAP architecture are outside the scope of NFV MANO, but they complement the NFV MANO functionality, as shown in the ETSI-published Figure **3**-**2**, where the NFV MANO blocks are shown in dark blue over the ONAP components that implement that functionality. However, while the functionality might be similar, the refence points between components are not the same. A loosely coupled end-to-end architecture with minimum dependencies and standard APIs between components is listed as a possible path leading to more convergence between MANO NFV and ONAP.

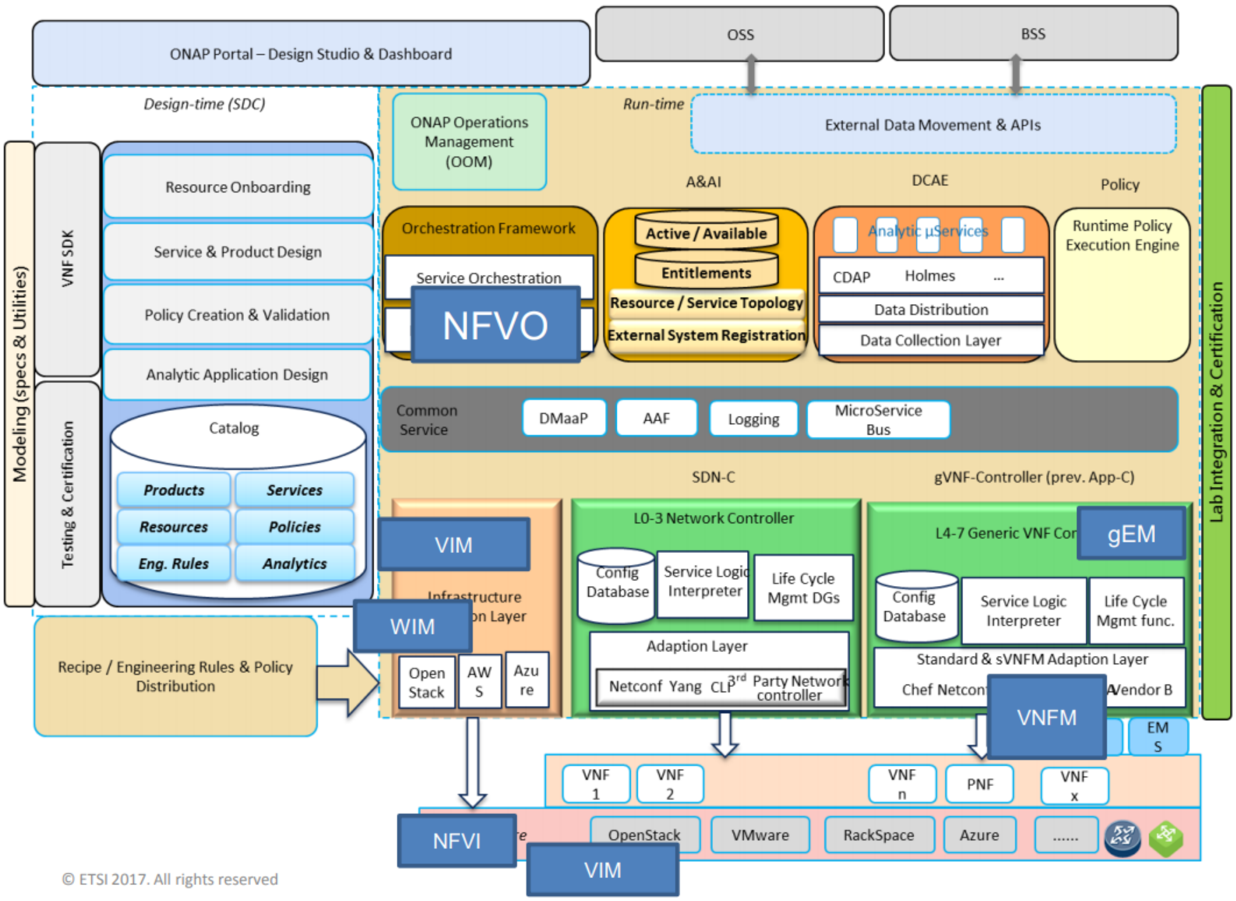

Figure 3-2: ETSI MANO NFV vs ONAP architecture [3]

3.2 Network Slicing

The NFs are used and composed for providing the required services towards the vertical through Network Slicing. Network Slices are defined by 3GPP as complete logical networks (providing Telecommunication Services and Network Capabilities) spanning over multiple technological domains (e.g., Access Network, Core Network). Network slicing support is part of the 5G SBA, as defined by 3GPP.

Network slicing is used in the context of the SBA to create dedicated logical network connections that can be built upon a common infrastructure. The requirements for 5G network slicing following 3GPP TR 22.891 [9] provide a high-level view and direction for the next generation work of 3GPP with respect to network slices. These requirements include:

- The operator shall be able to create and manage network slices that fulfill required criteria for different market scenarios;
- The operator shall be able to operate different network slices in parallel with isolation that for example, prevents one slice's data communication to negatively impact services in other slices;

- The 5G system shall have the capability to conform to service-specific security assurance requirements in a single network slice, rather than the whole network;
- The 5G system shall have the capability to provide a level of isolation between network slices to confines a cyber-attack to a single network slice;
- The operator shall be able to authorize third parties to create, manage a network slice configuration (e.g., scale slices) via suitable APIs, within the limits set by the network operator;
- The 5G system shall support network slice elasticity in terms of capacity with no impact on the services of this slice or other slices;
- The 5G system shall be able to change the slices with minimal impact on the ongoing subscriber's services served by other slices: specifically, of new network slice addition, removal of existing network slice or update of network slice functions or configuration;
- The 5G System shall be able to support end-to-end resource management for a network slice.

Each network slice is an isolated end-to-end network, tailored to support requirements of services from vertical industries. As such, three types of Standard Slice / Service Types (SST) have been specified by 3GPP in TS23.501 (see Table **3**-**1**), in line with the three major 5G-supported service types, as described in deliverable D1.1. Non-standard network slices are also supported in a 5G architecture.

Table 3-1: Standardised SST values

Service/ Slice Type	SST Value	Comments
eMBB	1	Slice type suitable for handling 5G enhanced mobile broadband
URLLC	2	Slice type suitable for handling ultra-reliable low latency communication
MIoT	3	Slice type suitable for handling massive IoT

A realization of a network slice is a network slice instance (NSI), as defined in 3GPP TR 28.801 [10]. An NSI includes all functionalities and resources necessary to support a certain set of communication services, thus serving a certain business purpose. An NSI is composed by Network Functions (NFs – either Virtual Network Functions VNFs or Physical Network Functions PNFs), as shown in Figure **3**-**3**. The connectivity between different NFs is described by the Network Slice Template (NST).

The information model and the relationships between the different entities is presented below in Figure **3**-**3**.

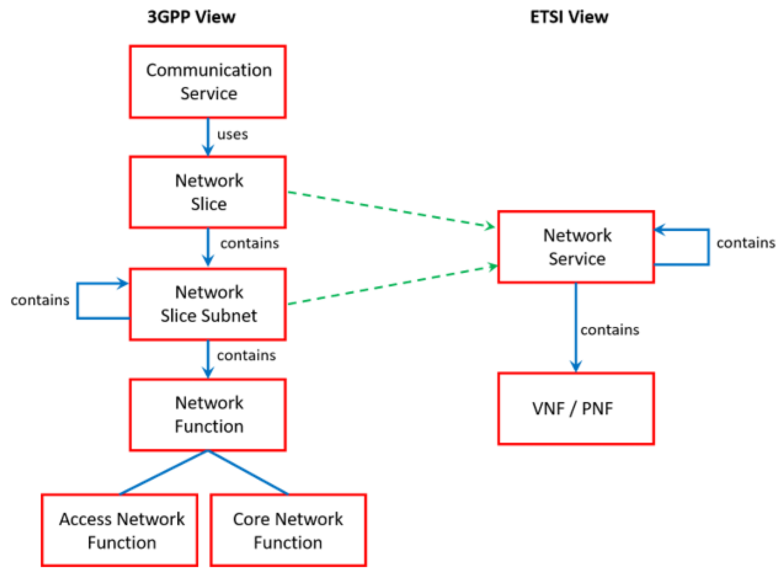

Figure 3-3: Relationships between 3GPP and ETSI Information Models

Therefore, a defined network slice provides information about:

- The type of service it supports, as defined in SST,
- The VNFs/PNFs it is comprised of,
- Connectivity between NFs as defined in NST.

3.3 Multi-domain Service Orchestration

In order to achieve the 5G goals in terms of dynamicity, performance and ease of management, an end-to-end orchestration is required through the multiple technological domains, such as RAN, CN, MEC, etc., as well as possibly through multiple geographical and/or operator domains. The challenge, however, is that traditionally, service orchestration is a very manual process and depending on how components are orchestrated in different technologies, operators or domains, they each may follow different standards and APIs. For example, slicing in the RAN domain considers issues such as underlying RAT and different configurations of RAN resources, whereas slicing in the CN domain is closer to the concepts of SDN and virtualisation.

Multi-domain orchestration can be interpreted in two ways:

- Multi-domain as multi-technology, which means orchestrating resources across multiple technology domains, e.g., RAN, CN, MEC, etc. in a single geographical domain and operator. As there are multiple resource management and orchestration frameworks for resource virtualisation and automated provisioning of resources and services, it is necessary to unify management and orchestration of different technology domains to realise end-to-end software defined infrastructures suitable to host 5G services.

- Multi-domain as multi-operator, which means orchestrating resources and/or services using domain orchestrators belonging to multiple administrative domains. In order to realise end-to-end orchestration, interaction between multiple infrastructure providers must be addressed at different levels, including resource management and orchestration, service management and orchestration and inter-operator Service Level Agreement (SLA) fulfillment.

For example, Figure **3**-**4** shows an example of end-to-end network slices across the RAN and CN domains, creating the logical slice across the RAN resources, as well as the NFs in the CN. The correct pairing function between RAN and CN slices must be in place, as well as orchestrators that can deal with the individual domains' characteristics.

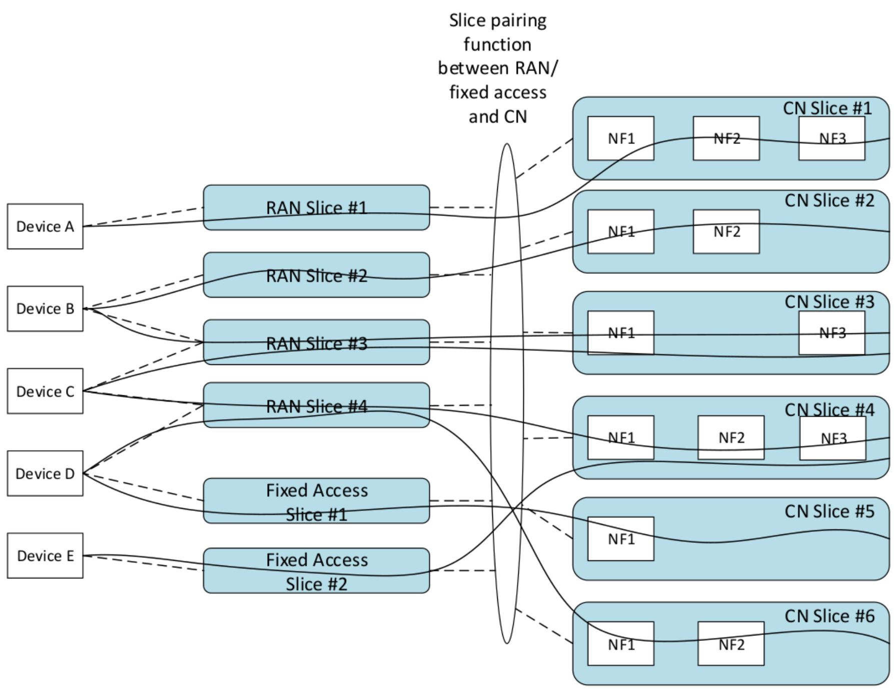

Figure 3-4: UE Connection with the network slices across the RAN and CN domains [11]

One solution to multi-domain service orchestration is a Multi-Domain Service Orchestrator (MDSO) that builds hierarchically on top of each domain orchestrator to orchestrate services end-to-end. Figure **3**-**5** Illustrates an example of such a solution. Real-time efficiency issues, as well as compatibility between the different orchestrator information models must be taken into consideration with this solution.

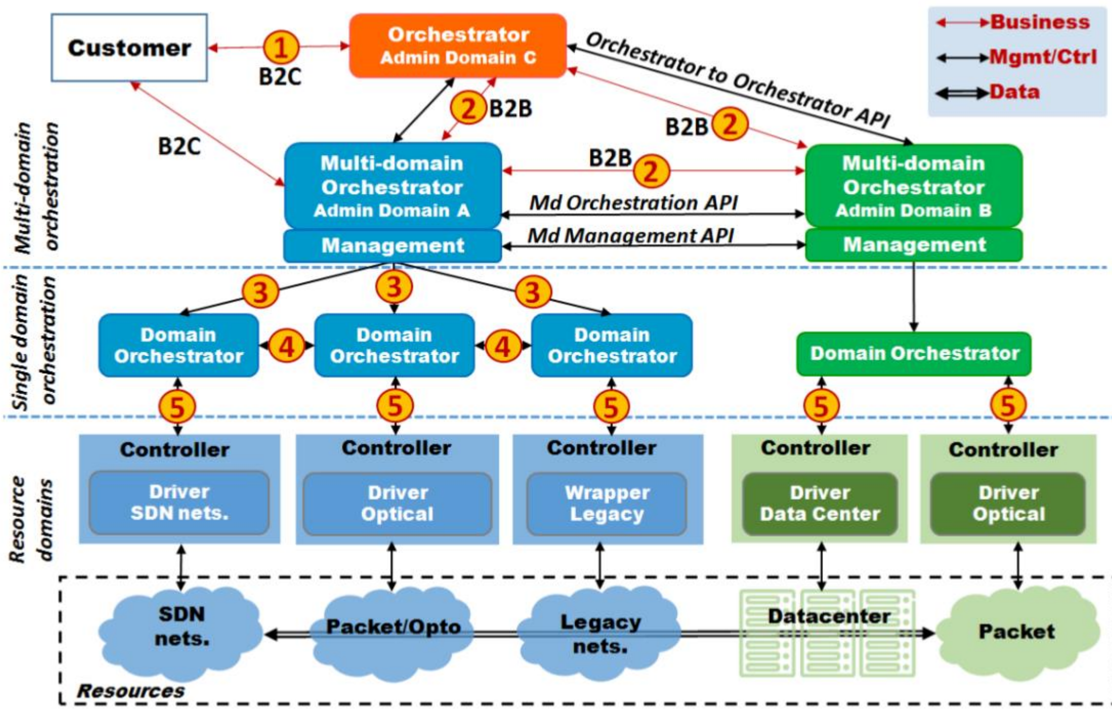

Figure 3-5: A framework for multi-domain service orchestrator (MDSO) [12]

According to [13], a MDSO has the following characteristics:

- Modular and programmable structure that supports control of multiple technologically diverse domains: cloud, multi-layer WAN, NFV, IP/MPLS, and more.
- TOSCA-based templates that enable rapid network services programmability and self-service in operating the network. This technology enables the network operator to program the network themselves which comes with significant effort and cost reduction in software professional services teams.
- Integration with SDN controllers, element/network management systems, and cloud management platforms.
- Support for service chains composed of physical network elements and SDN/NFV-enabled virtual components across multiple domains.
- Standardized and automated service delivery via repeatable, simplified and auditable processes.

3.4 Network Slice Management

The management and orchestration of network slices is specified in 3GPP TR 28.801 [10], in which the related management functions required to implement the NSIs are specified:

- **Communication Service Management Function (CSMF)**: Responsible for translating the communication service-related requirement to network slice related requirements;

- **Network Slice Management Function (NSMF)**: Responsible for management and orchestration of NSI;
- **Network Slice Subnet Management Function (NSSMF)**: Responsible for the management and orchestration of NSSI.

ETSI NFV MANO does not handle:

- Application-aware NS configuration and management,
- VNF application layer configuration and management,
- Management and deployment of PNFs, or their application layer configuration and management.

The lifecycle of an NSI is shown in Figure 3-6. The process depicted includes the stages for the preparation phase, the instantiation phase (Instantiation, Configuration and Activation), and the operation (Run Time) phase. Finally, the NSI is decommissioned when the slice is no longer needed. The instantiation, execution and decommissioning phases should be part of the NSFM (Network Slice Management Function).

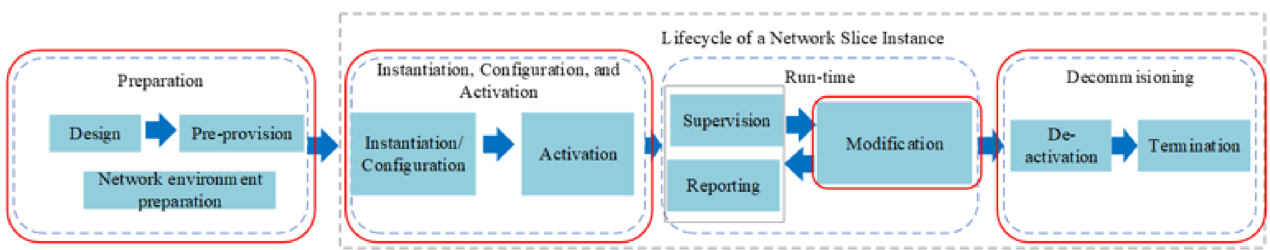

Figure 3-6: Lifecycle phases of a Network slice instance defined by 3GPP

3.4.1 Network Slicing Management and ETSI NFV MANO

At architectural level, ETSI report on Network Slicing support [14] presents the following envisioning of Network Slice Management within the NFV framework (Figure 3-7). To properly interface with NFV-MANO, the NSMF and/or NSSMF, the type of NS or set of NSs, VNFs and PNFs that can support the resource requirements for a Network Slice Instance (NSI) or Network Slice Subnet Instance (NSSI) need to be determined, as well as whether new instances of these NSs, VNFs and the connectivity to the PNFs need to be created or existing instances can be reused.

From a resource management viewpoint, an NSI can be mapped to an instance of a simple or composite NS or to a concatenation of such NS instances. The different NSIs can use instances of the same type of NS (i.e. they are instantiated from the same NSD) with the same or different deployment flavours. Alternatively, different NSIs can use instances of different types of NSs.

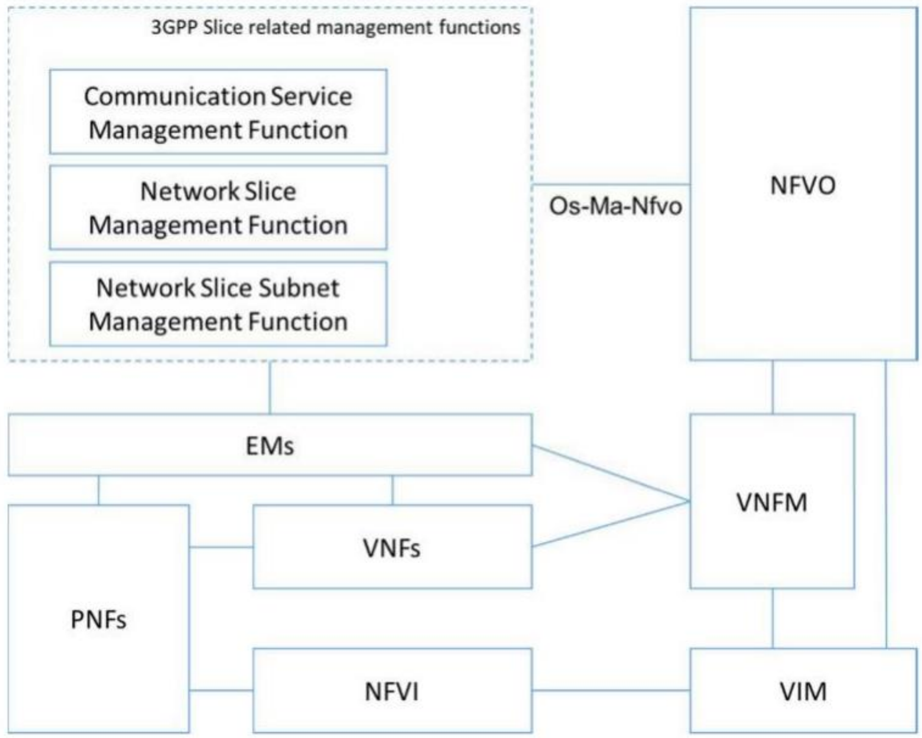

Figure 3-7: Envisioning of Network Slice Management within NFV framework [15]

3.5 Existing Solutions for MDSO

In this section we go through an overview of some of the existing multi-domain service orchestration solutions.

3.5.1 X-MANO

X-MANO [16] is an orchestration framework to coordinate end-to-end network service delivery across different administrative domains. X-MANO introduces components and interfaces to address several challenges and requirements for cross-domain network service orchestration, such as business aspects with architectural considerations, confidentiality, and lifecycle management. In the business aspects case, X-MANO supports hierarchical, cascading and peer-to-peer architectural solutions by introducing a flexible, deployment-agnostic federation interface between different administrative and technological domains. The confidentiality requirement is addressed by the introduction of a set of abstractions so that each domain advertises capabilities, resources, and VNFs without exposing implementation details to external entities. To address the multi-domain lifecycle management requirement, X-MANO introduces the concept of programmable network service, based on a domain-specific scripting language, allowing network service developers to use a flexible programmable Multi-Domain Network Service Descriptor, so that network services are deployed and managed in a customised way.

