TNOVA

NETWORK FUNCTIONS AS-A-SERVICE
OVER VIRTUALISED INFRASTRUCTURES

GRANT AGREEMENT NO. 619520

Deliverable D2.22

Overall System Architecture and Interfaces

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Executive Summary

Deliverable D2.22 presents the final outcomes of Task 2.2 with regard to the design and specification of the T-NOVA overall system architecture. The aim has been to produce an architectural proposal which fulfils most key NFV-related requirements, implements all use cases defined in D2.1 and at the same time allows implementation in a relatively short timeframe with reasonable technical complexity. D2.22 is a revised edition of the initial specification document (D2.21), incorporating all the necessary specification updates which were considered necessary after the first round of the implementation phase, also aligning with technological advances in the global NFV landscape.

The first step is the survey of currently proposed NFV architectures, drafts and trends in standardisation bodies (ETSI NFV ISG – Phase 2 and TMForum). The survey also includes industry initiatives, both open-source and proprietary (OPNFV, HP OpenNFV, Intel/Tieto, ALU CloudBand, OpenMANO, VMware vCloud), as well as research projects (Mobile Cloud Networking, CONTENT, NetIDE, UNIFY).

Considering the use cases and requirements laid out in D2.1 as well as the state-of-the-art in integrated NFV architectures, including standardisation trends, a high-level overall architecture is proposed, which encompasses all the component entities of the T-NOVA system. The architecture is structured in a layered logic, broken down into four layers:

- Infrastructure (NFVI) layer, which includes the physical and virtual elements (compute and storage nodes, hypervisors, data-centre and transport networks) in order to host the elements of the T-NOVA service. Two main domains are foreseen, the NFV data-centre infrastructures (NFVI-PoPs) and the wide area networks.
- Infrastructure Management layer, which involves all the management entities capable to virtualise the infrastructure assets and manage them
- Orchestration layer, which includes the T-NOVA Orchestrator, which coordinates the underlying management entities in order to establish and manage the end-to-end T-NOVA services
- Marketplace layer, which includes all the entities which promote multi-actor interaction and facilitate commercial exploitation of the system

Compliance with the current ETSI NFV ISG vision is sought at all stages of system design, especially concerning the terminology and the main architectural blocks, while several extensions are proposed, especially at the Marketplace domain.

Following, the sequence of interactions between subsystems for each use case is presented. These sequences are expressed as UML sequence diagrams and, via them, it is validated that all defined use cases can be realised within the proposed architecture.

Finally, a positioning of T-NOVA within the 5G landscape is also included, accompanied with a reference to recently started 5GPPP projects. It is shown that T-NOVA is very well aligned with the 5G vision and its results can be very valuable for future research initiatives in the 5G domain.

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1. INTRODUCTION

Deliverable D2.22 presents the final outcomes of Task 2.2 with regard to the design and specification of the T-NOVA overall system architecture. D2.22 is a revised edition of the initial specification document (D2.21), incorporating all the necessary specification updates which were considered necessary after the first round of the implementation phase, also aligning with technological advances in the global NFV landscape.

Most challenges in the field of Network Functions Virtualisation are associated with management operations, such as automated provision, configuration, optimisation, monitoring and rescaling. For this purpose, the key factor towards accelerating NFV adoption is not associated with a single specific technology, but rather with a complete end-to-end management framework which will fulfil all the key NFV-related requirements from the network operators' as well as the customers' point of view.

In this context, this deliverable considers a) the use cases and requirements laid out in D2.1 as well as b) the state-of-the-art in integrated NFV architectures, including standardisation trends, in order to derive a set of design principles and propose a high-level overall architecture, which encompasses all the component entities of the T-NOVA system. Compliance with the current ETSI NFV ISG vision is sought at all stages of system design, especially concerning the terminology and the main architectural blocks, while several extensions are proposed, especially at the Marketplace domain.

The deliverable proceeds as follows: Section 2 presents an overview of the NFV architectures, including the current ETSI and TMForum specifications, as well as industry initiatives, and research projects. Section 3 presents the overall T-NOVA system architecture, also including the rationale behind main design choices, as well as a high-level description of the main subsystems and interfaces. Section 4 describes the service lifecycle and the sequence of interactions, which implement the system use cases. Section 5 discusses the positioning of T-NOVA within the 5G research landscape and investigates the relevance with recently started 5GPPP projects, and finally Section 6 concludes the document..

2. NFV ARCHITECTURES SURVEY

The following sections aim to survey a number of integrated NFV enabling architectures, as proposed by R&D projects currently running, industry frameworks and solutions as well as efforts from Standardisation Bodies related to NFV.

2.1. ETSI ISG NFV

IT and Networks industries have been combining their complementary expertise and resources in a joint collaborative effort to reach broad agreement on standardized approaches and common architectures, which address identified technical challenges, are interoperable and have economies of scale.

As a result, an ETSI Industry Specification Group (ISG) with open membership was setup in the last quarter of 2012 to work through the technical challenges of Network Functions Virtualisation.

2.1.1. Outcome of ETSI NFV Phase 1 (2013-2014)

Phase 1 of ETSI NFV ISG, spanning the years 2013/2014, was mainly targeted at pre-standardisation. The outcome of this effort has been materialized in a set of 11 specifications, which provide the technical foundation to enable the development of an open, interoperable, commercial NFV ecosystem and sets the direction for future standardisation.

The following table provides the list of NFV Phase 1 specifications and a short comment on the potential impact to T-NOVA. A detailed analysis of each specification is outside the scope of this document. However, a high level description of the NFV architectural principles, outlined in GS NFV 002 is provided in section 2.1.2.

Name	Short description	Impact to T-NOVA
GS NFV 002 - Architectural Framework	Defines the basic NFV architecture.	Key reference to all T-NOVA WPs
GS NFV 003 - Terminology for Main Concepts in NFV	Provides terms and definitions within the scope of the ISG NFV.	Key reference to all T-NOVA WPs
GS NFV-INF 001 - Infrastructure Overview	Provides an overview of the architecture of the NFVI which supports deployment and execution of VNFs.	Key reference to WP4
GS NFV-INF 003 - Infrastructure;	Provides an architectural description of the compute & storage domain of	Key reference to WP4

Compute Domain	the infrastructure which supports virtualised network functions (VNFs).	
GS NFV-INF 004 - Infrastructure; Hypervisor Domain	Presents the architecture of the NFVI Hypervisor Domain which supports deployment and execution of virtual appliances.	Key reference to WP4
GS NFV-INF 005 - Infrastructure; Network Domain	Presents an architectural description of the Network domain of the infrastructure which supports virtualised network functions.	Key reference to WP4
GS NFV-INF 010 - Service Quality Metrics	Identifies metrics for NFV infrastructure, management and orchestration service qualities.	Important for evaluation activities to be carried out in the scope of WP7. Also for service monitoring processes (WP3/WP4)
GS NFV-MAN 001 - Management and Orchestration	Describes the management and orchestration framework required to provision VNFs and related operations.	Key reference to WP3
GS NFV-REL 001 - Resiliency Requirements	Presents network and service resiliency requirements in a virtualised network environment and the challenges resulting from VNF failures as well as from hardware/software failures, caused by a wide range of sources.	Useful as background information for evaluation activities to be carried out in the scope of WP7
GS NFV-SEC 003 - NFV Security; Security and Trust Guidance	Describes the security and trust guidance that is unique to NFV development, architecture and operation.	Not a core topic for T-NOVA, useful as background information
GS NFV-SWA 001 - Virtual Network Function Architecture	Identifies the most common and relevant NFV software architectural patterns and specifies functional requirements necessary to enable such patterns.	Key reference to WP5 (also to WP3, WP4, to a lesser degree)

The NFV ISG also provides an environment for the industry to collaborate on Proof of Concept (PoC) platforms to demonstrate solutions, which address the technical challenges for NFV implementation, to encourage growth of an open ecosystem.