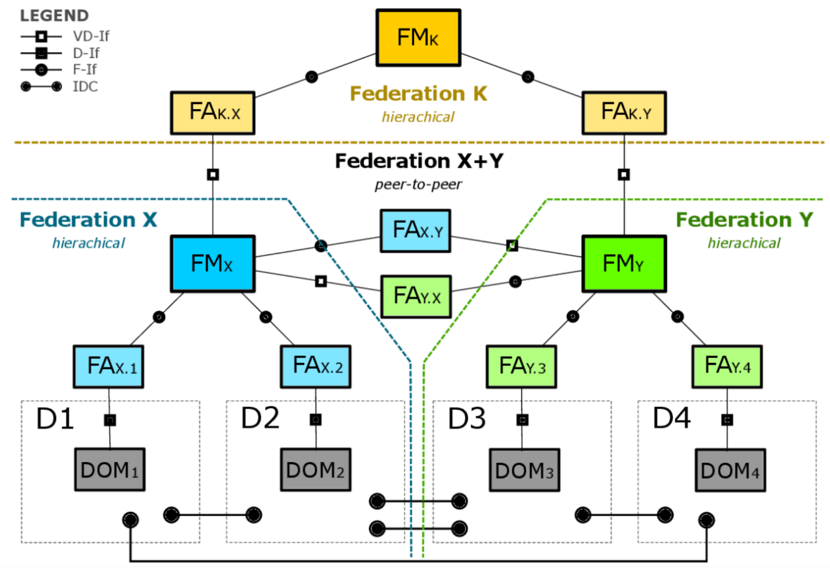

Figure 3-8: Example of domains, both hierarchical and peer-to-peer, managed by X-MANO [17]

3.5.2 Blue Planet

Blue Planet Multi-Domain Service Orchestration is an open and vendor-agnostic software solution that allows creation, deployment, and automation of the end-to-end delivery of services across both physical and virtual networks. Blue Planet service templates are based on the TOSCA standard, which provides mechanisms to help control workflow, describe relationships, and reflect dependencies that exist between various resources on a network. TOSCA based service templates allow network operators to program the high-level service intent required to execute end-to-end automation.

Blue Planet integrates standards-based NFV Orchestration (NFVO) capabilities, providing the full lifecycle management of VNFs and meeting the ETSI NFV MANO guidelines. When deployed for NFVO applications, Blue Planet automates the orchestration of NFVI resources across single or distributed data centers. Conforming to the ETSI NFV R2 specifications, Blue Planet also provides advanced visualization of the end-to-end flow of a network service consisting of VNFs and the relationships between them.

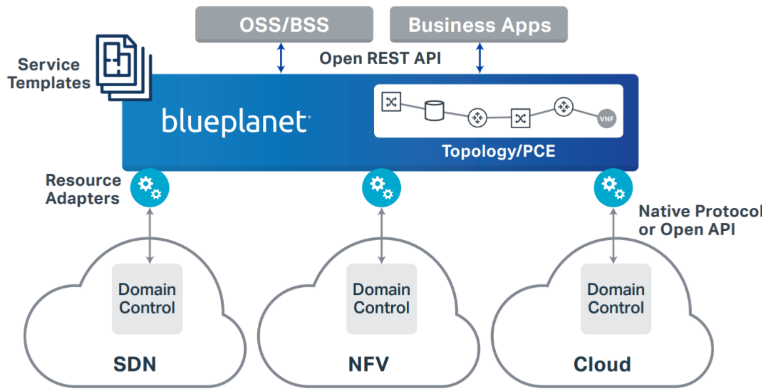

Figure 3-9: Blue Planet multi-domain service orchestration framework [18]

3.5.3 Ericsson Orchestrator

Ericsson Orchestrator [19] is part of Ericsson Dynamic Orchestration solution that provides orchestration across multi-domain and multi-vendor scenarios.

Figure **3-10** illustrates the overview architecture of the Ericsson Dynamic Orchestration solution.

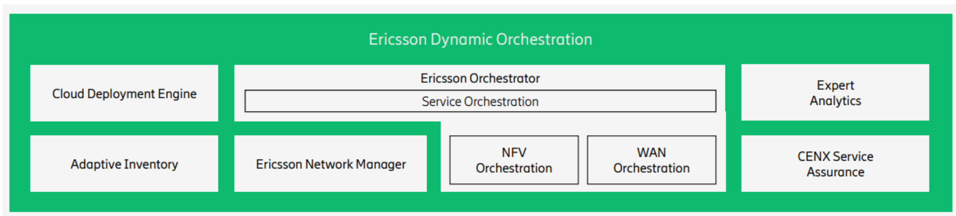

Figure 3-10: Components of Ericsson Dynamic Orchestration

The key components of the solution include:

- **VNF Onboarding**: To quickly Onboard and validate multi-vendor VNFs on the Service Provider environment;
- **End-to-End Orchestration**: To automate the instantiation and configuration of network services, including all intra-DC and inter-DC network services, across multiple domains and multi-vendor scenarios;
- **Element Management**: To provide VNF specific lifecycle management such as scaling and healing based on application specific knowledge;
- **Assurance**: To monitor application and infrastructure alarms, across domains, and enabling policy-based and automated self-healing scenarios for the customer services;
- **Inventory**: To provide a real-time topology as well as service design & assign capabilities for physical, virtual and hybrid customer services across multiple domains.

In the context of ETSI NFV MANO, the Ericsson Orchestrator fulfills the roles of NFVO, Generic VNF Management (G-VNFM) and Service Orchestration. It consists of three modules – Service, NFV and WAN Orchestration – that can be offered individually. The functionality of these 3 modules is described below:

- **Service Orchestration:**
    - Provides service orchestration of new 5G, IoT and network slicing use cases.
    - Provides network slice management, including LCM and configuration by using TOSCA as the template language.
    - Real-time inventory check carried out to generate a service instance design, which is then deployed across the resources.
- **NFV Orchestration:**
    - Performs NFVO, G-VNFM and Service Configuration Management (SCM).
    - Enables orchestration of resources across different VIMs (OpenStack or VMware) and both intra- and inter-data centers.
    - Automates the network service instantiation described in TOSCA/JSON formats.

  - Performs fault and performance management for the infrastructure by collecting and correlating alarms from the hardware and VIM.
  - Interfaces with multivendor Element Management System (EMS)/ VNFM through the Or-VNFM interface. The G-VNFM function provides LCM of VNFs that do not have a specific VNFM.
- **WAN Orchestration:**
  - Enables cross-domain orchestration across access, transport and core by interfacing with different domain managers and transport Software-Defined Networking (SDN) controllers.

The Ericsson Orchestrator is a solution adopted by telecom providers that reported significant reduction in provisioning time, satisfaction with automated deployment and healing of VNFs, as well as good performance at scale.

3.5.4 5GEx Project

Deliverable D1.3A presents the most significant H2020 projects whose results we can leverage in our solution. For each of the projects, where applicable, it also reports end-to-end service orchestration solutions. We are referring the reader to D1.3A for a description of these solutions. In this section, we include a reference to an orchestration-oriented ICT-14 project, whose focus was on enabling cross-domain orchestration of services over multiple administrations or over multi-domain single administrations. This project is called 5G Exchange (5GEx) [20].

Figure 3-11 shows the architecture of 5GEx. The multi-domain orchestrator MdO exposes service specification APIs (Customer-to-Business, C2B) that allow business customers to specify their requirements for a service. The MdO interacts with other MdOs via Business-to-Business (B2B) APIs to request and orchestrate resources and services across administrative domains. Finally, the MdO interacts with Domain Orchestrators to orchestrate resources and services within the same administrative domains. Note that MdO-only service providers such as 3rd parties are also considered by the reference framework. These MdO service provider does not own resource domains, but uniquely operates at multi-domain orchestrator level to trade resources and services.

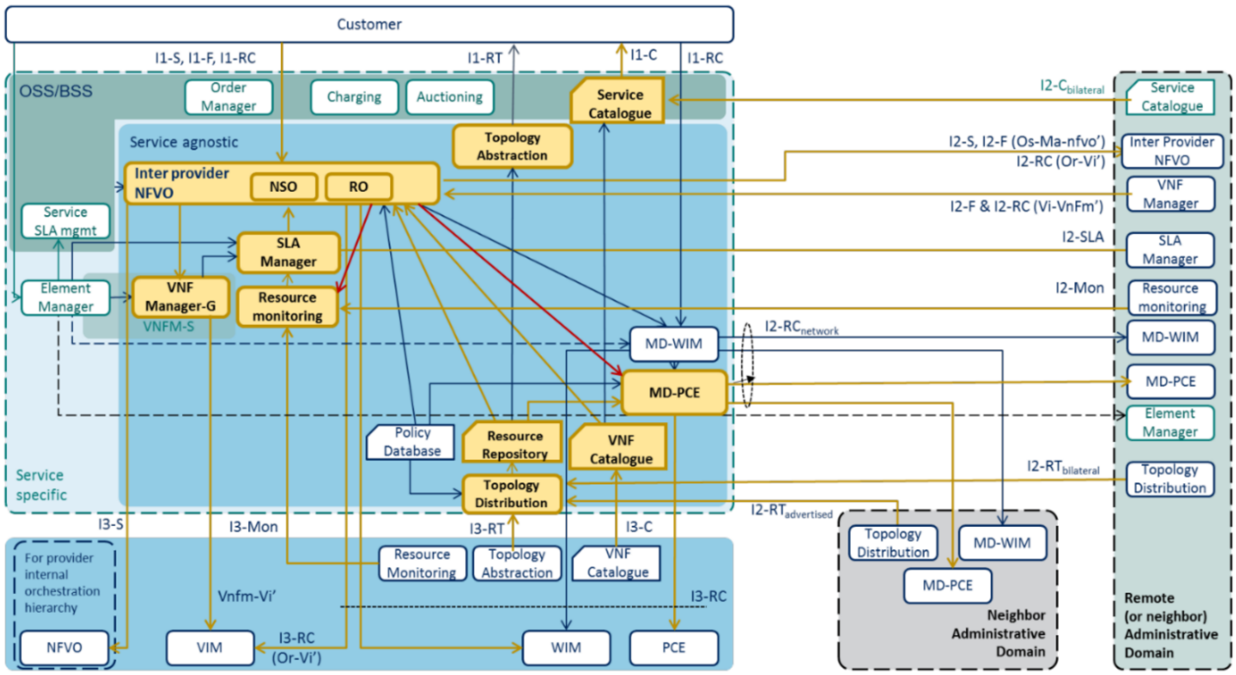

Figure 3-11: 5GEx Architecture [21]

There are three service layers envisioned in 5GEx to support end-customer facing service enablers as shown in Figure 3-12. These service layers are:

- Network Function Virtualisation Infrastructure as a Service (NFVIaaS): This service is offered;
- Virtual Network Function as a Service (VNFaaS);
- Valued added Connectivity as a Service (VACS) which is coupled with assured service quality (ASQ) infrastructure connectivity.

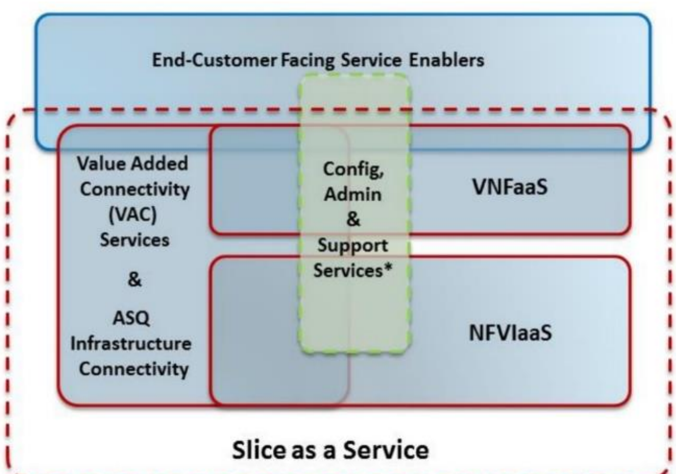

Figure 3-12 5GEx Service Categories and layers [22].
(*) Some Support Services may be applicable at the level of federation or community

These service layers and service categories are applicable to both interface I1 and interface I2. That is, these are the 5GEx wholesale Service Provider to Service Provider (SP-2-SP) business relationship where either both SPs are part of a 5GEx community (I2), as well as the SP-2-Enterprise business relationship where the enterprise is a 5G enterprise customer, for instance an online SP (OSP), interacting with the 5GEx primary service provider over I1.

In addition to these main layers, 5GEx also have a separate category of Config, Admin and Support Services. These can be bundled with NFVIaaS or VNFaaS or can be a service category by their own, where VNFs are handled by the customers.

Figure 3-13 shows the main functionalities covered by 5GEx, including service management, VNF LCM, catalogues spanning over multiple domains, topology and resource control functions, as well as monitoring and SLA.

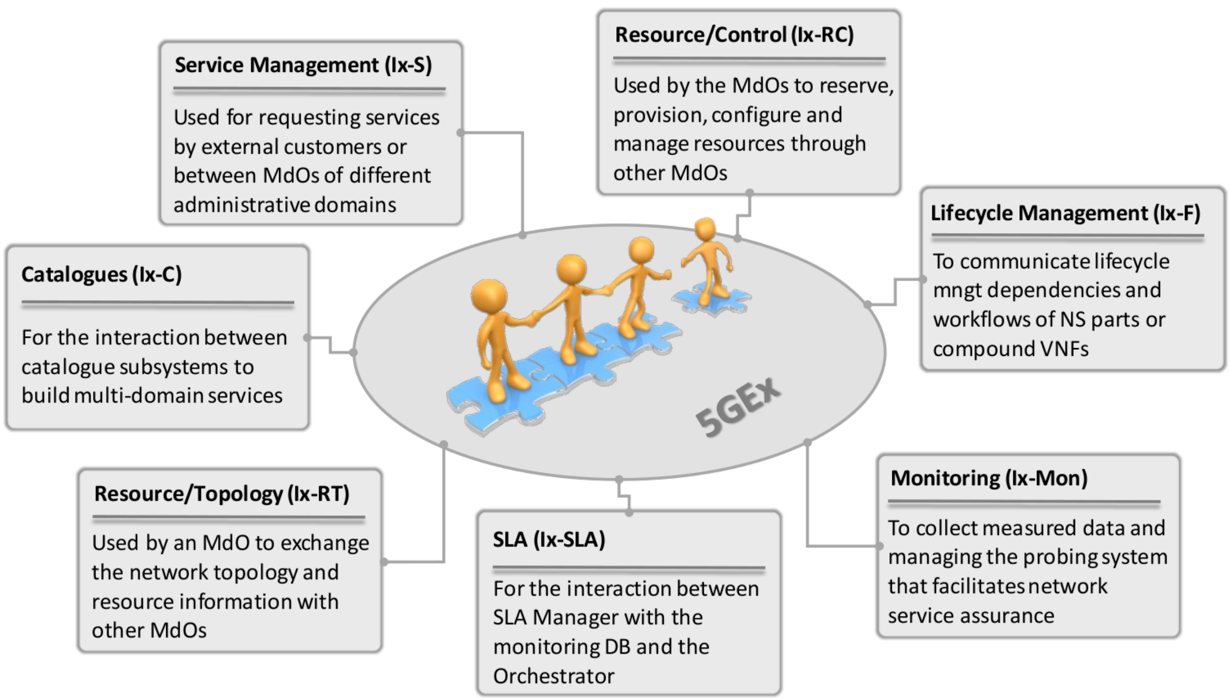

Figure 3-13: Function split of 5GEx Interfaces [22]

3.6 Challenges of Multi-domain Orchestration

The above analysis of standard orchestration, existing implementations and gaps, shows that there are multiple challenges that come with providing end-to-end multi-domain orchestration. Some of these refer to:

- ***Performance*** issues when orchestrating across domains: for some 5G use cases, in particular uRLLC, this might be a real problem that will impact the way in which orchestration is implemented;
- When composing on top of individual domain orchestrators, not the same ***information models*** may be used by the underlying orchestrators and by the underlying domains, which means that translations must be put in place and missing gaps filled. An important question here is also how much of the domain-specific information is needed at higher levels of orchestration to ensure an efficient implementation;
- Different ***APIs*** exposed by the underlying orchestrators / domains, as not all orchestrators abide by standard APIs or they abide by different standards. This must also be taken into account by the MDSO;
- Lifecycle management, catalogue management and confidentiality management across domains.

4 Planned Deployments of 5G-SOLUTIONS Use Cases

In order to understand what type of orchestration we need to support the different verticals in our Living Labs (LL), we started by defining the Uses Cases (UC) and understanding which ICT-17 platform these use cases will be deployed on. This section presents a summary of the planned deployments for the 5G-SOLUTIONS use cases. The details of each of these use cases are presented in D1.1. These planned deployments are the starting point to understand the interaction and boundaries between 5G-SOLUTIONS and the underlying ICT-17 platforms that we use in terms of orchestration. The next section will look more closely into the features and orchestration solutions of 5G EVE, 5G VINNI Patras and 5G-VINNI Norway, while in Section 6, we provide our current understanding and plans for orchestration in 5G-SOLUTIONS.

Table 4-1: Mapping of use cases to ICT-17 platforms

LL	UC#	Use Case Title	Responsible Partner(s)	ICT-17 Project	ICT-17 Site
1	1.1	Time-critical process optimization inside digital factories	P&G, IRIS	5G-VINNI	Patras
	1.2	Non-time-critical communication inside the factory	GLAN, IRIS	5G-VINNI	Patras
	1.3	Remotely controlling digital factories	NTNU	5G-VINNI	Norway
	1.4	Connected goods	P&G, IRIS	5G-VINNI	Patras
	1.5	Rapid deployment, auto/re-configuration, testing of new robots	NTNU	5G-VINNI	Norway
2	2.1	Industrial Demand Side management	A2T	5G-EVE	Turin, Rome (only 5G RAN feature)
	2.2	Electrical Vehicle Smart Charging	A2T	5G-EVE	Turin, Rome (only 5G RAN feature)
	2.3	Electricity Network Frequency Stability	A2T	5G-EVE	Turin, Rome (only 5G RAN feature)
3	3.1	Intelligent Street Lighting	NURO, TNOR	5G-VINNI	Norway
	3.2	Smart Parking	NURO, TNOR	5G-VINNI	Norway (Trondheim)
	3.3	Smart City Co-Creation	TNOR, NTNU	5G-VINNI	Norway (Trondheim)
	3.4	Smart Buildings – Smart Campus	IBM	5G-VINNI	Patras
	3.5	Autonomous Assets and Logistics for Smart Port	TNOR, YARA	5G-VINNI	Norway (Herøya)
	3.6	Port Safety – Monitor & Detect Irregular Sounds	TNOR, NURO	5G-VINNI	Norway (Herøya)
4	4.1	Ultra High-Fidelity	CTTC, FNET,	5G-VINNI	Patras

			IRT, UOP		
	4.2	Multi CDN Selection	CTTC, IRT, UOP	5G-VINNI	Patras
	4.3	On-site Live Event Experience	LIVEU, CTTC, TNOR, UOP	5G-VINNI	Patras & Norway
	4.4	User & Machine Generated Content	CTTC, FNET, LIVEU, UOP	5G-VINNI	Patras
	4.5	Immersive and Integrated Media and Gaming	CTTC, NURO, UOP	5G-VINNI	Patras
	4.6	Cooperative Media Production	CTTC, FNET, LIVEU, UOP	5G-VINNI	Patras

5 Underlying 5G Platforms

This section describes the main features supported by each of the ICT-17 platforms on top of which we deploy the 5G-SOLUTIONS use cases, as well as their approach to orchestration.

5.1 5G-EVE – Turin Facility

5.1.1 Description

In this section we present an overview of 5G-EVE and, in particular, the Italian site facility that is planned to be used by the verticals in 5G-SOLUTIONS. The main site used in this project is Turin, with the possibility of using 5G antennas from Rome which will also be managed by the Turin site.

5.1.1.1 Overview of Site Capabilities

The 5G EVE Italian site facility is hosted in the city of Turin, where all 5G components will be deployed, starting from the radio elements to the distributed cloud PoPs with NFV capabilities, providing integration of lab-based and operational infrastructures. A part of the 5G site facility in Turin is based on existing and planned deployments in the context of the “Torino 5G” initiative. Initial 5G EVE use cases considered for validation on the Turin site facility are Smart Transport (Intelligent railway for smart mobility) and Smart Cities (Safety and Environment - Smart Turin). These use cases and their requirements have been used to date to understand the platform features that must be provided.

The Turin site facility will encompass 5G network elements including NR Access and 5G Core functionalities, provided by Ericsson and deployed into the TIM lab testing infrastructures and field operational networks. Additional testing facilities are also planned to be deployed by CNIT in the area of Politecnico di Torino, including 5G radio elements and an NFVI PoP. In summary, mobile radio access in the Italian site facility will range from wireless networks based on 5G standards (3GPP R15_Option 3x, as initial deployment) down to 4G LTE for preliminary validations and benchmarking, as well as local WiFi networks and NB-IoT for indoor deployments and specific connectivity with IoT devices.

On top of this physical infrastructure offering a good mix of capabilities, the Italian site facility will include SDN/NFV based control and orchestration tools, aiming at coordinating the deployment of VNFs, Network Services and network slices, thus matching the verticals’ requirements in terms of performance, availability and reliability. Through these control and orchestration tools, vertical-tailored and application-specific VNFs and functions in general will be deployed in support of the initial use cases mentioned: Smart Transport (e.g. for media streaming, traffic flows and user pattern analysis) and Smart Turin (e.g. for integration of IoT sensors and devices with the oneM2M [23] platform by TIM).