ETSI NFV Phase 2 is now under way with over 30 new Work Items, including normative specifications. Topics such as interoperability, operations and collaboration with other industry groups and Open Source initiatives are now in the scope of the ETSI NFV work programme. Further information on NFV phase 2, mainly from a T-NOVA perspective, is provided in section 2.1.3.

2.1.2. High-level NFV framework and reference architecture

The NFV concept envisages the implementation of NFs as software-only entities that run over the NFV Infrastructure (NFVI). Figure 1, published in the ETSI NFV global architecture document, illustrates the high-level NFV framework, composed of three main working domains:

- Virtualised Network Function (VNF), the software implementation of a network function, which runs over the NFVI.
- NFV Infrastructure (NFVI), which includes the diversity of physical resources and how these can be virtualised. NFVI supports the execution of the VNFs.
- NFV Management and Orchestration (NFV MANO), which performs the orchestration and lifecycle management of physical and/or software resources that support the infrastructure virtualisation, and the lifecycle management of VNFs. NFV MANO focuses on all virtualisation-specific management tasks necessary in the NFV framework.

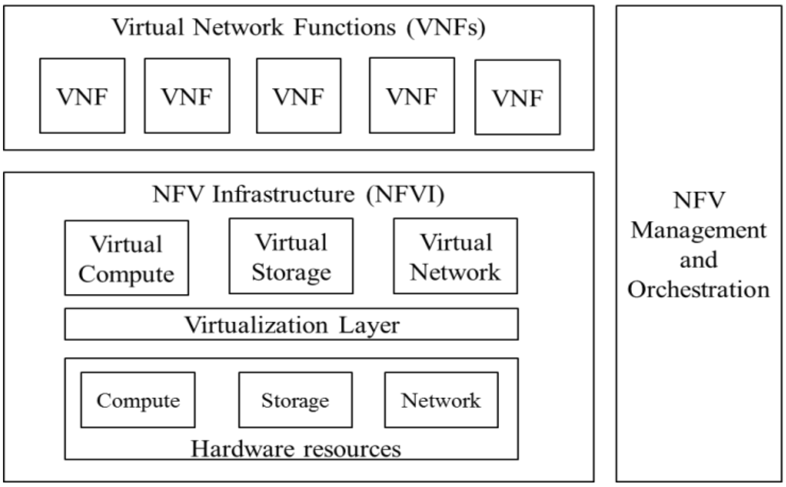

Figure 1. ETSI High-level NFV framework[1]

The NFV architectural framework handles the expected changes that will probably occur in an operator's network due to the network function virtualisation process. Figure 2 shows this global architecture, depicting the functional blocks and reference points in the NFV framework.

[1] Source: gs_NFV002v010101p - NFV - Architectural Framework

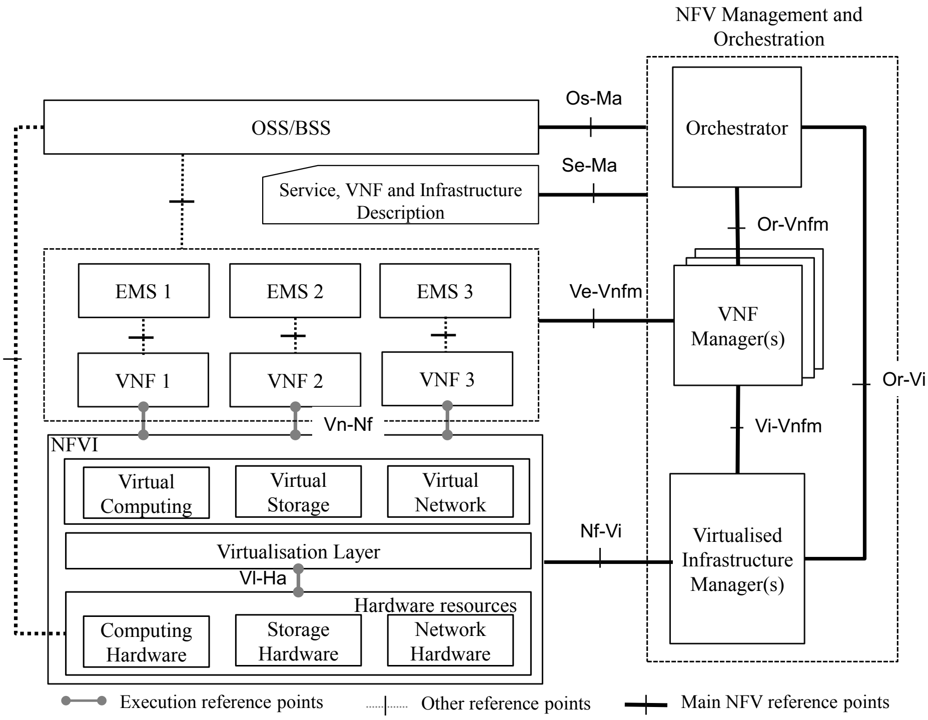

Figure 2. ETSI NFV reference architectural framework[2]

The architectural framework shown in Figure 2 focuses on the functionalities necessary for the virtualisation and the consequent operation of an operator's network. It does not specify which network functions should be virtualised, as that is solely a decision of the owner of the network.

In phase 1, three ETSI NFV ISG Working Groups were established following the identification of the above-mentioned domains (i.e. NFVI, SWA and MANO).

2.1.3. ETSI NFV Phase 2 (2015-2016)

ETSI NFV phase 2 extends the NFV charter, which is now mainly targeted at technology adoption and addressing areas such as testing/validation, performance/assurance, security, stability, interoperability, reliability, availability and maintainability. Collaboration with external bodies is also a key priority for NFV phase 2.

From the T-NOVA perspective, the working groups IFA and EVE deserve special attention, as described below (T-NOVA partners have actively contributed to some of these activities, as will be reported in WP7 deliverables).