The following subsections provide an overview of the main capabilities, in terms of services and features exposed, planned for the Italian site facility at the data, control and orchestration planes. For each plane, a dedicated subsection is provided. Note however that not all of these features are available at this point in time, and some of them are in the planning phase. These capabilities of the 5G EVE platform are being analysed in the context of the 5G-SOLUTIONS use cases that are planned to be deployed on 5G EVE. This is currently an ongoing effort.

5.1.1.2 Main Services and Features Offered

5.1.1.2.1 Data Plane

Table 5-1 presents the data plane capabilities for the 5G-EVE Turin site. These are important for understanding what features this facility provides towards the verticals.

Table 5-2: Italian site facility – overview of data plane service capabilities

Category	Technology highlights	Main (i/w) features and capabilities
RAN	**Spectrum**: B43 **Technology description**: 5G New radio non standalone (NSA) **Mgt/control/DP interfaces**: S1/X2	• New radio connectivity towards LTE signaling
Fronthaul/ Backhaul	**Technology description**: • FH - Active functionality of Transponders and Power Monitoring Units and built on the DWDM platform • BH – High capacity aggregation router **Deployment**: • FH - High density pizza box for indoor unit (for Baseband or RRU connection) and outdoor equipment unit (for RRU connection) • BH – Provides Radio aware transport for mobile backhaul with high 10GE density and 100GE switching capacity **Mgt/control/DP interfaces**: • FH - IPv4/IPv6 manageability by LCT/CLI and ENM BH – Managed by CLI, ENM, NETCONF and YANG [24] model	• FH - The Fronthaul active solution provides high capacity and low latency to ensure that even the most stringent transport requirements of LTE, LTE-advanced and 5G are met. • BH - Provides application aware traffic engineering with open and standardized interfaces, enabling network slicing and ability to tailor services for utmost agility
Core	**Technology description**: Distributed cloud (3GPPP) **Mgt/control/DP interfaces**: logical between different VMs and only physical connections will be towards the RAN (eNB and gNB) and towards the backhaul (switch)	• SR-IOV accelerator

ME Hosts	**Technology description**: DELL servers **Capabilities and deployment**: Multi-server without external storage **Mgt/control/DP interfaces**: Extreme switch as external host	SR-IOV accelerator
Cloud	**Technology description**: Ericsson Execution environment (CEE) **Capabilities and deployment**: based on Mirantis Openstack **Mgt/control/DP interfaces**: interface with external control and traffic switch	SR-IOV accelerator
PNFs	Not planned for the infrastructure but verticals will have PNFs.	Not planned
inter-site connectivity	**Technology description**: IPSec/GRE VPN tunneling	Two dedicated VPN gateways at the boundary of the control/orchestration and data plane intra-site networks

5.1.1.2.2 Control Plane

Table 5-3 details the tools, APIs, as well as features and services supported in 5G-EVE Turin at the control plane level.

Table 5-4: Italian site facility – overview of control plane service capabilities

Category	Technology highlights	Main (i/w) services and features
RAN controller	**SW tool(s)**: Ericsson Network Manager (ENM) **APIs**: Ericsson's proprietary	• Configuration of radio elements Seamless integration with configuration and management of other segments (transport, core)
SDN controller	**SW tool**: OpenDaylight [25] **APIs**: OpenDaylight base APIs	Base Opendaylight Beryllium/Nitrogen version features, applications and services.
ME Platform Manager & Orchestrator	**SW tools**: Ericsson ENM/NorthStar [26] **API:** NorthStar REST API	• Network Optimization • Predictable Deterministic Network State • Multiple User-Defined Constraints, Global network view Ordering and Synchronization of Paths

ME Platform Manager & Orchestrator	**SW tool(s)**: Ericsson orchestrator as manager of the distributed edge/core cloud deployment **Underlying VIM**: OpenStack Queens **APIs**: Ericsson's API only for network nodes	• Edge breakouts Redirection of traffic flows to local edge applications
VIM	**SW tool(s)**: OpenStack Queens; in Ericsson VIM modules are in CEE **APIs**: at least base OpenStack APIs and components	• Management of virtualized infrastructure resources Integration of network, compute, storage Openstack components

5.1.1.2.3 Orchestration Plane

Table 5-5 presents the main capabilities of 5G-EVE Turin at the orchestration level. This is important to us in terms of understanding supported orchestration features, but also possible integration points with 5G-SOLUTIONS.

Table 5-6: Italian site facility – overview of orchestration plane service capabilities

Category	Technology highlights	Main (i/w) services and features
OSS/BSS	**SW tool** Ericsson Orchestrator for generic VNF **APIs**: Ericsson proprietary	• Generic VNFM for multivendor VNFs • VNF LifeCycle Management • Integration with multi-vendor EMS
Slice Manager	**SW tool**: Ericsson Service Orchestration **APIs**: Ericsson proprietary	• Network Slice design • (BluePrint Design, BluePrint Validation) • Network Slice instantiation (VNF Instantiation, Network Infrastructure configuration, Network Elements integration) • Network Slice operation (Network Slice re-configuration, Supervision and Performance, Network Slice Scaling and Upgrade) • Network Slice termination (De Activation, Re-set configuration)
NFVO	**SW tool**: Ericsson Orchestrator **APIs**: Ericsson proprietary – ETSI NFV SOL002 – SOL005 [27] (planned 2019)	• NS lifecycle management • NS Descriptor-driven orchestration • TOSCA support for NS

		Description
VNFM	**SW tool**: OSM R4 [28] **APIs**: ETSI NFV SOL005 as northbound APIs [27]	• NS packaging and on-boarding • NS instantiation, manual scaling, termination • NS monitoring leveraging on OpenStack Telemetry services • VNF Day0. Day1, Day2 configurations
VNFM	**SW tool**: ENM – Ericsson Network Manager for Ericsson PNFs and VNFs **APIs**: Ericsson proprietary	VNF lifecycle management for Ericsson's PNFs and VNFs (instantiate, terminate, scale, heal)
Available VNFs / MEC Apps / NSs	**SW tool**: Nextworks' Slicer (open-source) [29] • **APIs**: REST APIs (non-standard)	• Vertical services lifecycle management and provisioning • Network slice management functions

5.1.2 Key Features for Service Orchestration & Management

5G EVE is deployed on multiple sites, each site being responsible for its own management and orchestration of services internally. The individual sites are connected through a layer of Internetworking Framework, which manages the communications between sites and also offers multi-site orchestration features. Further, an additional web portal is exposed to Vertical users to implement and run their experiments, as shown in Figure 5-1.

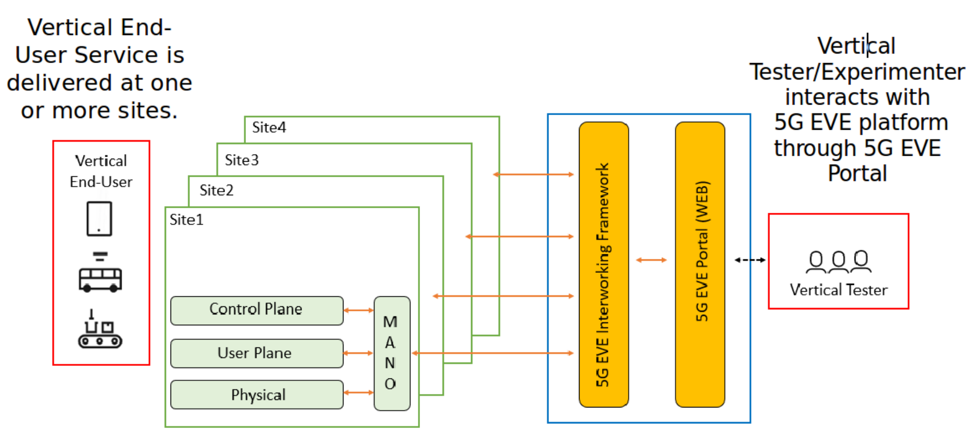

Figure 5-1: Experiment Architecture of 5G-EVE [30]

Figure 5-2 illustrates 5G-EVE APIs. As can be seen in the figure, individual sites are orchestrated internally and are not planned to be exposed to the 5G-SOLUTIONS MDSO. Instead, the experiment Portal will be interfacing with 5G-SOLUTIONS.

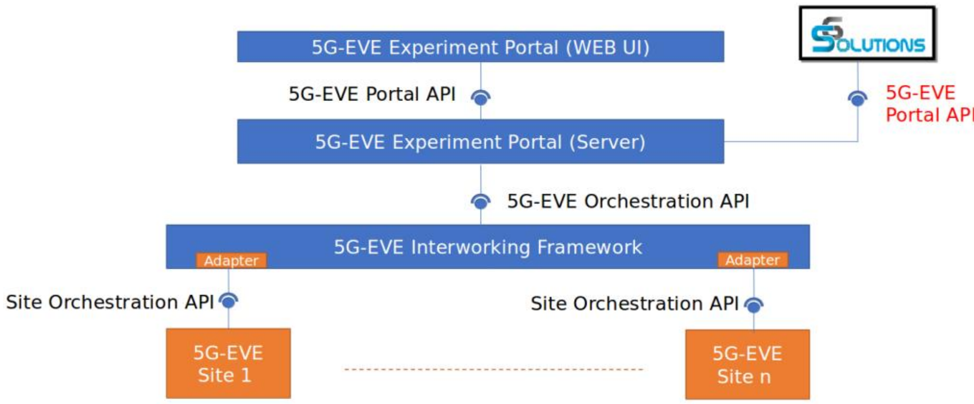

Figure 5-2: Illustration of 5G-EVE APIs and proposed interfacing with 5G-SOLUTIONS

5.1.3 Target interworking capabilities, features and services

The interworking framework is work in progress at this stage. However, there is a first proposal defined for the interworking capabilities, features and services that will be provided by the 5G EVE platform, based on the technical requirements coming from the 5G EVE use cases (which are different than the 5G-SOLUTIONS use cases) and also considering the heterogeneous services and features offered by each 5G EVE site. The 5G EVE interworking framework is a unique selling point of the 5G EVE end-to-end facility, which aims at providing a unified and integrated experimentation platform spanning heterogeneous sites, where diverse 5G capabilities and tools are deployed. Therefore, it is a combination of coordination features for the seamless orchestration and execution of vertical use case experiments over heterogeneous infrastructures.

5.1.3.1 Preliminary Interworking Framework Architecture

The interworking framework was designed from scratch in the context of 5G EVE, trying to enhance, combine and integrate, where possible, existing solutions for multi-site orchestration, catalogue and inventory of NFV network services, VNFs and network slices, monitoring of network and service performances. Figure **5**-**3** shows the preliminary interworking framework architecture diagram and high-level functional split, as well as its logical positioning with respect to the 5G EVE experiment portal and the four site facilities. In particular, the interworking framework sits between the experiment portal, that is the frontend of the 5G EVE platform and the site facilities where the vertical use case experiments have to be deployed for testing and validation 5G and service specific KPIs.

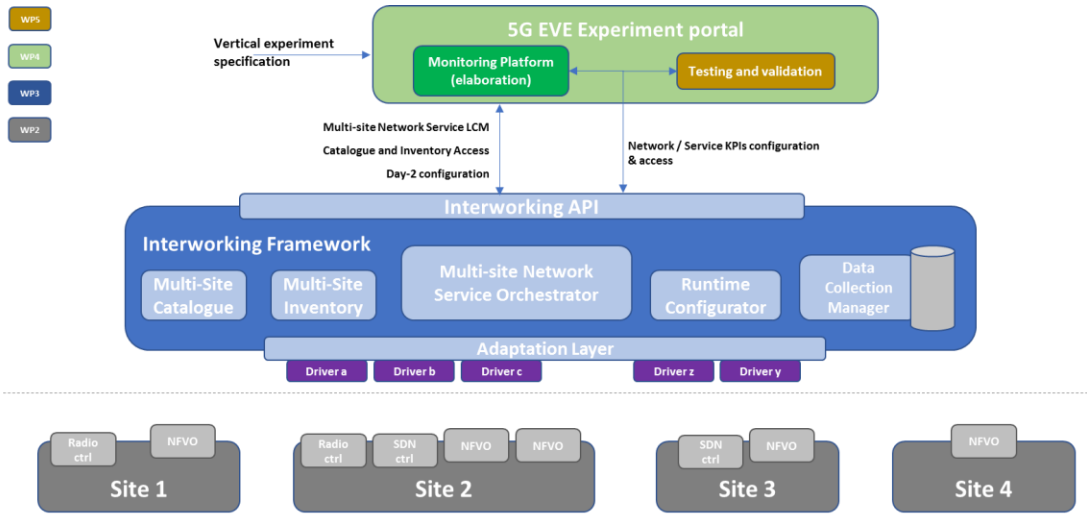

Figure 5-3: Preliminary interworking framework architecture [31]

The two main reference points exposed and provided by the 5G EVE interworking framework are:

- The *Interworking API* exposed at the northbound towards the 5G EVE experiment portal;
- The *adaptation and abstraction interface* at the southbound for providing a common and unified access to the individual site facilities services and APIs.

As a general reference for modelling and descriptions of end-to-end network services and slices within the interworking framework, the followed approach is the one proposed by ETSI NFV, as discussed in Section 3.2. In this context, the Interworking API can be considered as a collection of primitives that aims at exposing a common interface and model for end-to-end Network Services and slices provisioning in support of the vertical use case experiments. It is important to highlight that the interworking API is not only a provisioning interface, but it is also conceived to expose additional features for the operation of the vertical use case experiments, including runtime configuration of the network services and slice elements (e.g. VNFs), and monitoring of network and service performance metrics in support of the validation of targeted KPIs within each experiment. In summary, the interworking API exposes at least the following services:

- Access to multi-site catalogue to allow the 5G EVE experiment portal to:
    - Retrieve Network Service and VNF Descriptors modelling the network slices that can be provisioned in the end-to-end facility;
    - On-board new Network Service and VNF Descriptors to fulfil the requirements of vertical use case experiments.
- Access to multi-site inventory information to allow the 5G EVE experiment portal to retrieve details of already provisioned Network Services in support of vertical use case experiments;
- Provisioning and lifecycle management of end-to-end Network Services in line with ETSI NFV Management and Orchestration (MANO) principles and operations;
- Configuration of 5G network and service performance metrics to be monitored and collected during the execution of vertical use case experiments;

- Common and site independent access to collected monitoring information for each vertical use case experiment, for processing and analysis by the 5G EVE experiment testing and validation tools;
- Runtime configuration of Network Services and VNFs, to enable the 5G EVE validation framework to dynamically apply vertical-oriented service logics and configurations (following the vertical's experiment requirements and constraints) with a common approach and interface. It is worth to highlight that ***this runtime configuration is not intended, at least in this initial phase of the interworking framework definition, to be directly exposed and offered to the verticals.***

The Adaptation Layer**,** shown in Figure **5**-**3**, has the main goal to abstract the heterogeneous capabilities and APIs exposed by the 5G EVE site facilities, mostly focusing, in this preliminary interworking framework definition, on orchestration and control features. Therefore, it exposes to the interworking framework components a set of common internal APIs and models for accessing per-site management, control, orchestration and monitoring services, and translates them into the site-specific APIs and models. In particular, the common APIs and models provided by the adaptation layer are intended to provide transparent access to those site features and services listed in section 4.3 in [31] as required to fulfil the vertical oriented technical requirements. As depicted in Figure **5**-**3**, for each of these required per-site features and services, the adaptation layer is equipped with specific drivers providing the required translation from the common interface to the site-specific APIs.

The interworking framework architecture, as presented in Figure **5**-**3**, is comprised of the following functional components:

- Multi-site Network Service Orchestrator: responsible for coordinating the provisioning and lifecycle of Network Services across the site facilities, as required to deploy end-to-end network slices for the execution of vertical use case experiments;
- Multi-site Catalogue: decouples the Network Service Descriptors exposed to the 5G EVE experiment portal (possibly spanning multiple sites and logically representing the actual network slice offers) from the Network Service Descriptors collected from each of the site facilities (representing the actual capabilities of the sites), enabling keeping track of dependencies and restrictions of each 5G EVE site facilities, as required for deciding where to deploy a given network slice in support of a specific vertical use case experiment;
- Multi-site Inventory: keeps the information on provisioned and instantiated network slices in the 5G EVE end-to-end facility and is fully managed, in terms of information stored, by the Multi-site Network Service Orchestrator;
- Runtime Configurator: allows to apply tailored runtime configurations to the provisioned end-to-end Network Services and VNFs in support of the vertical use case experiments;
- Data Collection Manager: coordinates the collection and persistence of all those network and vertical tailored service performance metrics that are required to be monitored during the execution of experiments for testing and validation of the targeted KPIs.

A detailed description of the functionality of each of these components is included in Annex 1 (section 9.1).

The interworking framework is planned to evolve in time, based on the complexity and the vertical requirements that will be deployed on top of 5G EVE, evolving from support for single site, to complete inter-working, including the data plane. Figure 5-4 illustrates the planned implementation stages.

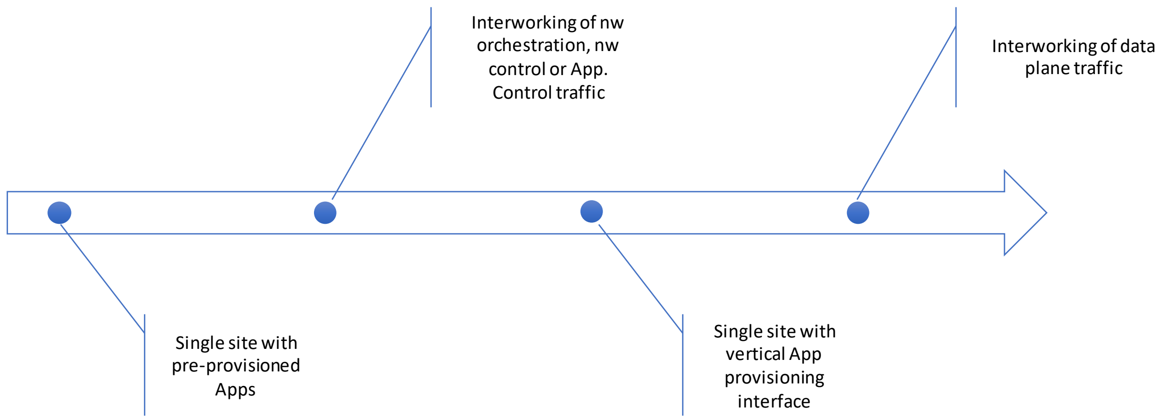

Figure 5-4: Interworking framework implementation stages

There are two main dimensions along which the interworking framework will evolve:

1. ***Single site.*** Starting from verifying that a Vertical use case can be deployed in any site, while differentiating between two phases:
    - Deploying an NSD (Network Service Descriptor) using pre-provisioned, pre-certified VNFs: Verticals are allowed to define network services that use existing VNFs.
    - Deploying a full NSD, including VNFs, not clear at this point if this requirement can be fulfilled completely in 5G EVE, due to the current state-of-art of cloud technologies and their diversity.

2. ***Interworking****.* Interconnecting more than one 5G EVE site and distinguishing among the kinds of cross-site traffic:
    - Orchestration should be a basic requirement for all sites
    - Control traffic (both network and application)
    - Management traffic, e.g. for monitoring data
    - Data plane traffic.

Data plane traffic is the most demanding one and is more difficult because it depends on the physical network capabilities to be compliant with the requirements. However, so far, there is no clear vertical use case for using it, therefore the analysis of this interconnection is postponed for the moment.

Table 5-7 shows the required phase of the interworking framework per 5G service type. We assume that **uRLLC** services are not going to use inter-site deployments, as their requirement of bandwidth and latency discard any deployment that physically is not near the RAN. Also, we expect that only **eMBB** use cases will require a data plane interconnectivity. However, as **eMBB** and **uRLLC** are demanding in bandwidth and latency respectively, we assume that the provisioning and life-cycle management of the vertical application, most probably deployed at the edge environment, are critical and require one dedicated interface.

Table 5-7: Requirements per 5G Service Type

	Single site with pre-provisioned Apps	Single site with vertical Apps provisioning interface	Interworking of orchestration and/or control	Interworking of data plane
eMBB	●	●	●	●
mMTC	●		●	
URLLC	●	●		

5.1.3.2 Target Site Support for Interworking

Based on the technical requirements that the 5G EVE facility has to meet in order to support the set of target use cases considered in the 5G EVE project, the project defined the set of capabilities and functionalities that the site facilities need to implement in order to deliver, operate and monitor the 5G services related to the reference use cases. Some of these functionalities (from the control to the orchestration plane) are managed internally to each site, without the need to expose their characteristics or programmability towards the upper layer of the architecture, while others should be properly advertised and/or made available through programmable primitives to enable the coordination, orchestration and monitoring of vertical-driven 5G experiments. Thus, the latter category of capabilities and functionalities will be exported from the single sites towards the 5G EVE interworking framework. Table 5-8 summarizes a list of identified target capabilities and functionalities to be supported by each site facility and, for each of them, indicates if it needs to be exposed towards the interworking layer. It is worth highlighting that these target capabilities are required to be provided by the 5G EVE site facility ***independently of the single or multi-site nature of the vertical use case*** experiments. Details about each of these features are presented in Annex 1 (section 9.2).