IFA (Interfaces and Architecture): The responsibilities of this working group include the delivery of information models and information flows to support interoperability at reference points and the refinement of the architecture and interfaces leading to the production of detailed specifications. As of July 2015, 14 IFA Work Items were active, including the following ones with direct impact on T-NOVA:

[2] Source: gs_NFV002v010101p - NFV - Architectural Framework

- IFA001: Acceleration Technologies; Report on Acceleration Technologies & Use Cases (Impact on WP5)
- IFA005: Or-Vi reference point - Interface and Information Model Specification (Impact on WP3/WP4)
- IFA006: Vi-Vnfm reference point - Interface and Information Model Specification (Impact on WP3/WP4)
- IFA007: Or-Vnfm reference point - Interface and Information Model Specification (Impact on WP3/WP5)
- IFA008: Ve-Vnfm reference point - Interface and Information Model Specification (Impact on WP3/WP5)
- IFA011: VNF Packaging Specification (Impact on WP5/WP6)
- IFA012: Os-Ma-Nfvo reference point - Application and Service Management Interface and Information Model Specification (Impact on WP3/WP6)
- IFA013: Os-Ma-Nfvo reference point - Interface and Information Model Specification (Impact on WP3/WP6)
- IFA014: Network Service Templates Specification (Impact on WP3/WP6)

EVE (Evolution and Ecosystem): According to the terms of reference[3], this working group is responsible to develop feasibility studies and requirements in relation to a) new NFV use cases and associated technical features, b) new technologies for NFV and c) relationship of NFV with other technologies. It should also maintain an overall view of NFV-related work performed elsewhere (e.g. SDOs, industry groups, open source communities) and develop gap analysis on industry standards in areas relevant to NFV.

As of July 2015, the most relevant EVE Work Item for T-NOVA (particularly WP4) is EVE005 "Report on SDN Usage in NFV Architectural Framework", which performs a systematic analysis of how SDN and NFV can be used in a common environment and identifies the most common design patterns for using SDN in an NFV architectural framework. It also identifies potential requirements stemming from NFV/SDN integration.

Any relevant input coming from T-NOVA development and experimentation can be conveyed to the EVE WG through the common members PTIN and HP.

2.2. TM Forum

TM Forum (TMF) [1] is a global trade association of service providers and suppliers with the overall objective of progress and success in the digital economy. Key focus areas include trying to reduce costs and risks, improving business agility and growing business through knowledge, tools, standards, training and practical advice. Its activities are organized in three strategic programs: agile business & IT, customer engagement and Open Digital. In relation to the first of them, TM forum works in 4 key areas: Business & IT transformation, Business metrics and KPIs, Cybersecurity and Managing virtualized Network and Services.

In the context of this last mentioned area is where TMF has recently kicked off a major new project with the aim of creating a blueprint for a new generation of service

[3] https://portal.etsi.org/Portals/0/TBpages/NFV/Docs/NFV_EVE_WG_Terms_of_Reference.pdf

provider support systems to achieve business agility when delivering virtual network and services; it is the zero-touch orchestration, operations and management (ZOOM) project. [2]

The TMF ZOOM project, already in its first stages, has settled its objectives mainly to contribute in the definition of the new virtualized operations environment to delivery of virtualize network services, while allowing the interaction between physical and virtual components to dynamically assembled into personalised services, achieve agility in business and operations practices, define new security approaches to protect infrastructure, functions and services, and complement on-going work of ETSI and other standard organizations working together to provide the management platform and transformation guidance to support successful deployment of NFV.

In this direction, the technical reports released so far by TM Forum ZOOM related to NFV are the following:

- **TR229 ZOOM/NFV User Stories** [3]

This report provides a snapshot of the User Stories that have been identified by the ZOOM project team and encompasses:

- Scenarios being developed in The TM Forum NFV Catalyst program [4]. The projects under this program we have looked at in T-NOVA are the following:
    - Orchestrating SDN and NFV While Enforcing An SLA Over A WAN.
    - CloudNFVTM: Dynamic, Data-Driven Management and Operations.
    - NFV Management Ecosystem.
    - Service Bundling In A B2B2X Marketplace
- Requirements in ETSI and ATIS Reports [5, 6] [7] [8].
- Agile brain storming sessions amongst Service Providers active in the ZOOM Project.

T-NOVA looked at this TMF work in the previous Task T2.1 when defining use cases, business scenarios, roles involved and initial SLA issues.

- **TR227 TM Forum Specifications relevant for MANO Work** [9]

This document was developed by TMForum with the aim of providing feedback to the ETSI NFV ISG MANO workgroup MANO GS (V0.3.6, 2014-02) about the possible applicability of TM Forum specifications to areas that ETSI is working on. The expertise of the content of the MANO document was provided by TM Forum members who are also engaged in ETSI MANO. The contents were reviewed by the ZOOM Project to validate the TM Forum assets.

The document contains a description of the set of TM Forum documents that are relevant for MANO work. It identifies areas where each TM Forum document can help to standardize the information presented and interfaces of the MANO reference points. These areas, which are under the Business & IT transformation TMForum area are as follows:

- Information framework description (SID): A technology-neutral information model that defines entities and their relationships in a managed environment.

- Business process framework (ETOM): A hierarchical catalog of the key business processes required to operate a service-focused business.
- Integration framework description, that proposes, among others, the creation of a:
    - catalog of Business Services based on Service Oriented principles;
    - platform or domain-based enterprise architecture that provides the business agility required to compete in today's market; and
    - definition of critical standard interfaces that speed integration.

These reports will be taken into account in T-NOVA mainly when defining the marketplace, where a business service catalog will be developed, the service description scheme, SLA management, etc. Extended information about these TMForum activities will be included in the following deliverables.

- **TR228 TM Forum Gap Analysis related to MANO Work** [10]

This technical report is the answer of TMForum's members to the latest NFV Management and Operations (MANO) architecture document, published on July 8 [11], providing an updated GAP. It focuses in two aspects of ETSI work: the MANO interfaces and the MANO information description elements, comparing them with the TM Forum Frameworx APIs and the Logical Resource and Service models, respectively.

Analysing the document, we gather that one of the topics that TM Forum identifies that is missing from MANO, is a detailed implementation model on how to manage operational and business support systems in a hybrid legacy and virtualized environment, something that ETSI is not addressing so far.

In line with this result TMF, ZOOM points out further key future objectives for NFV scheme such as focusing on end-to-end virtual network and operations management, working on network functions virtualization (NFV) procurement requirements, and ensure security and quality of service across operators' networks.

Though the scope of the interface between the MANO architecture and the existing OSS/BSS system of operators is not within T-NOVA scope, T-NOVA will provide a first step on the direction of this research line by means of the implementation of the marketplace, which will implement some of the functionalities of a BSS system of an operator, and what will be a first input for latest studies in the interoperability with OSS/BSS existing systems, that TMF ZOOM intends to address in the future.

2.2.1. Update on TMForum NFV related work – July 2015

It is since February 2015 when TMForum ZOOM project increases considerably its research towards NFV, further than the first insights that we surveyed in July 2014 and explained in the previous section. Those were focused in analysing ETSI NFV work and provide business good practices. In February 2015 TMForum launched its inaugural research report on NFV [1] which addresses, among others, the following topics:

- NFV definition based on ETSI NFV architecture.