Table 5-8: Summary of identified basic capabilities to be implemented in the site facilities

Capability / Functionality	Description	Exposed to I/W framework
UEs and SIM (Subscriber Identity Module) cards logistic	Intra-site management of mobile user equipment and related SIM cards.	No
Basic subscriber configuration	Intra-site configuration of subscribers.	No
RAN selection and configuration	Dynamic selection and configuration of the Radio Access Network (e.g. for allocation of radio resources).	Yes
Edge Computing	Advertisement of MEC hosts and related capabilities. Management and allocation of virtual resources on MEC hosts.	Yes

NFV / Slice orchestration	Provisioning and management of NFV Network Services and network slices, including: • on-boarding and queries of descriptors, VNF packages and slice templates; • provisioning, termination and query of VNF/NS/slice instances; • explicit management of RAN and EPC/5G Core instances; • Day 0, Day1, Day 2 VNF configuration	Yes (some specific features can be hidden in a given site facility, e.g. RAN configuration and EPC instantiation may be managed internally, on-boarding of vertical's packages may be not permitted, etc.)
SDN-based network control	Programmability of the physical network in the transport and/or the radio domain, as exposed through SDN controllers.	Optional
Monitoring	Tools and platforms for collection of monitoring data related to different kinds of metrics, with mechanisms for monitoring configuration, polling of metrics values, notifications, etc.	Yes
Testing tools	Tools to emulate background traffic or mobile UEs for testing and KPI validation purposes.	Yes

The planned interconnection capabilities at the orchestration and control plane level are presented in Table **5**-**9**. While the orchestration interconnectivity mostly targets the interaction of each site facility orchestration component with the interworking framework itself, the cross-site connectivity at control and data planes is a key requirement for the execution of vertical use case experiments spanning multiple sites.

Table 5-9 Summary of identified inter-site connectivity requirements

Capability / Functionality	**Description**	**Exposed to I/W framework**
Orchestration plane interconnection	A direct communication among per-site orchestration components is not required, as the interworking framework Multi-site Network Service Orchestrator provides the needed cross-site coordination features. However, each site still needs to be interconnected with the interworking framework at the orchestration level. As this orchestration interconnectivity requirement is critical for the execution of any vertical experiment, we require **99.9% of reliability**	Yes

Control plane interconnection	Cross-site connectivity for control plane communications (e.g. among 4G or 5G core control plane components) may be required for the execution of cross-site use cases. The requirement is to have cross-site connection with: • **99.9% of reliability** • **minimum of 20Mbps of bandwidth**	Optional. It may require coordination from the interworking framework

As can be seen, the interworking framework is under development and its evolution will also influence the deployment of the 5G-SOLUTIONS use cases.

5.1.4 5G EVE support for 5G vertical deployments

The following features are supported by 5G EVE as support for running vertical use case experiments. As can be seen, this is a preliminary analysis and many of these characteristics are not (completely) in place as of now.

Table 5-10: 5G-EVE Supported features for running vertical use case experiments

Feature	Target Capability / Functionality	Description
Advertisement of edge computing capabilities	Edge Computing	The capabilities of the distributed cloud platform shall be exposed to make the interworking framework aware of location and availabilities of resources at the edge.
Integration of open-source and commercial NFV orchestrators	NFV / Slice orchestration	Two NFV orchestrators are planned to be deployed and used in the Italian site. Their roles (e.g. managing separate infrastructures) and integration shall be defined, as a preparatory step for their exposure to the interworking framework.
Vertical VNFs runtime configuration	NFV / Slice orchestration	A common interface and model for runtime vertical VNF configurations shall be provided to the interworking framework to expose it to the verticals.
Configuration of monitoring metrics to be collected	Monitoring	A common interface and model for configuring what to monitor for a given use case experiment shall be implemented for its exposure to the interworking framework Data Collection Manager.
Measurement of UE position and location	Monitoring	The exact position and location of UEs is required in the vertical use cases deployed in the Italian site. Dedicated applications or monitors have to be provided to measure and expose this information.
Measurement of QoE for video streaming	Monitoring	A dedicated function, monitor or application for measuring QoE of end-users consuming video streams shall be implemented to expose such metrics to the interworking layer common database.
Measurement of per-device	Monitoring	The per-device throughput is a target KPI for the Smart

throughput		Transport 5G onboard video streaming use case scenario, and specific tools to measure and expose it are required. This may be provided by end-devices emulators embedding measurement functions (e.g. based on iPerf).
Integration of WiFi/Bluetooth beacons in the 5G network	NFV / Slice Orchestration Monitoring	The provisioned slices have to consider the integration of WiFi/Bluetooth beacons with the 5G mobile network as sensors for tracking user mobility and behavior.
Orchestration interconnection	Cross-site connectivity	Connectivity with the 5G EVE interworking framework shall be established with a minimum reliability of 99.9%

5.2 5G-VINNI

5G-SOLUTIONS will use two 5G-VINNI facilities, one located in Greece (Patras) and the other one located in Norway (Trondheim and Herøya). Since these facilities come with different capabilities, as well as different orchestration solutions, we will present them separately in the following sub-sections.

However, both 5G-VINNI facilities have the same way of interfacing with the customers deploying use cases on top of 5G-VINNI. This is based on a Service Catalogue that can be browsed by the customers and at the end of the process, an SLA between 5G-VINNI and the customer is created. An example is shown in Figure 5-5, where a customer asks for a service of type eMBB to be deployed.

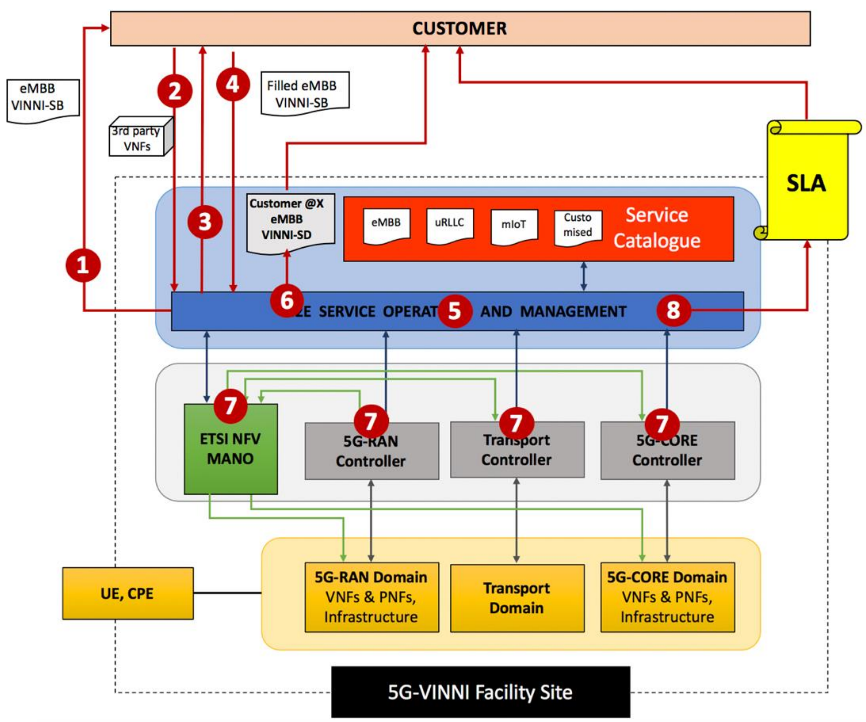

Figure 5-5: From a service order to an SLA: the CSC selects the VINNI-SB corresponding to the eMBB service type [32].

5GVINNI defines a service blueprint (VINNI-SB), from which an SLA can be signed, following the steps illustrated in Figure 5-5:

- Step 1 refers to the customer browsing the catalogue and choosing the corresponding VINNI-SB for the type of service it requires.
- Steps 2 and 3 are optional and refer to the possibility to onboard customer-specific VNFs, as well the validation of these VNFs by the service provider.
- Steps 4 and 5 refer to the issuing of an order by the customer and the verification and validation by the platform/provider.
- Step 6 is the generation of a VINNI-SD out of the service order by the platform. This service order is available for changes until it is being scheduled to be in service.
- Step 7 refers to feasibility check of the order against the resources at infrastructure level.
- Step 8 is the creation of the SLA, if the feasibility check is successful.

Signed by the customer and the provider, the SLA documents the commitment of both parties for service provisioning and operation. For this reason, the SLA shall only contain the information that is strictly necessary to guarantee the network slice service (instance) will be provided as requested by the CSC. At the service layer, this information includes:

- Mandatory parameters of the VINNI-SB, and their values.
- Enabled optional parameters of the VINNI-SB (i.e. optional parameters that are relevant for the CSC), and their values.

The VINNI-SB defined in the process above (Steps 1-8) is composed of 4 parts, as depicted in Figure 5-6.

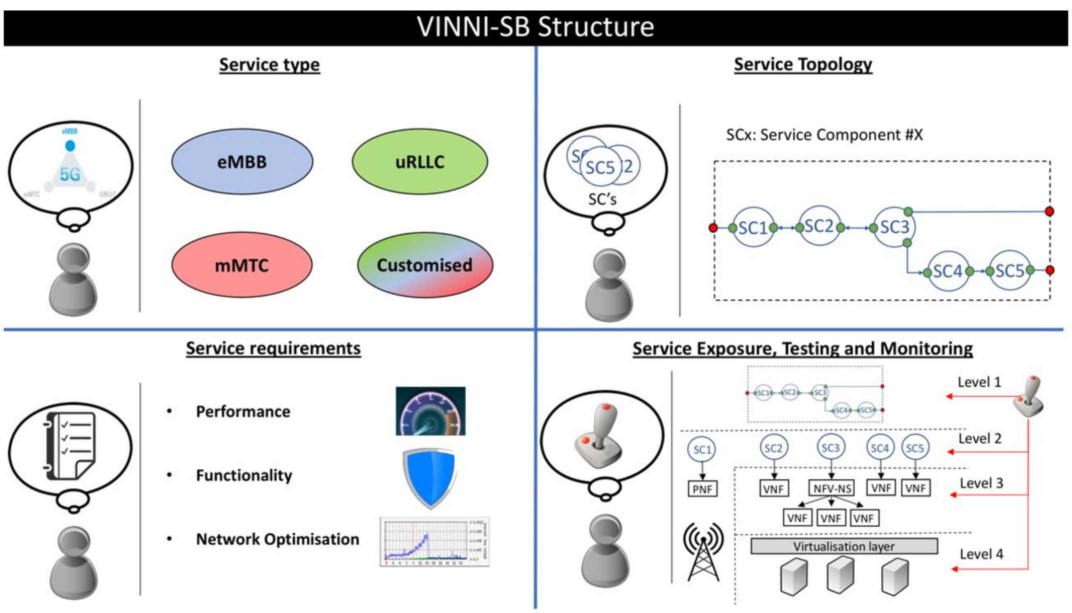

Figure 5-6: VINNI-SB Structure

The main 4 parts of a VINNI-SB are:

- **Service type**: high-level description of the slice service to be provided from this VINNI-SB (eMBB, uRLLC, mIoT and customized).

- **Service topology**: specifies the functional nodes of the slices and their associated topology. These functional nodes are technology-agnostic, modular, and can be easily chained to form different topologies, allowing for extension with the attachment of 3rd party VNFs.
- **Service requirements**: requirements of the slice service, including: i) performance requirements, ii) functional requirements and iii) network optimisation requirements.
- **Service exposure, monitoring and testing**: service capability exposure made available to the consumer. This exposure is based on a four-level classification, with each higher level allowing the consumer to gain access to a lower abstraction management entity. Depending on the selected level, the CSC can consume management data (e.g. performance measurements, fault data) and trigger enabled management operations (e.g. LCM) at different abstraction layers, which is relevant for testing and monitoring activities conducted at run-time.

Only a subset of these parameters is available to the verticals from 5G-VINNI Rel-1, after January 2020.

5.3 5G-VINNI – Patras Facility

5.3.1 Overview of site capabilities

The following Figure **5-7** illustrates the overall architecture and components of Patras facility:

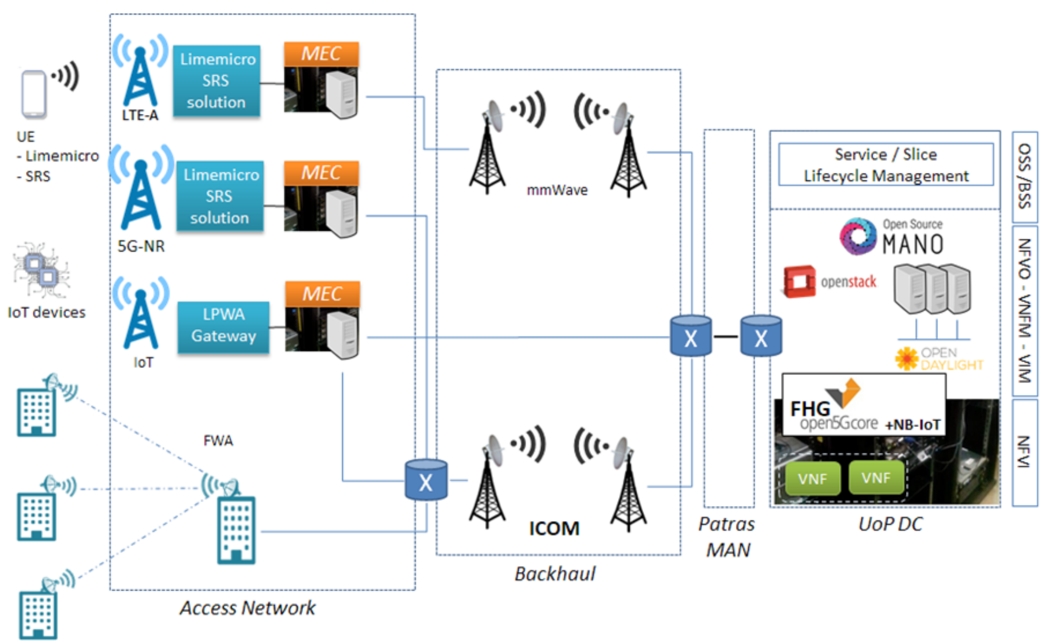

Figure 5-7: Architecture of 5G-VINNI Patras Facility [33]

As seen in the picture, the Patras facility will provide:

- 5G standard-conformant components and Core Network infrastructure (extension of the VINNI-SD Open5GCore toolkit);

- mmWave backhaul (from ICOM) to link the Access Network to the Core Network, and Fixed Wireless Access to provide broadband services to the facility;
- Integration of Fraunhofer Group (FhG) Open5GCore with Limemicro SDR platform and the SRS UE and g/Enb;
- Enabling the E2E deployment of multiple customised-slices over the whole network – access, transport and core. This will further include the slicing of the IoT devices at the edge of the network;
- Support for MEC orchestration and mobility management features for the interactive mobile streaming edge services.

A detailed description of the components supported by the Patras facility are included in Annex 2 (section 9.3). The Patras facility supports the following capabilities:

Table 5-11: Capabilities of Patras facility

No.	Capability name
1	Service Orchestration (via OSM NBI services)
2	NFV MANO (OSM) and NFVI (OpenStack)+DPDK
3	Slicing (Orchestration via OSM extensions, use of dedicated CN instances)
4	5G RAN open source radio (Lime, SRS)-700-800MHz, 3.5.-3.8GHz
5	5G Core (FhG Open5GCore)
6	SDN (ODL)
7	NB-IoT, LTE-M (FhG NB-IOT core)
8	UEs based on Limemicro's SDR and SRS software
9	mmWave backhaul (Intracom)
10	MEC support
11	GEANT[2] connectivity
12	Service Orchestration (via OSM NBI services)

The Patras 5G testbed will focus on the validation of a series of KPIs, related to developed/deployed features and the selected use cases. The set of 5G-VINNI use cases that were used for capability and KPI definition in Patras are: 1) Information society on the road (eMBB); 2) Collaborative gaming AR/VR (URLLC and eMBB), 3) Ultra-high fidelity media AR/VR (URLLS and eMBB), and (4) Intelligent navigation (URLLC and eMBB).

5.3.2 Key Features for Service Orchestration and Management

In terms of orchestration, the NFV and NS orchestration in Patras is based on OSM, initially OSM R5 in 5G-VINNI Rel-0, and progressing towards OSM R6 (with its proposed advances in terms of monitoring) after January 2020.

The Network Slice definition follows the information model described in Section 3.2, where the network services can be viewed as the resource-centric view of a network slice subnet, and these network slice

[2] https://www.geant.org/

subnets can be flexibly combined to build out different (E2E) network slices. Network slices are instantiated by NSIs, which can be managed through the Slice Manager module of the OSM NBI.

Once deployed and operative, NSIs can be delivered to corresponding OSM clients following the NSaaS (Network Slice as a Service) model, allowing customers to build on top their own services and carry out experimentation activities on the infrastructures. This delivery implies the definition of an appropriate exposure level, according to the requirements set by each OSM client and its networking expertise. Different exposure levels mean that the OSM client is allowed to consume management data at different abstraction levels, and to reach management blocks placed at different abstraction layers to trigger LCM operations.

The provisioning of NSIs can be described throughout their lifecycle. 5G EVE is aligned with the lifecycle management process for network slicing in 3GPP TS 28.530 [34], presented in Section 3. Specific operations for preparation, commissioning, operation and decommissioning phases are presented in 9.4.

5.3.3 Defining and Exposing Network Services

The Service Catalogue is a feature that will be exposed by the facility site portal and will contain various service offerings of the facility site. These service offerings will be delivered under the Network Slice as a Service (NSaaS) model. This model relies on the deployment of NSIs and their delivery towards 5G-VINNI customers, allowing them to build on top their own services and carry out experimentation activities on them.

The Service Catalogue is maintained by the facility site via the portal user interface, where the facility site can define its service offerings through VINNI-SBs, as described in Section 5.2.

5G-VINNI Customers can define requirements through service descriptors, which contain specific attributes of a Service Blueprint for the specific customer.

The Service Catalogue will also expose an API based on TM Forums OpenAPIs [35], as follows:

- TMF633 Service Catalogue Management API
- TMF641 Service Ordering

Since the facility uses OSM, the Service Catalogue utilizes the SOL005 NBI API of OSM to expose Network Service Descriptors (NDSs) as well as Network Slices Templates (NSTs). Figure **5**-**8** illustrates the Service Catalogue in OSM architecture. The Service Catalogue performs transformations from the ETSI-defined models as used by OSM for describing VNF, NSDs (SOL001, SOL004, SOL006) and the NST defined by OSM to the TM Forum OpenAPIs models.

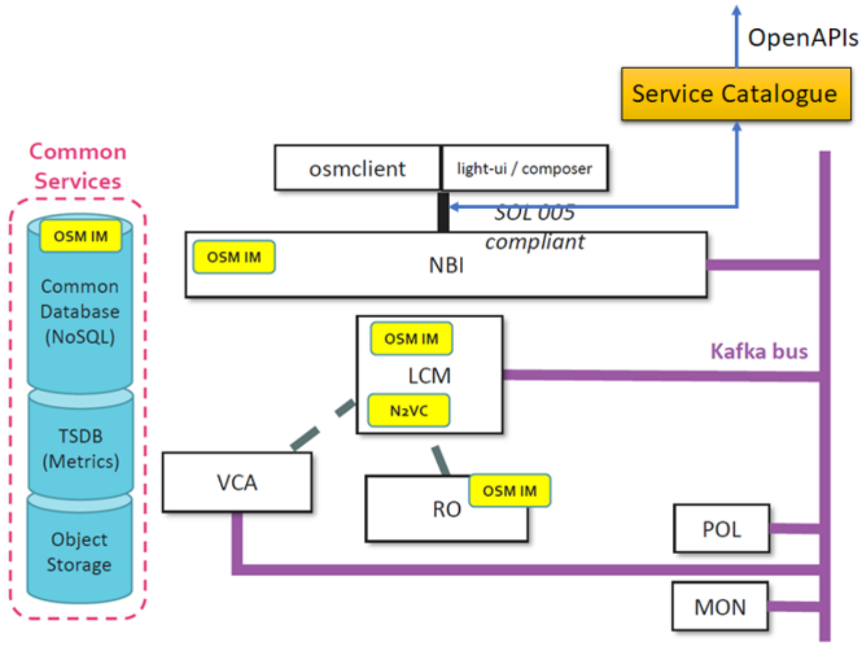

Figure 5-8: Service Catalogue in the OSM architecture [36]

5.3.3.1 Definition and On-boarding of VNF, NSD Descriptors to the Different Service Catalogues

Two roles will be able to upload VFN and NS descriptors and define slices to be onboarded in the facility site, the customer and the provider. This is done through the facility portal, which mainly:

- holds information about user data and roles retrieved from other repositories like OSM Keystone
- holds information about VNF, NSD, Network Slices
- Utilizes the OSM repository/catalogues via the OSM SOL005 NBI API
- Categorizes artifacts

Customers can access the catalogue through the Patras Facility site portal (https://patras5g.eu), where the following artifacts can be managed:

- Users
- VNFs/NSDs catalogue
- NFVO endpoints via OSM NBI
- Deployment requests

The facility site portal implements the RESTful protocols specification for the Os-Ma-nfvo [37] Reference Point. The portal will utilize the following features:

- **NS and VNF Package Management**: REST wrapper for the NS and VNF package service via resource Descriptors. Provides methods for onboarding, updating and downloading NS and VNF packages.

- **VNF Descriptor Management**: REST wrapper for VNFD descriptor management provides methods for onboarding, updating, querying, and deleting a VNF descriptor through the Individual resource Descriptors and Content.
- **VNF Lifecycle Management**: REST wrapper for the VNF lifecycle management service. Provides methods for querying a VNF and retrieving VNF records via resource Descriptors.
- **Network Service Descriptor Management**: REST wrapper for the NSD service (via resource Descriptors). Provides methods for onboarding, updating, querying, and deleting a network service descriptor.
- **Network Service Lifecycle Management**: REST wrapper for network service lifecycle management. Provides methods for instantiating, updating, finding, and terminating a network service (NFV-NS). Also provides methods for creating, updating, listing, and deleting or VNF forwarding graph (VNFFG). This will be implemented via the NS Lifecycle Management interface.
- **Network Slice Template Lifecycle Management**: REST wrapper for network slice template lifecycle management. Provides methods for instantiating, updating, finding, and terminating a NST.
- **Hosting of third party VNFs and Images management**: 3rd party VNFs can by on-boarded through the portal. However, VNF Images are uploaded to the facility site only from the Network Operator that has also access to the VIM. The customer must request the upload of VNF Images and also provide any licensing details.
- **VNF, NSD validation**: The facility site portal makes a validation in terms of packaging compliance and modeling. The facility site portal currently supports descriptors following the ETSI proposed YANG models (e.g. SOL001, SOL004, SOL006).
- **VNF upgrade/migration/suspension issues and dependencies with NSDs**: Deployed NSDs depend on specific on-boarded VNFs. Currently it is not possible to upgrade these VNFs due to dependencies.

5.4 5G-VINNI – Norway Facility

5.4.1 Overview

5.4.1.1 Overall architecture

The Norway facility is based on a collaboration between Telenor (providing the transport network and operational functionality), Ericsson (providing the 5G EPC/5G Core and 5G RAN components), Huawei (providing 5G RAN components), and Nokia (involved in orchestration).

Figure 5-9 shows the overall network architecture and how it is mapped to ETSI NFV. 5G Radio network will be provided by Ericsson and Huawei while 5G EPC, VNF-EMS and VNF-M will be provided by Ericsson and finally Nokia will be providing NFVI, NFVO, VIM and Service Orchestration functionality. VNF-M functionality is part of Ericsson's EMS product. Optionally it is also possible to deploy Nokia's VNF-M for 3rd party VNF applications. 5G Core will be provided in a later stage, beyond Release 1 (after January 2020).

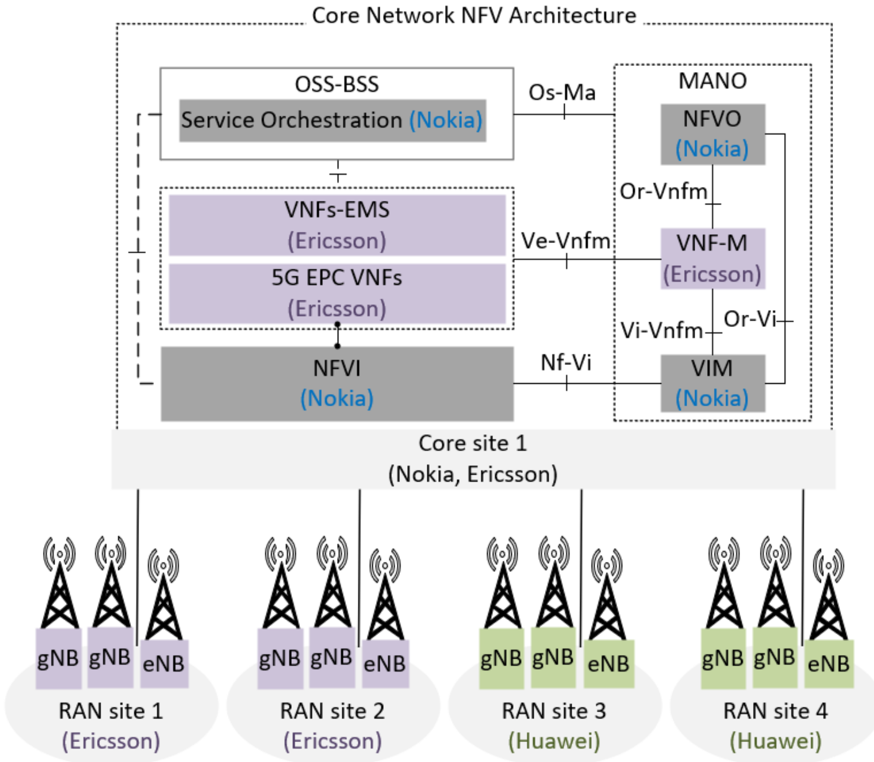

Figure 5-9: Norway facility overall network architecture [38]

5.4.1.2 *Supported Capabilities*

The Norway facility supports the following capabilities:

Table 5-12: Capabilities of Norway facility

No.	Capability name	Norway
1	5G New radio	Rel-1
2	Integrated low power wide area networks	Rel-1
3	5G-Core	Beyond Rel-1
4	Network slicing based on 5G-EPC	Rel-1
5	Network slicing based on 5G-Core	Beyond Rel-1
6	NFVI	Rel-1
7	MANO	Rel-1
8	E2E Service Orchestration	Rel-1
9	Edge computing	Beyond Rel-1
10	MEC Compliant edge computing	-
11	On-boarding containerized workloads	Rel-1
12	SD-WAN	-
13	Control user Plane separation (CUPS) architecture for maximum topology flexibility	Rel-1
14	Secure architecture with infrastructure zoning and with L4-7 Firewalling capabilities	Rel-1

The following capabilities and types of services are offered by 5G-VINNI Norway to ICT-19 projects:

Table 5-13: Types of services offered by 5G-VINNI Norway to ICT-19 projects

No.	Technical Services offered in Release 1 or beyond Release 1	Norway
1	eMBB slice	YES, in Rel-1
2	URLLC slice	YES, in Rel-1
3	mMTC slice	YES, in Rel-1
4	Autonomous core in the edge / Self-contained network (a)	YES, beyond Rel-1
5	Fixed wireless access	YES, in Rel-1
6	Firewalling (Layer4-7)	YES, in Rel-1
7	Flexible backhaul for redundancy (say via satellite) (b)	YES, beyond Rel-1
8	Interconnection with Public cloud (c)	YES, beyond Rel-1
9	Data fabric service involving correlation, aggregation and analytics (d)	YES, beyond Rel-1
10	Test and KPI validation	YES, in Rel-1
11	3rd party VNF hosting	YES, beyond Rel-1
12	Edge cloud	YES, beyond Rel-1
13	Interconnection with other 5G-VINNI Facility-sites	YES, beyond Rel-1
14	Interconnection with non-5G-VINNI Facility-sites (to be offered based on demand)	YES, beyond Rel-1
15	Individual device connectivity (both eMBB and IoT) to 5G-VINNI Facility via default slice	YES, in Rel-1

Remarks:

(a) ***Autonomous core in the edge / Self-contained network****:* This service involves spinning up a mobile core (Both control and data plane) in the edge for example in case the backhaul connection is broken which is essentially a self-contained network;

(b) ***Flexible backhaul for redundancy****:* This service involves providing redundancy in the backhaul for example via Satellite link;

(c) ***Interconnection with Public Cloud****:* The possibility of hosting the network functions in public cloud or extending the network slice in the public cloud;

(d) ***Data Fabric service****:* Service to extract, compute/transform and move data across the distributed network Facility (edge, fog, core).

Detailed information on the Network Functions supported by 5G-VINNI Norway is given in Annex 3 (section 10).

5.4.2 5G-VINNI Norway Orchestration Solution

5.4.2.1 MANO and NFVI

The orchestration solution in 5G-VINNI Norway is mainly based on the Nokia suite of orchestration products. The main MANO components are:

- A Virtual Infrastructure Manager (VIM) which is OpenStack based. For this site VIM is provided by NOKIA and its NCIR (NOKIA Cloud Infrastructure Real-time) software;
- There will be two Virtual Network Function Managers (VNFM) deployed in this site. Initially it will be the Ericsson ENM (Ericsson Network Management) and later for 3rd party applications, NOKIA's CloudBand Application Manager (CBAM) as generic VNFM. There is an optional VNFM, Nokia G-VNFM, intended for 3rd party VNFs when it is requested (no plan for deployment in Release 1);
- For Network Function Virtualization Orchestrator (NFVO), it will be NOKIA's CloudBand Network Director (CBND). It will be connected to VIM, VNFM and SDN Orchestrator (Nuage);
- On top of the NFVO there is a Service Orchestrator provided by NOKIA, FlowOne, which will be responsible for slicing lifecycle management;
- Software define network (SDN) is accomplished by deploying Nuage SDN platform.

For network orchestration and slicing management purposes, integration between the Service Orchestrator (FlowOne), NFVO (CBND) and Ericsson VNFM/EMS will be needed.

Figure 5-10 describes the Integration of MANO and NFVI, in which:

- **NEI** (Network Element Interface): A plugin maybe required between SO and EMS.
- **VNFM Plugin**: A plugin for Or-Vnfm will be developed between NFVO and S-VNFM.
- **VNO Plugin**: A plugin for Or-Vi will be developed between NFVO and VIM.

The hardware platform for 5G-VINNI is built based on NOKIA Airframe OR (Open Rack) hardware, NOKIA Airframe management switch and Nuage WBX leaf switches.

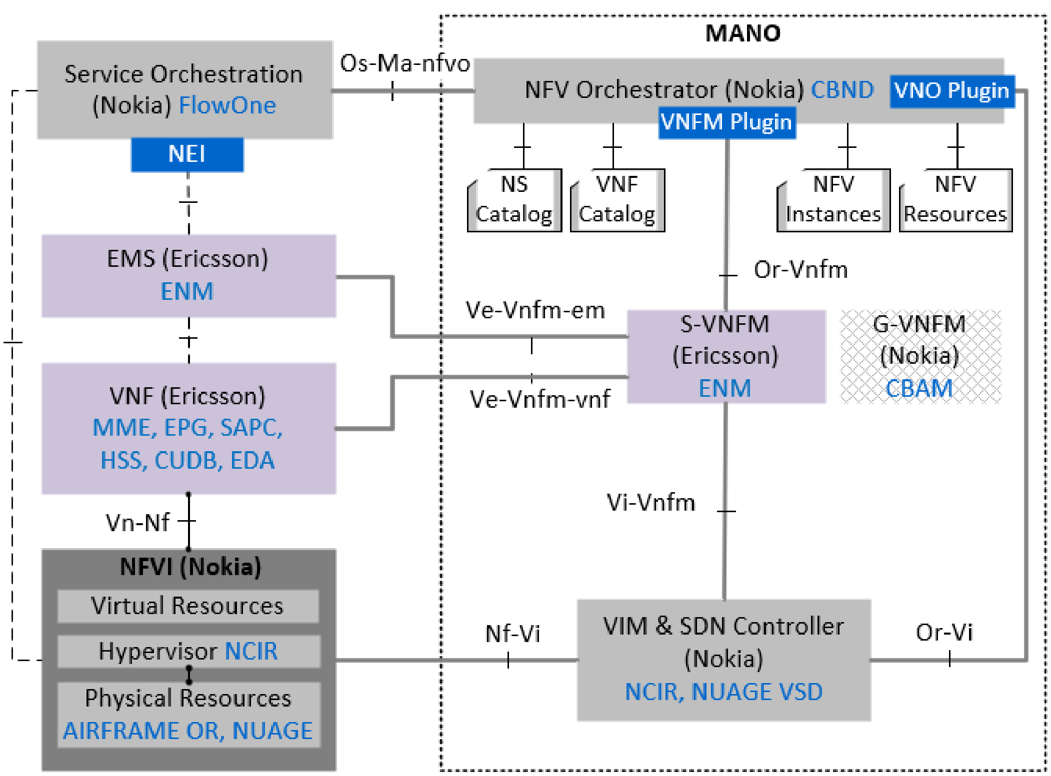

Figure 5-10: Norway Facility-site MANO and NFVI [38]

The interconnection between those components may require specific APIs and plugins, which are still in the analysis phase. The architecture components and their implementation are listed in Table **5-14**:

Table 5-14: Norway – Architecture and Implementation of management and orchestration

No.	Architecture recommendation	Implementation in Norway
1	NFVI Virtual Compute based on ETSI architecture	Supported, Rel-1: This will be based on **OpenStack NOVA service (NOKIA NCIR)**
2	NFVI Virtual Network based on ETSI architecture	Supported, Rel-1: Virtual network will be based on an enhanced DPDK solution (**Nuage AVRS**)
3	NFVI Virtual Storage based on ETSI architecture	Supported, Rel-1: Software defined storage will be implemented based on CEPH. OpenStack's Cinder and Nova services could be the clients
4	NFVI Compute	Supported, Rel-1: A hardware platform based Open Rack (OR) solution is used.
5	NFVI Storage	Supported, Rel-1: For storage OR servers will be used (2OU each)
6	NFVI Network	Supported, Rel-1: It's a one rack solution using a pair of leaf switches (Nuage WBX 210)
7	VIM based on ETSI architecture	Supported, Rel-1: VIM is based on OpenStack with three controllers (NOKIA NCIR)
8	VNFM based on ETSI architecture	Supported, Rel-1: There will be two types of VNFM. One specific VNFM (S-VNFM) for Ericsson's VNFs and potentially a generic VNFM (G-VNFM) for future deployments. G-VNFM will not be deployed initially
9	NFVO based on ETSI architecture	Supported, Rel-1: NFVO is according to ETSI architecture and interfaces. It will act as Service and Resource Orchestrator, with interface to VNFMs, VIM. It will also have interfaces to SDN and firewalls. For NFVO<—>VNFM (Ericsson) interface, a specific plugin was developed.
10	NFVO supports multiple VIM support	Supported, Rel-1: This can be supported, but currently there is only one site deployed in Telenor 5G-VINNI, thus NFVO will be integrated to only one VIM
11	NFVO to SDN integration	Supported, Rel-1: For on-boarding NFVO will be interact with SDN Orchestrator (Nuage VSP) for external network creation.
12	Catalog-driven orchestration across multiple management domains	Supported. Using Nokia FlowOne Rel-1
13	Onboard component specifications from third party sources (e.g. resource layer)	Supported. Using Nokia FlowOne Rel-1

14	E2E Service Catalogue: assembling the design service design (e.g. layout, parameters, transactions, policies, etc.)	Supported. Using Nokia FlowOne Rel-1
15	E2E Service Catalogue: publishing service catalog to northbound BSS functions	Supported. Using Nokia FlowOne Rel-1
16	E2E Active Inventory: persist service instance representations and pertaining virtual and physical resources	Supported. Using Nokia FlowOne Rel-1
17	E2E Service Process Manager: Scheduling, assigning and coordinating Customer provisioning related activities	Supported. Using Nokia FlowOne Rel-1
18	E2E Service Process Manager: Enriching or modifying request/order information under execution	Supported. Using Nokia FlowOne Rel-1
19	Verifying whether specific Service Request sought by Customers are feasible	Basic support for re-use of slices in Rel-1. Complex qualification scenarios beyond Rel-1 on case-by-case basis
20	E2E Service Process Manager: Decomposition of the Service into Service Components	Supported. Using Nokia FlowOne Rel-1
21	Coordinate execution of the service delivery orchestration plan, delegating Service Component implementation to Network Domain Controllers (e.g., sub-network connectivity), NFV MANO and external providers or partners	Supported. Using Nokia FlowOne Re l1

5.4.2.2 Network Slice / Service Orchestration

Nokia FlowOne solution is taking care of the E2E service orchestration function, including:

- Centralized SOM, all service delivery is managed in one place.
- Service lifecycle management for network slices and for UE provisioning, taking care of the correct delivery sequence when delivery order contains multiple hybrid services and steps.
- Service Model contains models how different services are delivered and needed resources reserved along different delivery processes. System can expose service model and its detailed information via API to external systems for e.g. enabling product service mapping with versioning.
- Install Base – external or internal and manages existing subscriptions and their services and resources up-to-date information.

The Nokia FlowOne architecture for Release 1 is illustrated in Figure **5**-**11**.

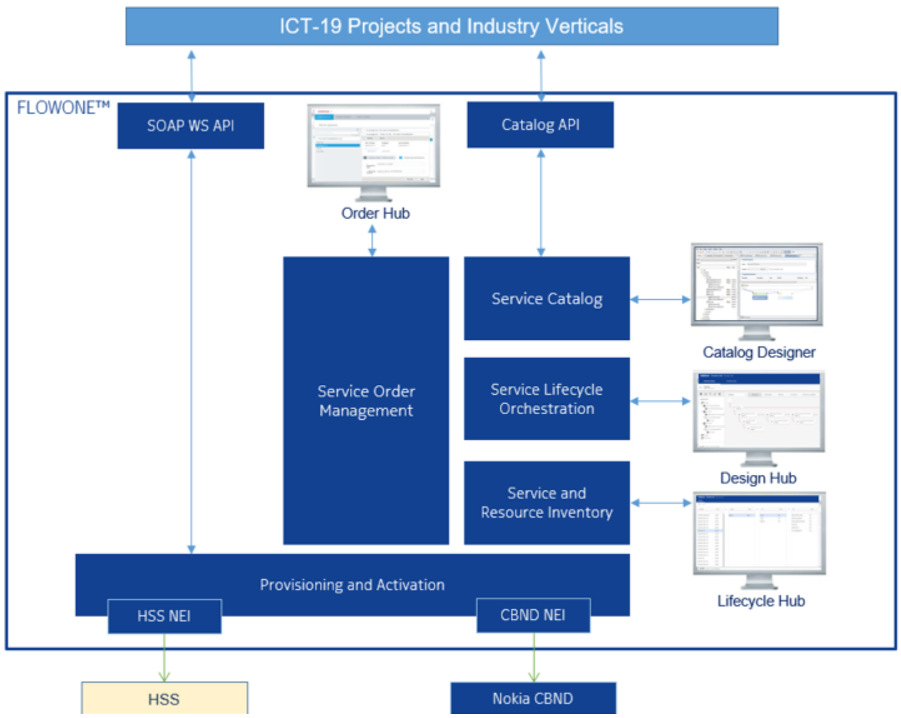

Figure 5-11: Norway Facility-site e2e Service Orchestration Architecture and Functions [38]

Table **5-15** describes each of the FlowOne components in Figure **5-11**, that will be deployed as part of 5G-VINNI Release 0.

Table 5-15: Norway Facility-site Nokia e2e Service Modules for Rel-0

Component	Description
Design Hub	User interface for designing service specification
Lifecycle Hub	User interface for accessing the service inventory
Order Hub	User interface to handle fallouts/error management
Service Lifecycle Orchestrator	Functionality for managing onboarding of network services and VNF's
Service Catalog Designer	User interface for designing service specification
Order Management	Nokia Order Management has the capabilities to control and monitor the progress of the service order from receipt to activation, through all the necessary physical an electronic workflow stage.
Service Catalog	Provides the service definitions and decompositions to more detailed service and resource level specifications
Service and Resource Inventory	In this project, FlowOne Service and Resource Inventory will be the master for network slice instances and UE subscriptions
Provisioning and Activation	Provides southbound integration capabilities to CloudBand NFVO and Ericsson HSS

In terms of Lifecycle Management of Network Slices, 5G-VINNI Release 0 will provide only a basic capability for network slice services, based on eDecor. The NSDs, containing associated VNFs, will be on-boarded into FlowOne and then used as templates to instantiate the network slices. From Release 1, FlowOne will support activities in the four 4 phases of the network slice lifecycle as described by 3GPP and presented in Section 3 (Figure **3**-**6**), starting with Provision and Decommission.

5.4.2.3 Service Catalogue

Since the service orchestration is realized by FlowOne, the service catalogue solution is therefore similar to the FlowOne solution, except for the implemented slice and NSD compositions.

The following B2B customer-facing services will be available to order: (1) eMBB, (2) mMTC, (3) URLLC. Once a slice service is ordered and is activated, it becomes available for end users (e.g., mobile phones, IoT devices, etc.) to order and subscribe. The following B2B2C customer-facing services will also be available for end users (Consumers) to order: (1) user Equipment for slice type eMBB, (2) user Equipment for slice type: mMTC, (3) user Equipment for slice type: URLLC

5.4.3 APIs

5.4.3.1 Internal Interfaces

A set of Interfaces/API's are being designed and will be implemented in the facility site across different nodes & domains. Table **5**-**16** enumerates the relevant APIs. Note that this is not an exhaustive list. There could be deviation during the project period.

Table 5-16: Norway Facility APIs

No.	Interface	Interconnection points	Norway
1	Or-Vnfm	NFVO<->VNFM	Https/Rest
2	Vi-Vnfm	VNFM<->VIM	Https/Rest
3	Ve-Vnfm-em/vnf	VNFM <-> EMS/VNF	SSH/SFTP, IIOP/TCP
4	Or-Vi	NFVO<->VIM	Http/Rest
5	Os-Nfvo	E2E SO<-> NFVO	Http/Rest
6	S1-C	gNodeB<->MME	SCTP, A1AP
7	S1-U	gNodeB<->SGW/PGW	GTP, 3GPP Rel-15
8	S6a	MME<->HSS	Diameter, 3GPP Rel-15
9	Mun	gNodeB<->ENM	Http/Rest
10	S5/S8	SGW<->PGW	GTP-C/U, 3GPP Rel-15
11	S11	MME<->SGW	GTP-C, 3GPP Rel-15
12	SGI	PGW<->External connections	3GPP Rel-15
13	Gx	PGW<->PCRF	Diameter, 3GPP Rel-15
14	Prov 1	Provisioning GW<->E2E SO	Cai3g (over SOAP)
15	Ud	CUDB<->HSS	LDAP
16	Sp/Ud	PCRF<->SPR PCRF<->CUDB	LDAP
17	Counters / alarms	ENM<->Core VNFs	sftp, snmp
18	ALLEGRO	E2E SO<->Customer	SOAP (https/Rest in future releases)
19	PRESTO	E2E SO<->Core EMS	TBD in future Releases
20	PRESTO	E2E SO<->RAN EMS	TBD in future Releases
21	PRESTO	E2E SO<->Transport EMS	TBD in future Releases

The E2E SO <-> Customer SOAP interface has been identified as a point of interest for integration with 5G-SOLUTIONS.