- Role that SDN plays in end-to-end provisioning and management of services over NFV infrastructure.
- Obstacles for NFV to "cross the chasm".
- Results of a survey of global service providers and industry experts on the drivers for NFV, the business and technological inhibitors, plans to adopt a DevOps approach to network operations, and the role for standards and collaboration groups;
- Importance of NFV and SDN proof-of-concept projects (PoCs) including coverage of several TM Forum Catalyst projects, three of which also doubled as ETSI PoCs;

In the form of Catalysts projects, as previously, TMForum has launched several rapid proof-of-concepts which leverage TM Forum best practices and standards, involving service providers, technology suppliers, and global enterprises to create innovative solutions to industry challenges. We have identified several of them that are aligned with the work already done in T-NOVA, such as:

- Security Functions in NFV; that aims to demonstrate the impact and value of dynamic security orchestration in an NFV environment (e.g. packet inspection, browsing protection and source reputation checking).
- Maximizing Profitability with NFV Orchestration; the objective of this catalyst project is to demonstrate how to instantiate, monitor and scale Virtualized Network Functions (VNF) based on technical parameters (SLA, QoS, etc.) and business metrics.
- NFV Management Ecosystem; this will be a rapid implementation of management and orchestration (MANO) as defined by the ETSI NFV ISG to demonstrate real-time, dynamic management of capacity, performance, quality of service (QoS) and service level agreements (SLA) as well as enabling real-time billing and compensation. This NFV ecosystem is enabled through use of standardized APIs from TM Forum. This PoC has important links with T-NOVA marketplace.

Other TMForum catalyst projects close to T-NOVA work but no directly relevant are:

- Zero-touch Network-as a-Service: Agile, Assured and Orchestrated with NFV
- Multi-Cloud SDN-NFV Service Orchestration
- Service Network Transformation based on NFV

The main reports released by TMForum during the last year relevant to T-NOVA work are the following:

- IG1124 ZOOM NFV Security Fabric Overview R14.5.1. This document outlines the TM Forum view on where the security fabric needs to be to support virtualized services and the requirements and dependencies that it may place on the underlying platform virtualization and infrastructure layers.
- TR236 Operations Flows for SDN Service Function Chains R14.5.1. This document covers several operations flows (e.g., order to service and from issue reporting / problem ticket creation to repair, with supporting security) for SDN Service Function Chains (Virtual Network Function (VNF) Forwarding Graphs).
- TR238 Fulfilling NFV MANO Interface Requirements R14.5.1. This document provides an overview of TM Forum interfaces and an analysis of how they can

be used to support various interface requirements from ETSI Network Functions Virtualization (NFV) Management and Orchestration.
- IG1122 NFV Readiness: Operating a Hybrid Virtualization Network Infrastructure R14.5.1. This briefing investigates some of the operations issues and proposes: A Migration Dashboard with a set of metrics to enable SP manage the transition from current network operations through a series of hybrid network operations stages. A set of exemplar hybrid operations scenarios are developed which illustrates some of the operations and OSS changes that will occur during the hybrid network operations – including additional interfaces, changes in where the data of record is mastered, etc.

Other recent TMForum reports relevant to T-NOVA in relation to business and marketplace aspects are analysed deeper in Deliverable D2.42. These are:

- IG1120 Virtualization Impact on SLA Management
- IG1127 End-to-end Virtualization Management: Impact on E2E Service Assurance and SLA Management for Hybrid Networks R15.0.0.
- IG1130 Future TAM Impacts by SDN/NFV R15.0.0
- TR244 TM Forum Information Framework Enhancements to Support ZOOM R15.0.0

2.3. OPNFV

OPNFV (http://opnfv.org/) is a recently launched initiative, which quickly gained traction and is starting to provide its first deliverables. It is a collaborative open source project, conceived inside the Linux Foundation, whose goal is speeding up the progress of NFV technologies through the implementation of an integrated and open reference platform. It aims at creating an ecosystem of developers, making available for them a physical infrastructure and a development toolset.

OPNFV has an important participation of industrial players. Two of T-NOVA's industrial partners (HP and Intel) are OPNFV Platinum Members. ETSI NFV ISG is seen by OPNFV as a key reference model to look at for its reference implementation.

Initially[4] OPNFV targeted for implementation two of the ETSI ISG components, i.e. the NFVI and the VIM. Furthermore, it proposed to create a set of API allowing to interconnect these components to the rest of an end to end NFV framework.

[4] https://www.opnfv.org/sites/opnfv/files/pages/files/opnfv_whitepaper_092914.pdf

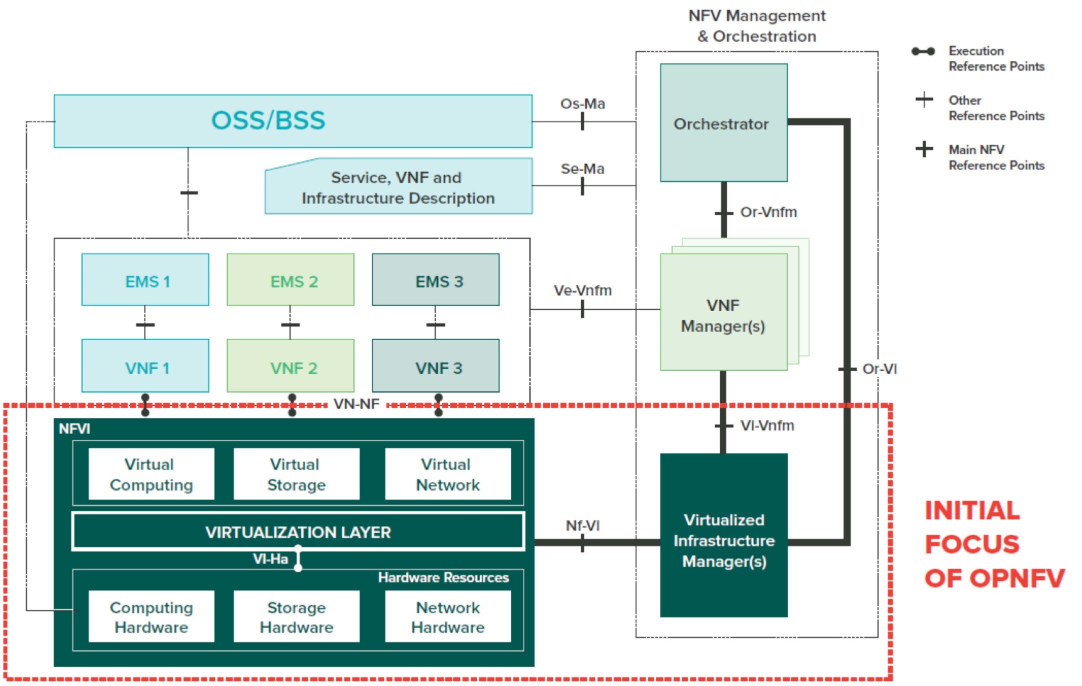

Figure 3. OPNFV mapping to ETSI reference architecture

NFV classifies its components' interfaces into four groups:

1. VNF to Physical Hardware (*Vi-Ha*)
2. Interfaces for Applications to Execute on Virtual Infrastructure *(Vn-Nf*)
3. Interfaces between Virtual Infrastructure and VIM (*Nf-Vi*)
4. Interfaces from VIM to VNF Managers and Orchestration (*Or-Vi and Vi-Vnfm*)

In June 2015, OPNFV made the first release of its NFVI and VIM modules, code named *ARNO*. ARNO provides the following functions[5]:

- **Baseline platform:** Arno enables continuous integration, automated deployment and testing of components from upstream projects. It allows developers and users to automatically install and explore the platform.
- **Deployment and test various VNFs**: End users and developers can deploy their own or third party VNFs on Arno to test its functionality and performance in various traffic scenarios and use cases.
- **Test infrastructure in community-hosted labs**: OPNFV unveiled a community test labs infrastructure where users can test the platform in different environments and on different hardware.
- **Automatic continuous integration of specific components**: As upstream projects are developed independently they require testing of various OPNFV use cases to ensure seamless integration and interworking within the platform. OPNFV's automated tool chain allows continuous automatic builds and verification.

5 https://www.opnfv.org/news-faq/press-release/2015/06/opnfv-delivers-open-source-software-enable-deployment-network

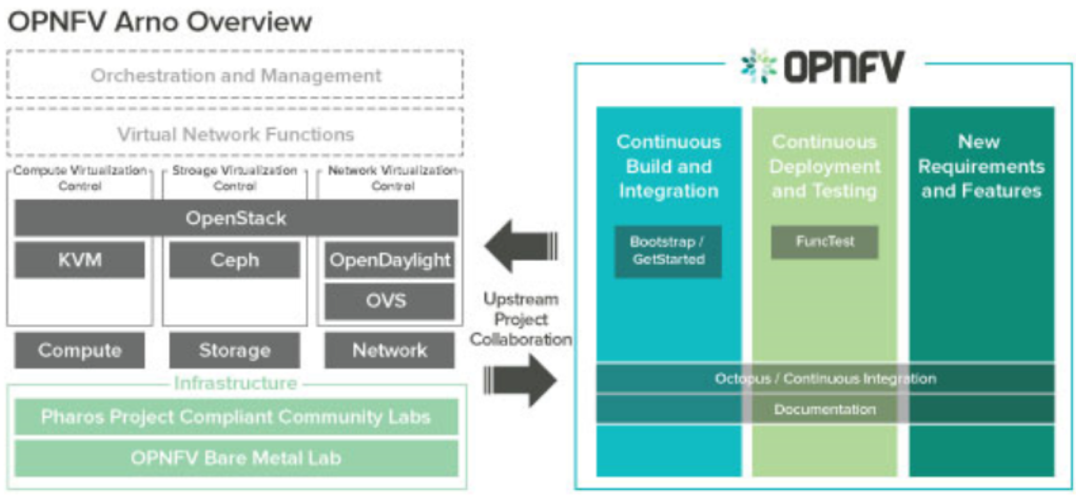

Figure 4. OPNFV ARNO release diagram

2.4. HP OpenNFV

OpenNFV [12] is a comprehensive project launched by HP, built around a proposed open reference architecture, encompassing a service portfolio, and enforced by an ecosystem of vendors, operators and application developers.

HP architecture is aligned with the ETSI model, and HP has a number of active contributors in the NFV ISG. OpenNFV main components are a NFV Infrastructure and a NFV Orchestrator module, in turn based on HP Converged Infrastructure and HP Converged Cloud propositions. It also capitalizes on the SDN role, and on HP's SDN technology assets. It is a modular architecture, basically vendor agnostic and allows a modularized approach to NFV take-up. Figure 5 shows the open model behind the OpenNFV architecture.

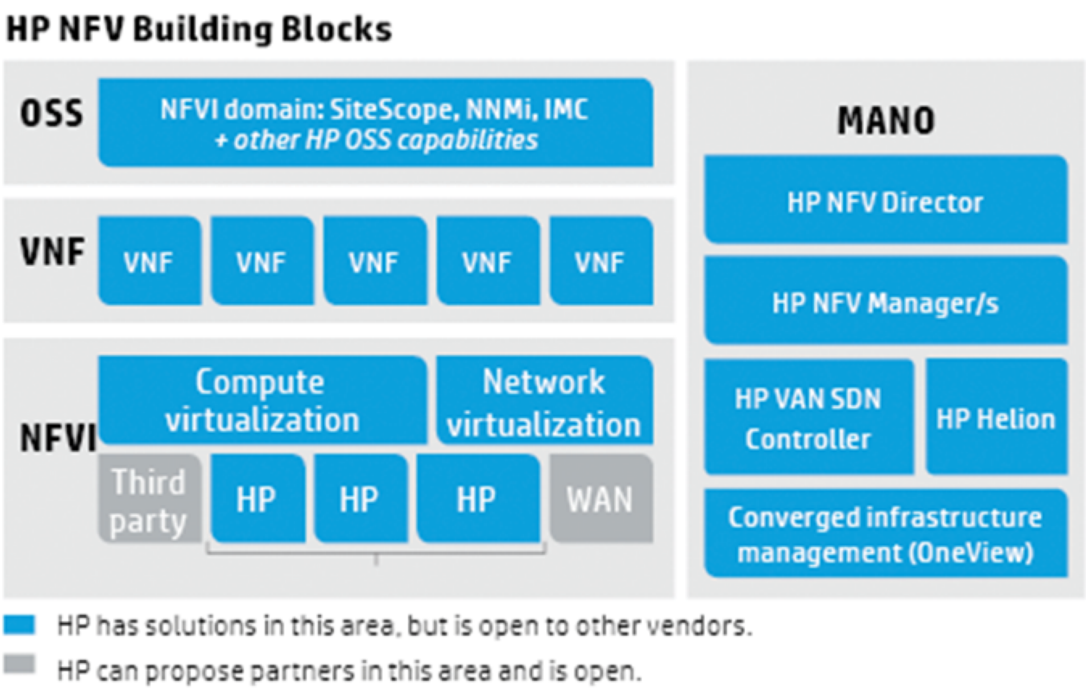

Figure 5. HP OpenNFV model

Figure 6 shows a functional view of the OpenNFV architecture.

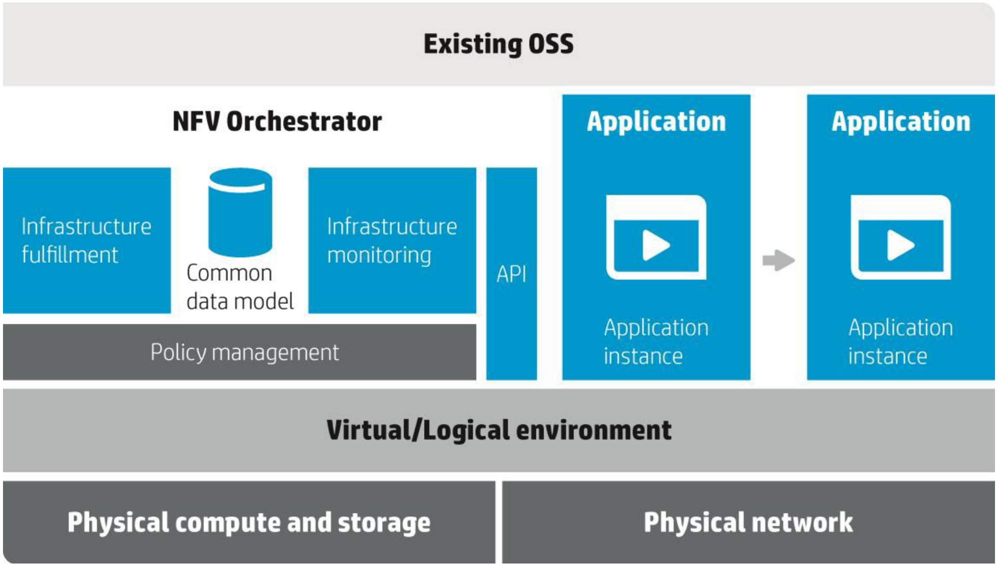

Figure 6. HP OpenNFV Functional Architecture

The virtualized NFV infrastructure layer includes compute, storage and networking plus their element management components. It's a logical infrastructure layer, designed to support both physical and virtualized resources at the same time. The NFVI layer offers pre-integrated modules supporting virtualization and performance enhancement technologies like SR-IOV and DPDK, to ensure that the hardware horsepower is suitable to seamlessly virtualize network functions without performance degradation. Multiple hypervisors can be supported, like VMware ESX, Microsoft Hyper-V, and Linux KVM.

On the network virtualization side, the architecture can seamlessly support automated provisioning of both physical and virtual networks. HP physical switches also support L2/L3 forwarding, bridging the gap between legacy and SDN-controlled networks. A comprehensive heterogeneous network management platform is also available.

HP Cloud System is the module that allows the NFVI layer to be viewed as a service, accessing the infrastructure resources through an OpenStack interface.

The NFV Orchestrator module (implemented by HP in the *NFV Director* component) implements the functions prescribed by the ETSI model MANO layer specification:

- Configuration of the virtualized computing infrastructure;
- Networking functions for the computing infrastructure to communicate with the physical network in an NFV application;
- Common data model for services and NFV instances (forwarding graph);
- Service and resources status management, including integration with existing OSS;
- Policy management: supervision of static (configuration) and dynamic (operation) policies.

The NFV Orchestrator is hypervisor-agnostic, so it can support different solutions both proprietary and open source.

2.5. Qosmos/Intel/Tieto

Intel has been an active player in supporting the development and evolution of NFV and SDN through industry and vendor specific initiatives. The network builders program for example is and industry initiative comprising of more than 70 companies. The goal of the program is to make it easier to build, enhance, and operate SDN/NFV-based infrastructure, while lowering capital and operating expenditures. The program publishes function specific architectures such as vEPC, vBRAS, vCPE etc. [13]

Intel has also worked with a number of industry partners to develop reference architectures for NFV. For example Intel has collaborated with Telecommunication Equipment Manufacturers (TEM's) provider QOSMOS and systems integrator Tieto to develop a reference architecture for NFV based on ETSI NFV ISG principles [14]. The architecture is designed to address key barriers to NFV adoption such as:

- Real-time performance
- Service Awareness - Allocation of resources to network functions based on the services they support
- Service Availability - Achieving the same level of service availability for end-to-end virtualised networks as non-virtualised.
- Network elasticity

The key components of the architecture are shown in Figure 7. This architecture was used to form the basis for a proof of concept (POC) that demonstrated a number of ETSI defined VNF use cases. The key components of the architecture are as follows:

Virtualised Network Functions – The PoC implemented reference software for LTE eNodeB and EPC (MME, SGW, and PDN GW), along with Tieto's Diameter Signalling Controller (DSC), which was deployed as a VNF. Qosmos' intelligent DPI was included and could be deployed either within a VNF or as a standalone virtual networking function component (VNFC). The associated Element Management System (EMS) for each VNF is integrated within the VNF subsystem, which monitors the operational condition of the VNF's as part of the overall Telecommunications Management Network (TMN).

NFV Management and Orchestration – This sub-system is responsible for the management of VNF deployments and lifecycle. The SDN controller is also contained within this sub-system with responsibility for flow control to enable intelligent networking. The architecture is orchestrator-agnostic however the reference implementation is based on OpenStack. The network management solution interfaces to OpenStack via Heat are used for automation and deployment.

Network Operations (OSS/BSS) – The architecture and reference implementation supports a NETCONF interface for OSS and a Cloud Infrastructure Management Interface (CIMI). The intent is to demonstrate that new VNFs can be deployed and managed from an end-to-end perspective within a telco cloud environment.

Cloud Platform – This sub-system is based on OpenStack, which has been modified by Tieto to include telco-grade supervision, statistics, diagnostics, fault and performance management capabilities.

SDN Networking – The SDN controller is compatible with OpenStack Neutron and supports SDN networking and legacy network management system (NMS) integration, and provides supervision, statistics and performance management. OpenFlow is used to communicate between the SDN controller and the Open vSwitch, which is managed by the OpenFlow Controller.