5.4.3.2 External Interfaces

Several external-facing interfaces are provided by the Norway facility site to their customers for accessing the catalogue management and requesting to deploy artifacts.

1. Catalogue Management interface: based on TMF 633 for querying the catalogue. The service catalogue also comes with an ‘on-boarding manager’ and a ‘design canvas’. It is suitable for human operation. One can on-board NSDs from NFVOs and then design a slice template and then *publish* it to make it available for ordering.
2. LCM interface: The Ordering portal is a BSS system not in the scope of 5G-VINNI, but work is ongoing to find an ordering portal. FlowOne will expose Service Ordering API based on TMF641. As a starting point, manual operations must be used.
3. Monitoring interface: monitoring of the network slice delivery order across its phases is available.
4. Resource Management interface: as an E2E orchestrator, FlowOne inventory will provide views of resources and its possible relationship with a customer. However, there is not much scope for resource management or resource LCM. This has to come in as LCM requests, via ordering.

Nokia FlowOne comes with the Service Catalogue and orchestrates the E2E service. It will on-board NSDs (Network Service Descriptors) from the NFVO. The NSDs shall be TOSCA-based service specifications. Once on-boarded, a solution designer (human) will use the Design Hub to design Slice specifications.

For inter-working with other facilities, the Norway facility is planned to inter-work with a 5G-VINNI UK Facility-site at the E2E Service Operations layer through the following interfaces, supported through the use of FlowOne:

- Service Ordering API
- Activation and Configuration API
- Service Inventory API
- Service Catalogue API

6 Challenges and Recommendations for 5G-SOLUTIONS Service Orchestration

6.1 Challenges

Section 3 discussed current standards and solutions for multi-domain orchestration, with their known challenges in terms of performance, APIs and models, etc. Section 5 presented the 3 platforms that 5G-SOLUTIONS will deploy use cases on, and interact with for the orchestration of the 5G-SOLUTIONS use cases. From the collaborations we started with 5G-EVE and 5G-VINNI, it became apparent that there are a number of challenges that we will need to address in 5G-SOLUTIONS for orchestration purposes:

1. While some of the 5G-EVE and 5G-VINNI orchestration implementations are known (e.g., for NFV MANO, 5G-EVE is based on OSM R4, 5G-VINNI Patras is based on OSM R5 evolving towards OSM R6, and 5G-VINNI Norway is based on Nokia CBND), the deployments are still ongoing and some of the details, requirements and APIs are not yet fully set in stone. For example, 5G-VINNI plans to have a first version of their orchestrator in place by M7 of 5G-SOLUTIONS, while 5G-EVE after M7, in 2020.
2. Moreover, ICT-17 projects were focused on providing 5G experimentation and KPI measurement platforms. While support for verticals exists in all of these platforms, the process to integrate with the platforms is yet to be defined and is currently work in progress.

These challenges are taken onboard by 5G-SOLUTIONS and addressed through several activities:

1. Collection of requirements for orchestration and classification of the use cases according to the type of orchestration support needed in 5G-SOLUTIONS. The results of these are presented in Section 6.3.
2. Collaborative effort between (a) UC owners, (b) underlying platforms, and (c) the 5G-SOLUTIONS CDSO (developed in WP2) to bridge the gap between application-level service description and Network Slice / Network Service Descriptor definition. In order to advance in this important area for integrating 5G-SOLUTIONS with 5G-EVE and 5G-VINNI platforms, Living Labs sessions have been organised with the involvement of all stakeholders (LL owners, UC owners, underlying platform owners, CDSO owners) and overseen by the Technical Management Committee. This is an ongoing process and its results will be included in the next version of this deliverable, as well as in the other impacted deliverables from different WPs.

6.2 Boundaries and Integration Points for Orchestration Between 5G-SOLUTIONS and the Underlying Platforms

The first rounds of discussions regarding the integration between 5G-SOLUTIONS use cases and 5G EVE / 5G-VINNI as the underlying platforms have led to the following conclusions:

- 5G EVE and 5G VINNI use OSM (R4, R5 evolving towards R6) and CBND as VNF orchestrators;
- They all abide by the Network Slice lifecycle management defined by 3GPP in TR28.801, as described in Section 3;
- 5G EVE's preference is to integrate with 5G-SOLUTIONS through the experimentation portal, and rely for the orchestration of the use cases on the orchestration tools in 5G EVE, as described in Section 5.1;

- 5G-VINNI is not in favour of exposing orchestrator-to-orchestrator APIs or using the SOL005 NBI for inter-domain communication. Instead 5G-VINNI will be compliant with TM Forum's Open API, in particular with regard to Service Catalogue and Ordering;
- Inter-site orchestration within 5G eve and 5G-VINNI is covered by the ICT-17 projects themselves.

These points are still under discussion and a more thorough analysis will be included in the next version of this deliverable.

6.3 Integration Requirements for 5G-SOLUTIONS Use Cases

For each of the use cases defined and described in D1.1, we have expanded the information presented in Table **4**-**1** with the use case proposed type of integration for orchestration. As such, we have classified the type of support needed for the orchestration into 2 categories, as described in deliverable D2.1:

(a) **Category A**: use cases that are planning to use the ICT-17 facility orchestration solution. In this case, the 5G-SOLUTIONS orchestrator requires from the underlying platform at least the following lifecycle actions:
   1. Activate Service –trigger the service deployment for the given service,
   2. Get Service Status –query the local orchestrator for the status of the deployed service,
   3. Subscribe to notifications – in case the ICT-17 platform orchestrator supports this, we will subscribe to notifications and display them in our event stream,
   4. Terminate Service –trigger the termination of the service.

   It is expected that in all ICT17 projects we integrate with, the API expose is https/REST based and that we have connectivity from the 5G-SOLUTIONS orchestrator to that API (directly or via VPN) and credentials are provided.

(b) **Category B**: use cases that are not using the ICT-17 platform orchestration solution. In this case, we differentiate between the following options:
   1. The use case has its own MANO orchestrator that is orchestrating it – in this case, it will be treated as Type A and lifecycle actions triggered from 5G-SOLUTIONS orchestrator;
   2. The use case needs to be orchestrated but does not have an orchestration solution. In this case, the 5G-SOLUTIONS orchestrator will provide end-to-end orchestration (including MANO NFV);
   3. The use case is orchestrated manually. In this use case, a close collaboration with the Use Case owner is needed to decide how this use case is reflected in 5G-SOLUTIONS orchestrator.

Table **6**-**1** presents a summary of the use case classification based on Type A/B support for orchestration, with the current level of understanding, taking into account that some use cases are more mature in their definition, while others are just starting.

Table 6-1: Summary of UC classification based on Type A/B support for orchestration

UC#	Use Case Title	Type of Orchestration	ICT-17 Project Site
1.1	Time-critical process optimization inside digital factories	B	Patras
1.2	Non-time-critical communication inside the factory	B	Patras
1.3	Remotely controlling digital factories	Undefined	Undefined
1.4	Connected goods	B	Patras
1.5	Rapid deployment, auto/re-configuration, testing of new robots	A	Norway
2.1	Industrial Demand Side management	A	Turin
2.2	Electrical Vehicle Smart Charging	A	Turin
2.3	Electricity Network Frequency Stability	A	Turin
3.1	Intelligent Street Lighting	Undefined	Undefined
3.2	Smart Parking	Undefined	Undefined
3.3	Smart City Co-Creation	A	Patras
3.4	Smart Buildings – Smart Campus	Undefined	Undefined
3.5	Autonomous Assets and Logistics for Smart Port	A	Oslo
3.6	Port Safety – Monitor & Detect Irregular Sounds	A	Oslo
4.1	Ultra High-Fidelity	A	Patras
4.2	Multi CDN Selection	A	Patras
4.3	On-site Live Event Experience	A	Patras
4.4	User & Machine Generated Content	A	Patras
4.5	Immersive and Integrated Media and Gaming	Undefined	Undefined
4.6	Cooperative Media Production	A	Patras

As can be seen in the table above, 12 use cases are of Type A, 2 of Type B, while 6 are undefined at this point in time. The first priority in terms of orchestration will be to integrate the use cases of Type A, while in parallel allowing the discussions for the Use Cases of Type B to evolve, so that we have a better definition of their requirements in terms of orchestration.

6.4 The Nokia CBND Orchestrator

We are planning to use the Nokia CloudBand Network Director (CBND) as a starting point for service orchestration in 5G-SOLUTIONS, where needed.

6.4.1 Functionality of CBND

CBND is aligned with the NFV Orchestrator functionality as defined by ETSI NFV MANO GS. CBND also automates lifecycle management of VNFs and Network Services and the corresponding virtualized network resources in full consistency with the defined business priorities and the relevant SLA parameters. The dynamic network level elasticity management ensures to align the resource consumption with the actual business priorities. CBND provides ease of use, the time and effort for VNF / Network Service provisioning (once defined) being reduced nearly to the dimension of a few clicks. Another advantage of using CBND is the use of well-defined open interfaces. Figure **6-1** shows the CBND components alignment with the ETSI NFV MANO view.

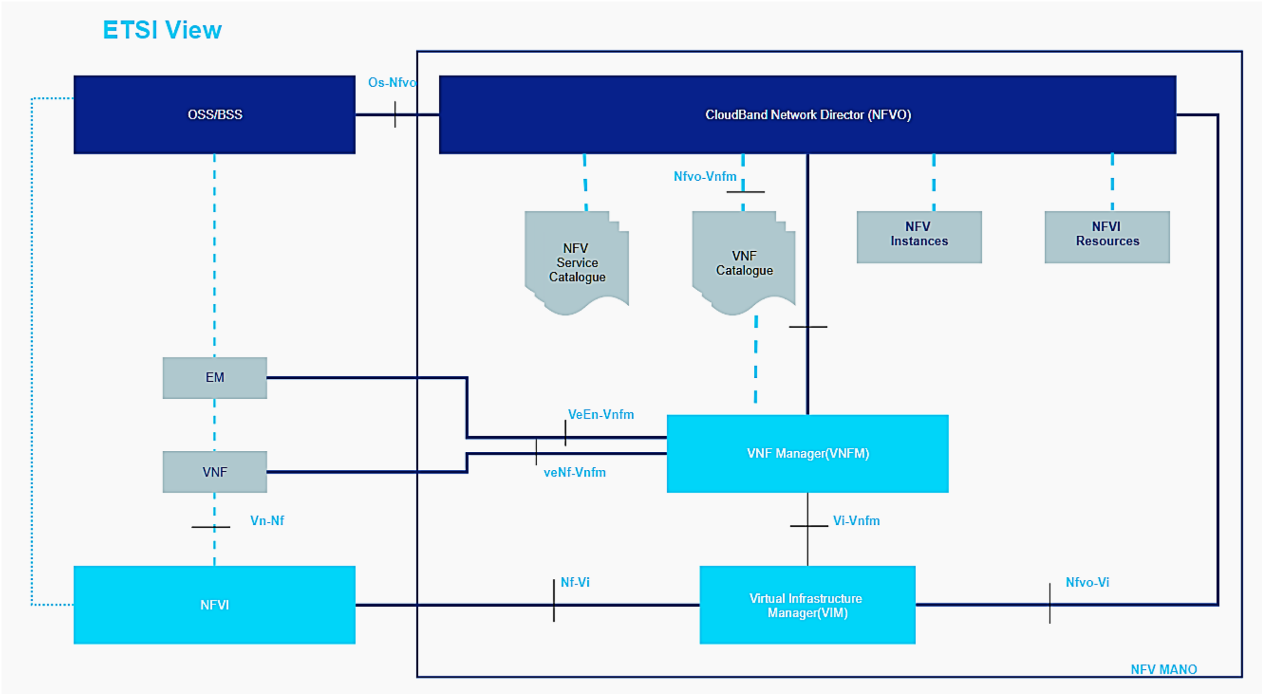

Figure 6-1: Alignment of CBND architecture with the ETSI NFC MANO view

The functionalities provided by CBND can be broadly classified into the following:

- Virtual Network Functions lifecycle management – deploy, configure, update, terminate,
- Network service lifecycle management – deploy, configure, update, terminate,
- Closed loop automated operations (such as NS LCM, custom workflows, VNF LCM etc.) based on the changing dynamic conditions of NS, VNF, managed resources and additional external event,
- Catalog of Virtual Network Functions Descriptors, Network Service Descriptors, and virtual networking components described using TOSCA,
- Inventory of NFVI resources, deployed network services and VNFs,
- Virtual Network Functions and Network service scaling to handle varying network loads,
- Virtual Network Functions and Network service monitoring for fault and performance,
- Disaster recovery management,
- Policy management framework for rule-based lifecycle management and orchestration,
- Multi-vendor, multi-technology and multi-cloud stack support for orchestration,
- RESTful open interfaces for efficient multi-vendor Telco cloud management.

CBND has been designed based on plug-in architecture principles, keeping the core business logic of orchestration intact, while supporting a varying ecosystem for orchestration. This is one of the reasons why we believe that the integration of CBND with the underlying platforms solutions is feasible.

CBND maintains a global view of all available and used NFVI resources across multiple data centers and clouds. It is normally integrated with multiple VNF Managers from different vendors to orchestrate network services composed of network functions from several vendors.

CBND is based on the concept of Network Service and Network Service Graph (NSG). The NSG describes a set of closely inter-working VNFs, which together realize higher level Network Services. Some NSGs may be directly associated to business services, and some may provide additional network resources that are required for the implementation of the business services. The NSG Template lists the VNFs composing the Forwarding Graph (a Forwarding Graph is subset of NSG closely inter-working VNFs) and also specifies how VNFs are interconnected.

As the evolution of the mobile network towards a fully virtualized architecture and 5G is envisioned to take place in a phased approach, the connection of still existing traditional physical resources is also described. The CBND stores the available Network Service Packages in the Network Service Graph Template Database.

CBND needs to interact with other products which are needed to realize the solution. The list of other products which form Nokia's CloudBand solution are the following:

- CloudBand Application Manager (VNF Manager)
- CloudBand Infrastructure Software (including Virtualized Infrastructure Manager (VIM))

CBND is a Multi-Vendor solution, there are business cases when CBND needs to interact with the VNFM of other vendors to instantiate and manage multi-vendor VNFs. CBND needs to interact with different VIMs like VMWare, OpenStack, etc. For this interaction, specific plugins can be defined.

6.4.2 The CBND Plugin Mechanism

In CBND, there is a plugin mechanism that allows easy customization of the entities managed and orchestrated by CBND. By default, the following types of entities are supported:

- **VIM** – Virtual Infrastructure Manager, a cloud infrastructure management such as Openstack or VMWare.
- **VNFM** – Virtual Network Function Manager, a management system to manage the lifecycle of virtual network functions (networking applications running in the cloud).
- **SDN Controller** – a software defined networks controller.
- **NF** – Network Function, a generic entity with network connectivity.

The plugins can be created for any of the above types or there is also an option to define new types though most new types can be modeled via the generic NF type. A plugin consists of the following components:

- **XML file** (mandatory), an XML defining the plugin;
- **Plugin Code** (optional), a piece of SW code implementing REST APIs to support the plugin. Code can be implemented in any programming language but most CBND plugins are in Java thus the code examples are also in Java. Not all plugins require code. Code is needed for example (1) when you want to provide monitoring for the entity or (2) when you need to implement an interface with a non ETSI compliant VNFM;
- **Mistral Workflow** (optional), a workflow to support the specific plugin behavior.;
- **TOSCA block** (optional), a Tosca-based definitions block to support the specific plugin behavior.

The following flows can be supported by the plugin mechanism:

1. **Define new inventory type**: Define the managed entity to be supported.
2. **Status Monitoring**: Define how to monitor the status of the new entry defined. Requires definition of a REST API to return the status according to a known format. (Note: some types support additional monitoring metrics (e.g. VIM).

3. **Connect to Network Service**: Define how to connect the entry to be part of an orchestrated service. Requires to define the parameters that will be requested when deploying the network service.
4. **Define a new type**: When existing types are not sufficient, can define new types (will require code). Can define the parameters needed to create the entity. Can validate the parameters and provide options.
5. **Define a new Mistral Workflow**: May be needed if the flow of operations when deploying the network service is different from the default.
6. **Physical Network Function (PNF)**: By default, the TOSCA block supports definition of a PNF but all needed functionality to support it has to be provided (e.g. the supporting code).

More detailed information on CBND and its proposed use is reported in the context of task T2.1, including deliverable D2.2. The options that we are exploring at the moment in 5G-SOLUTIONS in terms of E2E Slice management using CBND are:

1. CBND is a Network Service orchestrator that can be customized to handle multiple domains and coordinate slices across the different domains for fulfilment of different network services.
2. Using CBND with FlowOne used also in 5G-VINNI. FlowOne is needed when there are multiple slices to manage and we are talking about Telco scale production cases. In our case where we manage just a few specific use cases, FlowOne is not mandatory (but can also be considered). The starting point is to use only CBND for 5G-SOLUTIONS.

New plugins may be developed as needed according to the use cases we need to support. The exact plugins to be developed in 5G-SOLUTIONS will be defined as ICT-17 platforms' APIs are determined and use cases are defined and confirmed.

7 Extensions Towards Introducing More Automation in the Orchestration Area

In addition to the integration to the ICT-17 platforms, we are also investigating the introduction of Machine Learning based approaches as a means to optimize the end-to-end orchestration of Use Cases in 5G-SOLUTIONS.

7.1 Need for Automation and Prediction in a 5G Network

Automation has been a desired goal in telecom network management for many years. In the past, it has been slowly adopted as part of the network management domain, as traditionally network management knowledge has been built through experience and many operators felt that they needed control over the network behavior and settings, particularly as every network will come with its own particular settings, capabilities and deployments. However, with the emergence of 5G, it has become apparent that traditional manual ways of managing networks have become very costly and practically infeasible due to the scale, complexity and dynamicity of networks. In this new environment, automation becomes an essential component of future network management. Furthermore, 5G networks have defined the goal of supporting very diverse sets of use cases, both in terms of a diverse set of end users and sets of requirements that can be very different, ranging from ultra-reliable low latency (URLLC) to massive machine to machine communications (mMTC). This highlights the need for a flexible network management solution that can adapt to this very dynamic type of platform. In addition to this, we are now also talking about new network business models (e.g., XaaS models - IaaS, PaaS, NaaS, network sharing, etc.)

Therefore, virtualization has been introduced as a fundamental mechanism for reducing the costs in the network and providing the required flexibility needed in the new networks. However, this also introduces new challenges in terms of properly managing the extra complexity added by virtualization. Knowledge about the network will have to be built, with the understanding that it is very dynamic in nature and contexts change quite rapidly. Therefore, with 5G we are talking about a move from autonomic towards cognitive computing, in which machine learning and context awareness play a crucial role towards the proper functioning of the network [39].

7.2 Rule-based & ML-based Approaches

In the past, the need for automation had already been addressed in context of 4G by the introduction of self-* concepts such as self-configuration, self-optimization, self-healing, etc. However, the majority of these solutions that mainly target specific areas of automation (for example SON), still follow strict rule-based approaches that need to be designed by experts in the domain. One of the problems with these systems is that they will fail to scale with the ever-growing complexity of 5G networks and make it difficult to get a coherent picture of the holistic network status. This highlights the importance of adaptive and data-driven approaches to address dynamic nature of emerging telecom networks.

In the general, in the area of automation there are two main approaches:

1) **Rule-based approaches**: these approaches aim to address specifically defined automation needs in the network by use of predefined rules and policies. While these policies can also be adaptive

to address dynamic conditions of the network, they still need to be specifically defined by domain experts to individually deal with different problems in the network.
The upside to having a policy driven automation is that the solutions are usually robust and well defined to address specific tasks. However, they won't be able to scale with variation of problems in the network or complexity of the network, which may define new unknown issues that haven't yet been investigated.

2) **Data-driven approaches**: the second approach is to use data-driven techniques such as Machine Learning (ML) to learn the behavior of networks using statistics and measurements that are continuously generated and collected at different stages of lifecycle of the network.
The upside of using ML approaches is that they can readily scale and accommodate the dynamic nature of the network, i.e. the automation rules and policies are not required to be tailored for specific issues in the network. Further, these solutions are dynamic i.e. they are not required to be modified or amended as the network evolves or grows in complexity, since the methods will ensure that the new behavior is (re-)learnt over time. Moreover, since data driven solutions can be applied to similar data of different categories, they enable network management to address new problems that have not been examined before using previously implemented solutions. The only downside compared to rule-based approaches is that since these solutions are not hand-crafted for individual problems, they may not always be as robust as rule-based solutions that are designed by domain experts. So, they are usually accompanied by a measure of accuracy on how well they reflect and predict network behavior.

Today with emergence of 5G more data-driven solutions that use machine learning on network data are replacing rule-based approaches to address automation problems in the network. Some of these use cases include:

- Detection of network incidents using anomaly detection in the network (e.g., on counters and KPIs),
- Prediction of events using machine learning on network data,
- Detecting of relationships between KPIs by clustering counters with similar temporal behaviours using time series analysis,
- Recommendations for orchestration strategies / troubleshooting, etc.