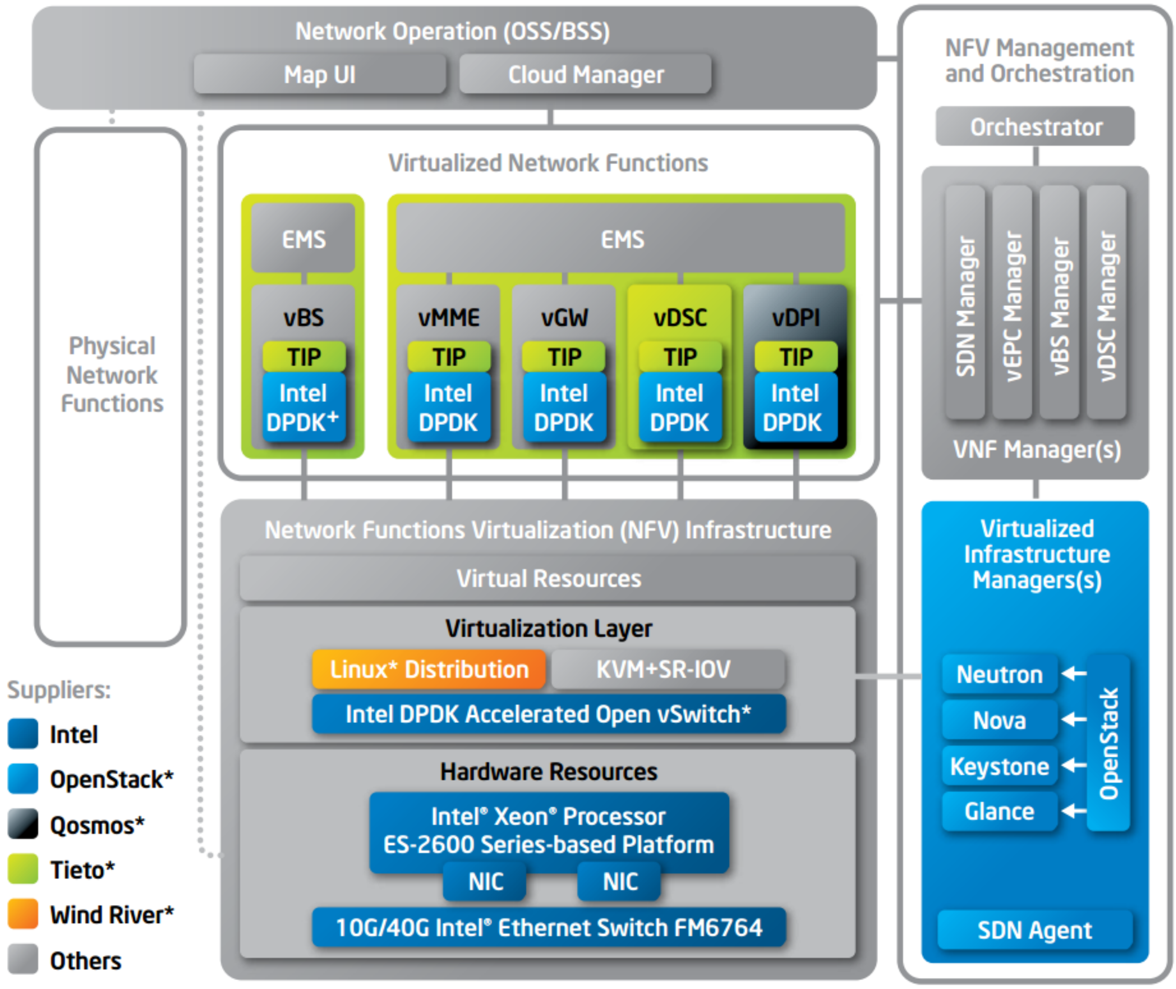

Figure 7. Intel NFV High Level Architecture

The designed architecture was validated through a PoC implementation and was used to illustrate three specific ETSI NVF use cases:

- Virtual Network Functions as a Service (VNFaaS)
- Virtualisation of a Mobile Core Network (EPC) and IMS
- Virtualisation of a Mobile Base Station (RAN)

2.6. Alcatel-Lucent CloudBand

The CloudBand NFV platform [15] aims at transforming carrier-grade service provider (B2B proposal) networks with distributed footprint into a single, manageable, virtual cloud.

2.6.1. CloudBand Overview

The overall architecture of CloudBand is illustrated in Figure 8.

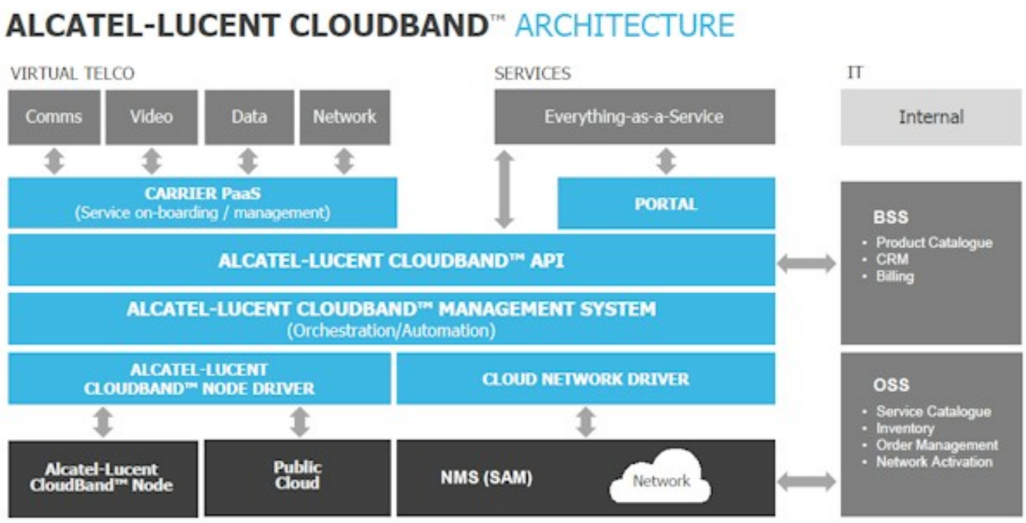

Figure 8. CloudBand Overall Architecture

The major characteristics of the architecture in Figure 7 are:

- Mono-vendor solution NFV / Cloud management
- Possible expansion to Everything as a Service offer[6]
- Cloud Infrastructure accesses via API from NFV and BSS
- Interface to public cloud
- NMS includes management of the CloudBand Network
- Multi-vendor support for cloud nodes

In addition, concerning the deployment, a distributed cloud infrastructure can accommodate a large number of small and medium datacentres, placed in different sites to spread services across multiple locations.

CloudBand also comes with a carrier PaaS (cPaaS) management tool that manages application lifecycle automatically and on-boards VNFs in the cloud. It hides the complexities of infrastructures and OS. It can automate and optimise application services like IMS or any other carrier grade service and facilitates operators to concentrate on other aspects of the application lifecycle namely provisioning, monitoring, healing and scaling (as shown in Fig 8).

The management of the PaaS allows defining rules for the placement, SLA, placement Zones, monitoring, Cloud resources, High availability (HA) and redundancy, tracking the full lifecycle of the deployed applications.

[6] The platform is supposed to be flexible to accommodate other services in the paradigm XaaS beside the ETSI VNF.

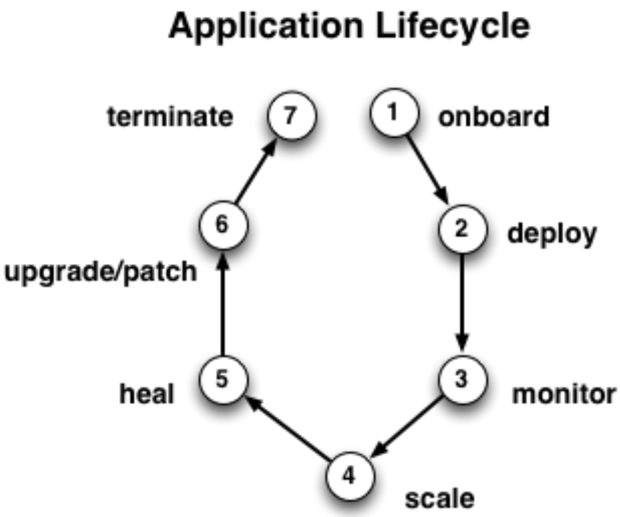

Figure 9. CloudBand Application LifeCycle

2.6.1.1. Analysis of key components

The key components of CloudBand are:

- Orchestration and Automation: CloudBand orchestrates and automates cloud resources across the network and geo-distributed data centers.
- Cloud Node Driver: It is a mediator layer that supports different node implementations.
- Cloud Network Driver: Allows operators to create separate, virtualized and distributed LAN networks on demand across multiple locations, enabling seamless connectivity to their corporate VPN, through VPN stitching (easy like VM creation).
- Analytics and Monitoring: All metrics are collected every minute from the cloud driver, and are stored in the Cassandra open source distributed database management system.