7.3 Available data and accessibility to experiment data

One of the goals of 5G-SOLUTIONS is to manage and provision network slices across multiple domains (including RAN, core networks, MEC, etc.) In order to investigate common slices across domains and predict optimized slices, network information such as type of resources, counters, KPIs, etc. need to be transparent across domains and readily accessible to the automation algorithms. Ideally the proposed method has access to:

- Raw counters and KPIs from use cases
- Use Case-specific counters and KPIs
- Network resources allocated to experiments
- Services and VNFs initiated and maintained throughout the lifecycle of the experiment
- Application logs

One way of accessing KPIs and counters is to directly interface with the ICT-17 platforms monitoring solution. This has two implications: (i) a dedicated interface is required between analytics platform and each individual platform and (ii) since a lot of automation solutions are on-line i.e. they continuously operate on streaming data, connections and equipment are required to support the throughput and bandwidth of this data flow.

Another method is using a centralized platform to gather measurements from all ICT-17 platforms and use cases through the 5G-SOLUTIONS analytics platform and interface with this analytics module to access the needed information. Detailed implications of using either of these approaches (centralized on decentralized) is further discussed in more details in D3.1 and challenges of each approach and the decision will be reflected on next version of deliverables.

Further, in order to predict slicing patterns, the analytics platform also requires access to CDSO to collect information about allocated radio, physical and virtual resources which can later be mapped to KPIs and counters collected from UCs during experiments. The interfaces for automation with the rest of 5G-SOLUTIONS are currently being investigated.

7.4 Envisioned ML-based Approaches for Slicing Patterns

We have two envisioned directions of research in this area:

1. The first one is predictive optimization of Network Service performance, based on training data sets that combine network counters and network-based KPIs with Use Case - specific KPIs.
2. The second one is related to the possibility of predictive slicing, by defining common slicing patterns that can be used in dynamic configuration settings. Using common slices as training data allows dynamic allocation of resources (over the different domains) by learning the relationship between network resources and service requirements from use cases. This direction will evolve as our understanding of the 5G-SOLUTIONS orchestration implementation matures. It might be different depending on the type of orchestration support we provide and the ability to access ICT-17 platform data related to configurations and performance.

New research trends on dynamic resource allocation and 5G network slicing resource utilization [40] and automating mechanisms for per-group slicing and resource-usage efficiency [41] have lately emerged. Similar methods will be investigated for predictive slicing in 5G networks.

Given the current status of the project, details of KPIs from use cases and allocated resources are not yet clearly defined. This ongoing process will be refined through the LL discussions, in collaboration with WP2 and WP3, so that slicing patterns will be better understood.

Finally, the feasibility and accuracy of envisioned methods in this section and solutions available in the literature highly relies on type and volume of data that is available from orchestrators and monitoring modules of the platforms. Discussions regarding availability of this data and collection mechanisms is currently under discussion in context of WP3 and an updated roadmap of ML-based methods will be included in the next version of this deliverable.

8 Conclusions and Next Steps

This deliverable has presented our initial plans and conclusions in terms of 5G-SOLUTIONS service orchestration. We have presented the following aspects: (1) orchestration in 5G, related to standards and existing solutions, in the area of NFV, network slicing, and multi-domain orchestration; (2) initial requirements for orchestration for the 5G-SOLUTIONS Use Cases, based on their deployment plans and need for orchestration support; (3) support for orchestration in the underlying ICT-17 platforms used in 5G-SOLUTIONS, namely 5G EVE Italy, 5G-VINNI Greece and 5G-VINNI Norway; (4) initial understanding of challenges, and planning of boundaries between ICT-17 platforms and 5G-SOLUTIONS, as well as integration points for orchestration; (5) initial innovative ideas in the area of ML-based optimisations for 5G service management and orchestration.

This deliverable brings together the point of view of the vertical industry requirements and the underlying platform support for management and orchestration and presents our initial challenges and plans in developing the 5G-SOLUTIONS service orchestration. It serves as a starting reference point to the work in WP2 and WP3, with more complete results in terms of integration and ML-based optimisations to be included in its next version.

The next steps will focus on further evaluating the orchestration requirements and available data for orchestration and automation solutions, which will be developed in collaboration with WP2. The results will be presented in the D1.2B which will be the v2 version of Task 1.2.

9 Annex 1: Components and features of 5G-EVE

9.1 Interworking Framework components

The **Multi-site Network Service Orchestrator** is the core component within the interworking framework and responsible for coordinating the provisioning and lifecycle of Network Services across the site facilities, as required to deploy end-to-end network slices for the execution of vertical use case experiments. It leverages on the per-site orchestration components and features, as they provide the fundamental logics and coordination within each 5G EVE site facility. Following the ETSI NFV EVE012 [14] approach described above, the Multi-site Network Service Orchestrator allows to provision end-to-end network slices as a combination of NFV Network Services, possibly across different sites when required. For this, the Multi-site Network Service Orchestrator contributes to the interworking API with lifecycle management operations, including on-boarding, based on the ETSI NFV SOL005 APIs [42], which specify the NFV Orchestrator northbound interface. Therefore, it is supposed to operate on top and coordinate, through the Adaptation Layer, the different per-site orchestration and control tools, e.g. at RAN, MEC or edge, transport SDN, NFV segment level. The Multi-site Network Service Orchestrator also provides the logic for selecting where to deploy Network Services and VNFs, according to the specific performance, resource and location constraints received through the interworking API and expressed by the vertical for the execution of its experiment. For this specific selection purpose, the Multi-site Network Service Orchestrator leverages on the information (in terms of running instances and their performances) available from the Multi-site Inventory and the Data Collection Manager. The Multi-site Network Service Orchestrator owns and manages the Multi-site Catalogue and the Multi-site Inventory, and it is responsible for keeping the information stored consistent and up to date.

The **Multi-site Catalogue** decouples the Network Service Descriptors exposed to the 5G EVE experiment portal, which may span multiple sites and logically represent the actual network slice offers from the Network Service Descriptors collected from each of the site facilities, representing the actual capabilities of the sites. By maintaining both these levels, the Multi-site catalogue can keep track of dependencies and restrictions of each 5G EVE site facilities, as required for deciding where to deploy a given network slice in support of a specific vertical use case experiment. For the time being, in this preliminary interworking architecture definition, verticals will be able to on-board their own VNFs in the Multi-site catalogue, as an automated procedure from the 5G EVE experimental portal. However, the option of having vertical VNFs on-boarding as an offline process in the per-site catalogues is also left open, especially for this first phase of the project. In addition to the legacy NFV-related information, the Multi-site Catalogue is intended to store any per-site additional information required for the vertical use case experiment and that is not dynamically exposed by the sites as described in section 4.3 in [31].

The **Multi-site Inventory** is the counterpart of the catalogue component for what concerns the information on provisioned and instantiated network slices in the 5G EVE end-to-end facility. It is fully managed, in terms of information stored, by the Multi-site Network Service Orchestrator, and it maintains detailed information of running. The Multi-site inventory exposes to the 5G EVE experiment portal the end-to-end Network Services instances deployed for a given experiment, augmented with additional service level information (e.g. list of monitored network and service performance metrics, runtime configurations, etc.). At the same time, it keeps the relation with the actual provisioned per-site Network Services, VNF instances and resource configurations (e.g. at RAN, MEC segments) in support of the given vertical use case experiment. The Multi-site Inventory also allows to collect (through the

Adaptation Layer or provisioned offline) and store any Network Service and network slice that may be pre-provisioned in each site, and that could be selected by the Multi-site Network Service Orchestrator for deploying and running vertical use case experiments.

The **Data Collection Manager** is a key component within the interworking framework, and it coordinates the collection and persistence of all those network and vertical tailored service performance metrics that are required to be monitored during the execution of experiments for testing and validation of the targeted KPIs. On the one hand, through the interworking API, for each experiment, it is allowed to configure the performance metrics that have to be measured for validating the specific use case KPIs. On the other hand, in turn, this monitoring configuration is mapped, through the proper logic provided by the Adaptation Layer, into a request for selective collection of network and service-related metrics to the involved 5G EVE sites. In this way, only the metrics needed to validate the KPIs required by the vertical will be monitored in each of the involved site facilities and collected by the Data Collection Manager (either with explicit queries or through publish/subscribe mechanisms) for their storage in a common database shared with the 5G EVE experiment portal.

The **Runtime Configurator** allows to apply tailored runtime configurations to the provisioned end-to-end Network Services and VNFs in support of the vertical use case experiments**.** While the Multi-site Network Service Orchestrator can handle Day0[3] and Day1[4] configurations during the Network Services and VNFs instantiation phases (i.e. by enforcing them through the per-site exposed NFV Orchestration VNF configuration services), experiment specific and vertical oriented Day2[5] configurations can be applied through the interworking API via a common interface exposed towards the 5G EVE experiment portal. This requires that each site facility, in turn, exposes such capability for Day2 VNF configuration.

9.2 Details of capabilities and features

UE and SIM cards logistic

The execution of the 5G EVE vertical use case experiments requires the availability of 5G ready UE and SIM cards. It is assumed that their procurement, identification and maintenance will be completely under the responsibility and management of each site and involved verticals. Each site/vertical is free to implement its own procedures and mechanisms for handling UEs and SIM cards.

The availability of UEs and SIM cards, together with their characteristics, will be anyway manually fed and stored in the interworking framework Multi-site Catalogue and exposed to the 5G EVE experiment portal. Thus, they will enable verticals to select and associate them to their use case experiments.

Basic Subscriber configuration

It is not expected that 5G EVE sites will expose the interfaces for configuring the subscribers. 5G EVE sites shall provide a set of subscribers for the experiments, possibly covering the different services

[3] Day0 refers to the cloud-init configuration of a VNF during its instantiation phase.

[4] Day1 refers to a VNF configuration after the instantiation phase for its proper functioning in the context of the Network Service.

[5] Day2 refers to runtime application-level VNF configurations that can be applied at any time of the VNF lifecycle.

provided by the site (eMBB, mMTC, uRLLC). Information about the available subscriber configuration sets will be stored in the interworking framework Multi-site Catalogue.

Radio Access Network selection and configuration

Each 5G EVE site is requested to advertise its RAN capabilities, at least in terms of geographical coverage. Therefore, whenever multiple RAN technologies and coverage options are available, the 5G EVE sites shall expose them to the interworking framework. This is required at the Multi-site Network Service Orchestrator to take appropriate decisions on where to deploy a given vertical use case experiment, either within a single site or across multiple sites. These RAN capabilities and coverage information are thus stored in the Multi-site Catalogue for their usage within the interworking framework.

As an additional consequent RAN-related capability, each 5G EVE site shall give the possibility to select either the geographical area or RAN technology (or both) when provisioning a Network Service or a network slice in a 5G EVE site in support. The exposure of dedicated interfaces for dynamic provisioning and configuration of RAN resources are considered for the time being (i.e. in the context of the preliminary interworking framework definition) as optional, as they are not required in all the use cases. In any case, RAN resources provisioning and configuration can be managed by each site NFV or slice orchestrator and thus being transparent for the interworking framework.

Edge Computing

The availability of edge computing environments is crucial for the execution of most of the 5G EVE vertical use cases. Multiple technology solutions are allowed, including MEC, fog computing and distributed edge cloud. Each 5G EVE site is required to advertise and expose to the interworking framework its availability of edge computing resources and capabilities (hosts, geographical location, network connectivity constraints and characteristics).

Additionally, the 5G EVE sites shall also manage the provisioning and configuration of virtual resources on MEC or edge hosts, according to network and service performance requirements (e.g. latency) and location constraints. This implies the implementation of advanced functionalities for network traffic steering and breakout at MEC/edge hosts and access to location services. However, the exposure of these features and services towards the interworking framework is subject to the specific per-site orchestration approach and paradigm. Indeed, the MEC/edge control and orchestration may be hidden under NFV or slice orchestration services.

NFV / Slice orchestration

Given the network slice modelling and approach followed by the interworking framework and based on the ETSI NFV EVE012 [14] principles (see section 4.1 in [31]), the support of NFV orchestration services in each 5G EVE site has to be considered as one of the key mandatory features. However, NFV orchestration includes a wide plethora of capabilities, features and functionalities for the provisioning and lifecycle management of network slices, Network Services and VNFs (instantiation, modification, scaling, termination, etc.). In the context of 5G EVE, the per-site NFV orchestration tools have to take into account the interaction with the interworking framework and its Multi-site Network Service Orchestrator, that acts as an overarching coordinator of NFV orchestrators across sites, and if needed within the same site. Indeed, it is assumed that each 5G EVE site shall expose NFV orchestration capabilities, but it is allowed for each site facility to have more than one NFV orchestrator, e.g. to manage different portions of the infrastructure possibly dedicated to deploying different types of service (vertical applications and VNFs vs. 5G mobile network VNFs).

For the sake of their integration with the interworking framework and thus the 5G EVE platform, the site NFV orchestrators shall offer:

- Access to NFV catalogues for querying and on-boarding VNFs and Network Service Descriptors;
- Network Service and VNF lifecycle management, including provisioning, query and termination of instances;
- Network Service and VNF dynamic modification, e.g. through scaling operations;
- Day0, Day1 and Day2 configuration of VNFs.

As optional features, NFV orchestration could provide advanced capabilities for Network Service self-healing and auto-scaling in support of demanding use cases with very stringent requirements in terms of availability and service continuity. Moreover, as further optional and advanced capability, the NFV orchestrator could directly manage and expose RAN and EPC/5G Core instances.

SDN-based network control

Each 5G EVE site facility may make use of SDN-based network control solutions to dynamically program the physical network in the transport or the radio domains, e.g. leveraging on one or more SDN controllers. From a 5G EVE interworking framework perspective, the exposure of SDN network control primitives provisioning of network connectivity in the intra-site 5G infrastructure is not considered as mandatory feature. Such programmable network control capabilities can be considered as hidden under the management of per-site NFV and slice orchestrators. However, in the case of 5G EVE sites with multiple NFV orchestrators deployed and exposed to the interworking framework, the exposure of SDN-based network control primitives may ease the interconnection and stitching of independent Network Services towards the provisioning of end-to-end intra-site network slices.

Monitoring

The monitoring of 5G network and service performance metrics is a key requirement in 5G EVE to enable testing and validation of the vertical use case targeted KPIs. Indeed, 5G EVE provides an end-to-end experimentation facility, where verticals can deploy their use cases and validate 5G technologies against their application domains to demonstrate the benefits they can achieve. For this reason, each 5G EVE site shall provide advanced monitoring capabilities to measure a wide and complete set of 5G network and service metrics that allow fulfilling the vertical use case requirements, as reported in section 3 of [31].

More than that, the dynamic and per-experiment configuration of 5G network and service metrics to be measured and collected is required to be exposed towards the 5G EVE interworking framework by each site facility. This allows the Data Collection Manager in the interworking framework to translate and map the vertical use case experiment target KPIs into lower level metrics to be measured and collected. At the time of writing, given the preliminary nature of the interworking framework definition, 5G EVE sites have two options for exposing monitored data to the Data Collection Manager in the interworking framework:

- Offer an interface for polling 5G network and service performance metrics;
- Push the 5G network and service performance metrics into the common database.

Testing tools

The execution of the 5G EVE vertical use case experiments requires realistic conditions for proper testing and validation of the targeted KPIs. Indeed, to enable 5G EVE (and external users when they will start to use the platform) verticals to validate the 5G technology's expected benefits in terms of network and service performances, the experiments over the project end-to-end facility need to be performed in the appropriate real-time conditions.

This means that at least background traffic generators and emulators of UEs shall be available for their usage in the experiments. Therefore, as a minimum requirement, testing tools need to be known (together with their capabilities) at the interworking framework and stored into the Multi-site Catalogue for their selection and usage in vertical use case experiments. More than the availability, it will be required that each site should expose dedicated interfaces to configure this testing as part of automated experiment execution. Whether these configuration interfaces will be exposed to the interworking framework or directly to the testing and validation framework within the 5G EVE experiment portal is still under discussion (in WP5 and WP3).

Cross-site connectivity

5G EVE sites shall declare the type of connection available towards Internet or other public networks. Also, they must provide the capability of creating an interconnection with other 5G EVE sites using IP VPNs (in compliance with the plans of each site facility reported in 5G-EVE public deliverable D2.1 [43]), and where possible and available leveraging on the pan-European GEANT research network. Connectivity with 5G EVE Turin as a cross-site connection may also be investigated in the context of 5G-SOLUTIONS. Cross-site orchestration connectivity is required for enabling the communication between the interworking framework and each of the 5G EVE sites. This communication is basic for the execution of any vertical experiment and for that reason we included a basic requirement for this type of cross-site connectivity, which expects a reliability of at least 99.9%.

Cross-site control plane connectivity is required for allowing cross-site execution of a vertical use case experiments, when control plane interworking is required for proper communication among control VNFs or network functions in general. As example, for the Industry 4.0 use case scenario (as reported in section 3.1.3 of [31]), advanced deployments may require multi-site execution with interconnection at the level of the LTE S6a interface for managing subscriber data in standard roaming. Similarly, considering the Smart Tourism scenario of section 3.1.2 of [31], a cross-site control plane interworking at LTE S1-11 interfaces level may be required to radio and edge elements and functions deployed at vertical site (e.g. IFEMA) and core in the 5G EVE 5TONIC site. Taking these two cases as references for expressing some target performances in the case of control plane interworking, we require a cross-site connectivity that guarantees a minimum bandwidth of 20 Mbps, with a reliability of 99.9%.

Cross-site data plane connectivity is not to be considered as a strict requirement at this stage of the project, as none of the 5G EVE vertical use cases need it for its execution. In any case, it is expected that future use case experiments, coming from new verticals using the 5G EVE platform (e.g. from ICT-19 projects) will bring new requirements, including interworking at the data plane level for multi-site deployments. For this, we included a preliminary recommendation for cross-site connection with the following characteristics: 99.9% of reliability, 200 Mbps of guarantee bandwidth and maximum latency that depends on the distance of each site (as listed in the form of interworking recommendations in section 5 of [31]).

Annex 2: Specifications of 5G-VINNI Patras Facility

9.3 Components and features

This section provides a description of different components in 5G-VINNI Patras facility.

Cloud/MANO services

Currently, the Patras/Greece facility is equipped with a cloud platform offered by the University of Patras, able to host core network components, as well as NFV and MEC deployments. The cloud platform offers a total computing power of 212 CPUs and 768 Gigabytes of RAM and 30 TB of storage. Two servers with 4x10GbE NICs DPDK enabled will be also available.

On top of our cloud hardware, a rich set of state-of-the-art SW tools is already available, which comprises our platform for experimentation called Cloudville. These include OpenStack as the cloud operating system, while OSM (but also OpenBaton via FhG) will be available to allow NSD/VNF deployments. Prometheus alongside with Grafana are installed for monitoring purposes. At the same time, Elastic search and Kibana are installed and being used to collect and visualize data extracted from IoT devices and sensors.

Access Network, MEC devices and UE

In Patras/Greece facility there will be 3 Outdoor base stations together with MEC devices at the Patras campus and at the City of Patras placed at properly selected places to facilitate the execution of test plans together with around 6 UEs. UoP together with ICOM will implement and integrate any standardized APIs and services to provide MEC functionality, including the virtualization of edge IoT devices, i.e., IoT Slicing, as a VIM component.

LimeMicro's hardware will be used for both handset and base station. LimeMicro specialises in field programmable RF (FPRF) transceivers and open source LimeSDR, LimeNET platforms for the next generation of wireless broadband systems. These products offer an unprecedented level of configurability and will be used in the Patras/Greece to create wireless communication networking equipment using commodity hardware, i.e., x86- based machines that can be programmable and reconfigured to run on any wireless communications frequency and mobile standards from 2G to 5G networks of the future.

SRS will integrate its software suite into the LimeMicro SDR hardware platform as well as interworking with the Fraunhofer open5Gcore will be assured. SRS will provide a set of selected 5G NR features for srsLTE that will be available for KPI validation within the project. SRS will extend their code base for both UE and (g/e) NB to support the 5G NR scalable numerology for configurable subcarrier spacings, integrate the new channel coding, and higher order modulation types supported by 5G. This work will serve as a proof-of-concept and feasibility study of an SDR-based 5G NR implementation. We are intending to adopt the non-standalone (NSA) mode for 5G NR in which a NR gNB will provide user-plane traffic services for a NR-capable UE to a master 4G eNB.

Backhaul

ICOM will provide to the Greek facility state-of-the-art mmWave backhaul and Fixed Wireless Access (FWA) solutions. The UltraLink™-GX80 all-outdoor mmWave PtP Ethernet radio at 70/80 GHz (E-Band), that provides a 10 Gbps backhaul capacity, will be used to interconnect the g/eNBs with the core network and the data centre at the UoP premises.

Further, ICOM's FWA solutions will be used to provide broadband access to public organisations' sites (e.g. University Campus, City Hall, etc.) in the city. The WiBAS™ OSDR PtMP all-outdoor radio, as it has been enhanced to provide >1.5 Gbps aggregate sector capacity and < 1 ms latency through the phase 1 project SPEED-5G, will be used.

Within the project ICOM will add support for SDN-based network slicing to the wireless backhaul and FWA network segments.

Core 5G /IoT services
In Cloudville, apart from Service Slice life-cycle management services and OSM, the FhHG Open5G Core will be installed. The Fraunhofer Open5GCore implementation is a 5G oriented implementation of the core network (currently 3GPP Release 14 and 15, Release 16 planned in two years). The Open5GCore enables the connectivity service as requested within the 5G networks. To support NB-IoT, the Patras/Greece facility will host the Open5GCore NB-IoT extension, which is the first implementation of the essential 3GPP NB-IoT features (Release 13 - TS 23.682) enabling the demonstration of low energy IoT communication. It addresses the current stringent needs of the 5G use cases to provide low power, low cost-efficient communication for a massive number of devices. On the NBIoT, LTE-M radio side there will be both commercial licenced as well as open source solution available

MEC
The Patras/Greece facility will provide support for Mobile/Multi-access Edge Computing on two fronts:

- **IoT Slicing**: A Virtualized Infrastructure Management (VIM) (sub-)component will be designed, implemented and integrated within the overall MANO architecture, to enable the virtualization of the available edge IoT resources (sensors/actuators) for access within individual network slices.
- **Mobile streaming applications support**: The facility will support MANO mechanisms for the realization of high throughput, low latency, mobile types of applications (e.g., gaming, AR/VR) and corresponding test cases. Such mechanisms will include DNS and traffic flow management (on Mp1 ETSI MEC interface) for baseline service orchestration, as well as mobility support mechanisms i.e., mobility management events such as application context transfer, user redirection network/application level), and a subset of the Location Service (ETSI GS MEC 013) for triggering mobility management events.

9.4 Provisioning of network slice instances in Patras Facility

The lifecycle management of NSIs carried out by Greek NOP is compliant with this 3GPP view, thanks to the conceptual outline the OSM information model. In the next subsections, each phase will be discussed individually.

Preparation phase

This phase begins when CSP receives a service order from the CSC. At that moment, a VINNI-SD is created out of VINNI-SB and stored in OSM repository. Then, CSP checks if that VINNI-SD is feasible (e.g. check if all the mandatory parameters have been specified, if there is enough capacity, etc.), and if so, sends corresponding network slice requirements to NOP. With these requirements, the NOP carries out a set of operations arranged into sub-phases: NST design and NST on-boarding.

For the first sub-phase, the NOP takes the received requirements and translates them into the following tuple: {required NST, instantiation parameters}, so NOP can deploy the NSI when and where required. For the preparation phase, only the first field of this tuple is relevant. The required NST shall follow the information model introduced at the beginning of [44] and shown there in Annex A. This NST can already exist (pre-defined NST, designed beforehand) or not (NST created on demand) in the service catalogue. To handle these two scenarios, two operations are made available to NOP through NST management interface (Section 3 of [44]):

- **nst-create**: allows designing an NST from scratch. This operation is triggered by the NOP when there is no pre-defined NST that can be reused for the definition of the required NST.
- **nst-update**: allows modifying some fields from a given NST. This operation is triggered when the required NST can be obtained by updating some of the content of an already existing NST.

Either of the abovementioned options allows NOP to have the required NST designed, and thus the first sub-phase completed. From that moment onwards, the NST is on-boarding can get started.

In this second sub-phase, the NOP aims at injecting the required NST into the service catalogue. This process not only consists in on-boarding the NST itself, but also the NFV-NS and VNF Packages referred by the NST (see information model in Annex A). OSM's NBI offers APIs that support CRUD (Create, Read, Updated, Delete) operations to handle these NFV-NS and VNF packages (and their contained NSDs and VNFDs). In these operations, the necessity checks to validate in-model and cross-model consistency are performed. These API calls are implemented over the NFV-NS/VNF Package management interfaces and the NSD/VNFD management interfaces described in [44].

Once the on-boarding process finishes, the NST is stored in the service catalogue, so it can be used for NSI creation later on. At this moment, the NOP can invoke two operations from NST management interface:

- **nst-list**: allows listing NSTs available in the service catalogue.
- **nst-show**: allows showing the content of a given NST.

When the NOP finishes invoke either of the two operations, the preparation phase gets finished.

Commissioning phase

Once the NST and corresponding NS/VNF Packages have successfully been on-boarded in the service catalogue, they can be used as deployment templates for the actual NSI deployment. Alike the preparation phase, the commissioning of the NSI from the NST is a phase that can be split into two sub-phases: network slice instantiation and NSI configuration.

Network slice instantiation consists of the day0 operations that allows creating an NSI where all the components are instantiated. These operations are defined at all the abstraction levels, ranging from VDU level (e.g. VNF component) to network slice level, and are invoked using the VNF, NFV-NS and network slice lifecycle management interfaces described in [44]. To trigger the instantiation of a network slice, the NOP will consume the nsi-create operation from the network slice lifecycle management interface.

For nsi-create operation, the two fields of the tuple {required NST, instantiation parameters} that was derived in the preparation phase is now needed. A brief overview of the steps that OSM takes when this operation is invoked is shown below:

First, the NOP analyses the content of the NST and decompose it into its constituents: network slice subnets and virtual links connecting them.

Secondly, for each network slice subnet, the corresponding NSSI is created. This NSSI is an NFV-NS instance. For the deployment of this NFV-NS instance, the following information is considered:

1. **Instantiation parameters**: from the tuple {NST, instantiation parameters} derived in the preparation phase. The NOP extracts from these parameters the requirements that are relevant for the network slice subnet to be instantiated.
2. **NSD information element**: from the IM of the required NST. This information element points to the NSD that will be used for deploying the NFV-NS instance. This instance can be deployed in various forms (e.g. with different topologies, with different capacity) and with different deployment constraints considering the above instantiation parameters, by using the mechanisms that NSD has for that end (e.g. flavoring, affinity/anti-affinity rules, etc).
3. **Iss-shared-nss information element**: from the IM of the required NST. This information element specifies if the above NSD can be shared or not. If this information element set to YES, and if an already NFV-NS instance provides similar capabilities to those needed by the NSSI, then that NFV-NS instance can be associated with the NSSI. Otherwise, a new NFV-NS instance needs to be deployed.

Thirdly, for each virtual link providing inter-NSSI connectivity, the corresponding virtual link instance is created. For the deployment of this virtual link, the following information is considered:

1. **Instantiation parameters**: from the tuple {NST, instantiation parameters} derived in the preparation phase. The NOP extracts from these parameters the requirements that are relevant for the virtual link to be instantiated.
2. **VLD information element**: from the IM of the required NST (see Annex A). This information element points to the VLD that will be used for deploying the NFV-NS instance. This instance can be deployed in various forms (e.g. with different QoS parameters) considering the above instantiation parameters, by using the mechanisms that VLD has for that end (e.g. flavoring).

With the abovementioned steps, the NSI is already created, although not configured. To start the configuration process, day-1 operations are required at the NSI components. Typical day-1 operations include model-driven interaction with (Virtual/Physical/Hybrid) NFs through the use of Juju charms, which allow NEPs to encapsulate their configuration mechanisms (e.g. YANG/NETCONF, Ansible, SSH+scripts). For (V/P/H) NF application layer configuration, two different kinds of Juju charms can be used: native charms and proxy charms. A brief comparison of these two Juju charms: Native charm vs Proxy charm.

- **Native**: Juju charm used for those NFs that are able to run charms inside, e.g. cloud-like VNFs. NF interaction happens directly from the orchestrator
- **Proxy**: Juju charm used for those NFs that do not support running charms inside, e.g. PNFs. Proxy charm uses the appropriate configuration protocol to interact with the NF and run the desired actions from the primitive.

Operation phase

Once the NSI has been successfully commissioned, the NSI becomes a relevant object for further operation actions. Unlike 3GPP view, operation phase in OSM includes deactivation/activation (e.g. pausing/resuming) as part of the set of modification operations that can be triggered at run-time, depending on the outcomes resulting from the supervision and reporting activities carried out over the NSI throughout its lifetime. Examples of basic supervising and reporting activities that the NOP can conduct over the NSI are allowed through the following operations, all exposed in the network slice lifecycle management interface:

- ***nsi-list***: list of all operative NSIs
- ***nsi-op-list***: show the history of operations that has been triggered over the NSI since its creation.
- ***nsi-op-list***: shows the information of the operation over a NSI
- ***nsi-show***: shows the record of the NSI
- Other more sophisticated activities can be performed, assisted by the MON module, or by the Bugzilla

Depending on the information received from these supervision and reporting activities, the running NSI might need to be modified, in order to keep it in the desired state. For this end, the NOP can trigger a wide variety of day-2 operations over that NSI. These API-driven operations are quite aligned with the specificities indicated by the CSC in the VINNI-SD, and can fall into one of these categories:

1. **Operations at the virtualized resource level**: includes operations that has a direct impact on the virtualized resources supporting the NSI. Examples of these operations include scaling operations (e.g. subjected to upper and lower thresholds), creation and deletion of performance measurement jobs, subscribe and notify operations for performance metrics and fault alarms, instantiation and termination of testing components to complete test campaigns, etc. Depending on the service exposure level selected by CSC, these operations can be performed at different abstraction levels, e.g. ranging from NSI level to VNF instance levels.
2. **Operations at the application level**: includes operations that are relevant only for the specific functionality that the NSI offers. Examples of these operations include the addition, modification and deletion of new subscribers, changes in security parameters, changes in routing across the service chain, etc. Those actions need to be enumerated and codified in the constituent NFV-NS Packages the NST refers to and are exposed by the API as primary actions available in that given NSI.

Decommissioning phase

As any other (on-demand) instance of a manageable entity, it is possible to decommission an NSI. This decommissioning means removing all the dedicated components and releasing their underlying resources, but not the shared and dependent components. For those components, they need to be reconfigured and their resources should be adjusted accordingly. To illustrate this scenario, consider the case where a NSSI from the NSI that needs to be decommissioned was deployed using a running NFV-NS instance (e.g. an NFV-NS instance also serving other NSSI from another NSI). In such a case, where the NSSI from the NSI to be decommissioned is removed, the NFV-NS instance cannot be removed. Otherwise, the other running NSSI will be affected. To avoid this, when removing the required NSSI, the NFV-NS instance will be re-configured (e.g. disassociated from the removed NSSI) and scale-in accordingly.

As seen again, the lifecycle management of NSSI and NFV-instances, although dependent, are separate.

For the decommissioning phase, Spanish and Greek NOPs may invoke the nsi-delete operation through the network slice LCM interface.

10 Annex 3: Supported VNFs/PNFs in 5G-VINNI Norway Facility

<u>5G RAN</u>

The 5G RAN will initially use the 3.6 GHz TDD band (80 MHz) and 4G anchor carrier in 2100 MHz FDD band. The initial Radio node will later be expanded with radios that support the 26 GHz frequency band (up to 800 MHz, actual bandwidth used depends on the granted trial license by the Norwegian spectrum authority NKOM). The 4G 2100 MHz radio will be connected to a traditional passive base station antenna and both 3.6 GHz gNB and 26 GHz gNB will use Massive MIMO radios where the radios are integrated with the antenna in one physical unit.

The interface between Radios and Baseband Units will be CPRI for LTE and eCPRI for the Massive MIMO units limiting the required fibre links to a minimum (Figure 10-1).

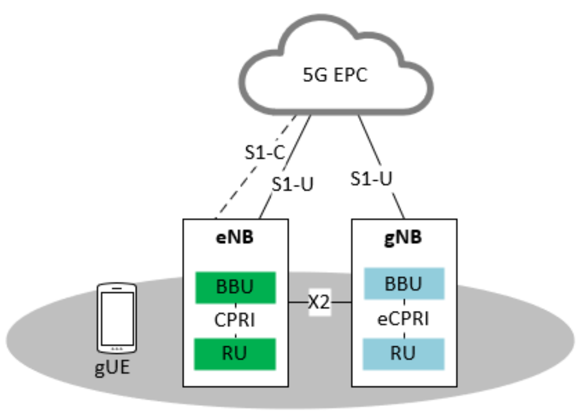

Figure 10-1: Norway Facility-site 5G RAN

The backhaul towards the Core Network, initially S1 interface, is terminated in a site router that is also connected to a GPS receiver providing accurate synchronization signal required for TDD transmissions. The baseband unit provides the node synchronization based on an external synchronization source provided by GPS or the transport network connection.

Downlink user data is sent over the LTE leg or the NR leg. The selection of a specific leg is based on the NR connection quality that can be set with system configuration. The NR leg is used when the quality is optimal based on the set value. In case the NR quality is below the set value, the LTE leg is used. Downlink Fast Switch enables to switch between the LTE air interface and the NR air interface for the transmission of downlink user plane traffic.

For Downlink Dual Connectivity Aggregation, the downlink user data is sent simultaneously over the LTE and NR legs. A flow control mechanism at the gNodeB guides the traffic over the different legs to minimize the reordering at PDCP layer of the UE.

The radio site parameters for Huawei nodes are 3.5GHz (80 MHz BW) NR, 28 GHz NR (800 MHz BW) and 2100 MHz LTE (20 MHz). Each base station from Huawei will have two sectors with individual radios in every frequency bands i.e. every base station site will have 6 radios. The solutions provided into this project will be based on 3GPP standards and can be integrated towards other 3GPP compliant systems and interfaces. Huawei's RAN solution will support high level CU-DU split with the DU implementing the real-time part (PHY, MAC, RLC) while CU implementing the non-real-time (PDCP, RRC) as shown in Figure 6 Huawei 5G CU-DU Split. For CU-DU separated scenario, a new F1 transmission interface is added for CU-DU transmission.

5G EPC Ericsson

5G EPC deployed for 5G-VINNI is Ericsson EPC enhanced to support 5G/NR (Opt. 3) according to 3GPP Release 15. All 5G EPC VNFs will be deployed in Telenor Norway Datacentre and running on the Nokia Open-stack infrastructure. There will be one common NFVI infrastructure hosting all 5G EPC VNFs. It will be green field deployment and no integration with existing network infrastructure is needed.

Figure 10-2 shows logical interfaces in target network architecture supporting 3 slices.

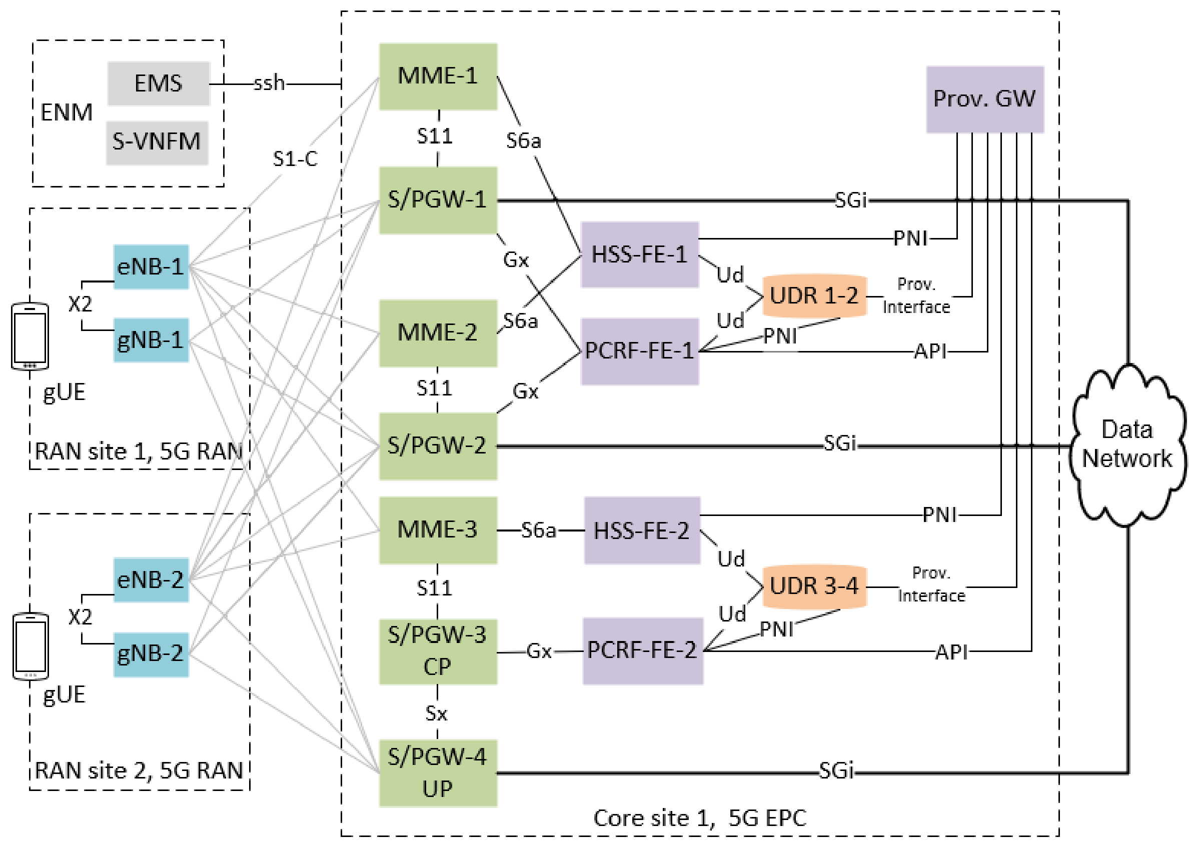

Figure 10-2: Norway Facility-site 5G Ran & EPC Core network topology

5G EPC VNFs that will be dynamically deployed from NFVO:

- **MME** - 3x VNFs will be deployed and integrated with all eNBs and gNBs. Each MME will serve one 5G slice. All MME will be stand-alone none of them configured in MME pool; All eNBs and gNBs will be shared with all three slices.
- **S/PGW** - 4x VNFs will be deployed. Slice URLLC will be supported with a CUPS thus one S/PGW will be configured as Control Plane GW and one as User Plane GW. S/PGW selection will be preconfigured statically on MMEs no DNS will be used.
- **HSS-FE** - 2x VNFs will be deployed. Two slices will have shared HSS-FE while the URLLC slice will have dedicated HSS-FE. Subscriber profiles will be provided by one of two external UDRs (UDR1-2 and UDR3-4). Both HSS-FE will be stand-alone not back up each other. UE Usage Type parameter used for DCN selection will be part of subscription profile provided by HSS-FE or alternatively could be also statically preconfigured on MME.
- **PCRF-FE** - 2x VNFs will be deployed. Two slices will have shared HSS-FE while the URLLC slice will have dedicated HSS-FE. Data-plans, User Profiles and Policies (Rules) will be stored in internal databases while Subscriber profiles will be provided by one of two external UDRs (UDR1-2 and UDR3-4). Both HSS-FE will be stand-alone not back up each other.
- **UDR** - 2x UDR pairs will be deployed. One UDR pair consist of two VNF. These UDR pairs are independent and does not back up each other.

  Two slices will have shared UDR1-2 while the URLLC slice will have dedicated UDR3-4

- **Provisioning GW** - 1x VNF instance is common across all slices; provides 5G User and Policy Profile provisioning in UDR and PCRF and NW Slicing Profile provisioning.

VNF Element Management System (EMS)

The VNF EMS functionality will be provided by Ericsson Network Manager (ENM). ENM provides centralized operation and maintenance of radio and core. Also provides powerful and unified performance and configuration management, software, hardware and fault management for VNFs, together with security, self-monitoring and system administration for the ENM itself.

Edge Site

The virtualized infrastructure design of the edge site will be a scaled down version of the core sites, with lower footprint VIM control plane with relaxed redundancy of only two hot standby VIM instances and one firewall for security zoning.

Edge sites[6] are planned in the Norway Facility-site, but the exact location(s) has not yet been decided and will depend on requirements of the funded ICT-19 projects. The plan is to decide the location considering the capabilities of the transport and RAN network used in addition to the needs of the ICT-19 projects. The edge sites are planned to be implemented in Rel-1.

The plan is to also support autonomous edge sites, meaning that the edge site should be able to operate as full mobile network in case the link breaks down. This is a requirement from multiple verticals (e.g. defence, manufacturing).

There are multiple areas to consider for the design of edge sites including the NFV components (NFVI, VIM, SDN, SDS), the mobile core network whether it is data plane nodes only or fully autonomous edge sites, service chaining, the support for Cloud RAN potentially requiring real-time performance, and support for 3rd party applications potentially demanding high volume storage.

The NFVI platform of Nokia is the Airframe and shown in Figure **10-3**, which scales from centralized data centres to the far edge data centres. These are provided as either rack-mounted or open rack, based on OCP. It's the latter that has been chosen in the 5G-VINNI project as central node, and that is candidate for a deployment of an edge DC in Rel-1 of 5G-VINNI.

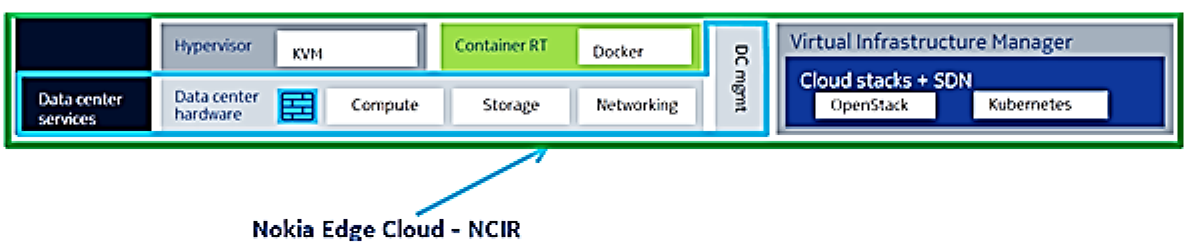

Figure 10-3: Nokia's edge cloud

6 Note that we use the term edge site and not Multi-Access Edge (MEC). The reason is non-compliance to the ETSI ISG MEC standards at this stage

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