2.6.1.2. Automated Lifecycle Management - Descriptors

The CloudBand platform includes an automated lifecycle management. With the virtualization of the telecommunications industry, service providers have the opportunity to introduce tools similar to cloud automation as part of their operational arsenal.

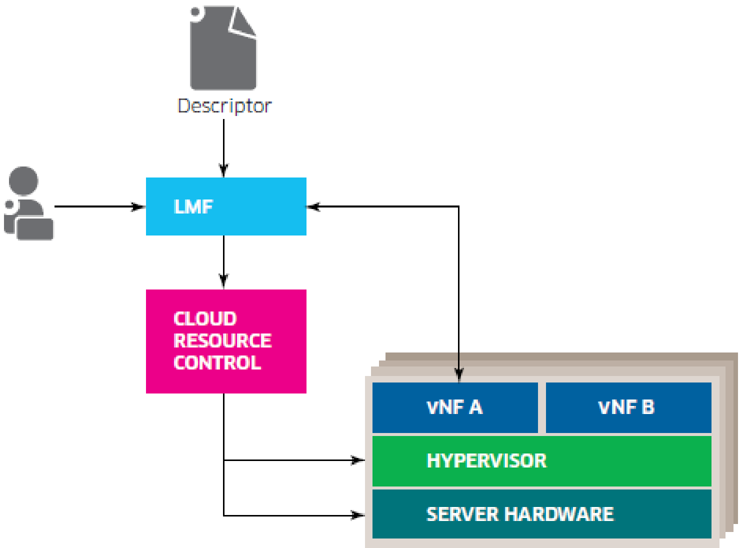

Figure 10. VNF deployment sequence

The process uses a descriptor that is generally provided by the VNF vendor. This descriptor defines the structure of the VNF (and sub-functions needed to run as an independent VM) and deployment and operational aspects, such as computation, storage and networking requirements.

These descriptors are mapped to requests to the cloud resource control to create VMs and to identify software images to be downloaded and initiated on those VMs. Once the VMs are up and running, the LMF configures parameters of the VNF components based on instructions in the descriptor.

2.7. OpenMANO

OpenMano is an open source project that provides a practical implementation of the reference architecture for Management & Orchestration under standardization at ETSI's NFV ISG [REF-1]. OpenMano has been released by Telefonica Labs under Apache 2 license and it is available from GitHub[7].

The OpenMano software consists of three major components, each one of them covering one layer of requirements associated to the MANO architecture of the ETSI NFV ISG:

- **openvim**: reference implementation of an NFV VIM. It interfaces with the compute nodes in the NFV Infrastructure and an SDN controller in order to provide computing and networking capabilities and to deploy virtual machines. It offers northbound interface, based on REST (i.e. openvim API), where enhanced cloud services are offered including the creation, deletion, and management of images, flavors, instances, and networks. The implementation of this component follows the recommendations in ETSI-PER001, NFV Performance and Portability Best Practices [REF-2].

[7] https://github.com/nfvlabs/openmano

- **openmano**: reference implementation of an NFV Orchestrator. It interfaces with an NFV VIM through its API and offers a northbound interface based on REST (openmano API), where NFV services are offered including the creation and deletion of VNF templates, VNF instances, network service templates and network service instances
- **openmano-gui**: web UI to interact with openmano server, through its northbound API, in an user-friendly way.

Figure below depicts the relationship of the different software components of the OpenMano platform with the ETSI NFV reference architecture. In the right side of the image, in blue boxes, the openmano components are depicted. It can be seen how the *openmano* performs both Orchestration and VNF Management, while *openvim* is devoted to virtualized infrastructure management.

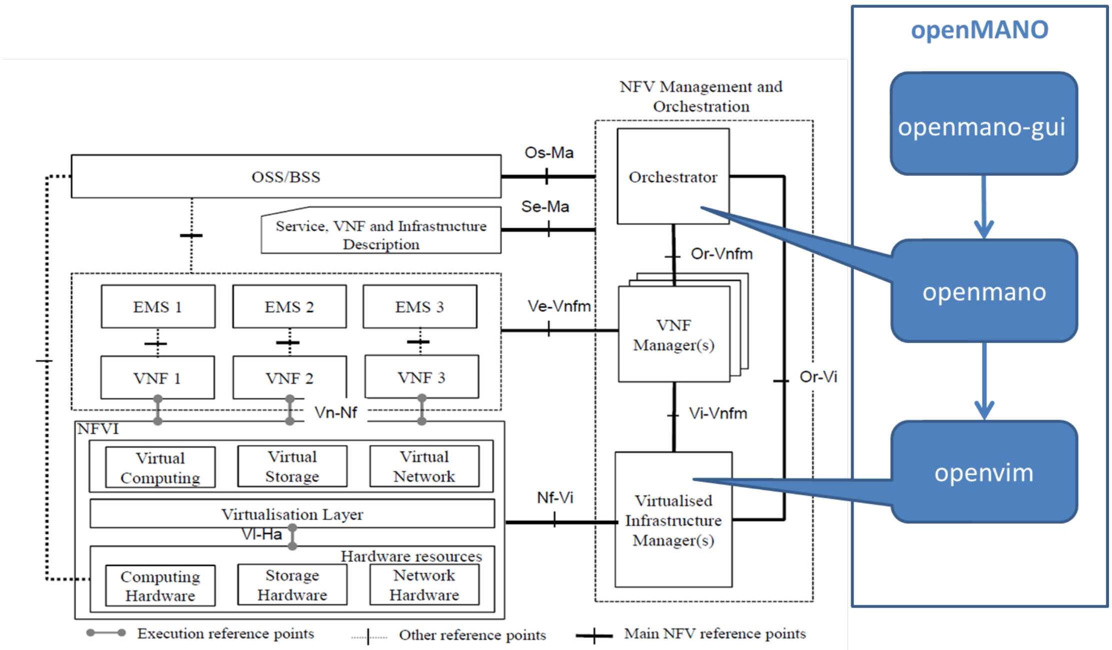

Figure 11. OpenMANO relation to ETSI NFV architecture

Complementary to the previous figure, a quick analysis on the correspondence between the OpenMano components and the T-NOVA architectural components produces a one-to-one analogy between them. Thus, figure below depicts how the *openvim* is the analogy to the *T-NOVA IVM* and the *openmano* is the analogy to the *T-NOVA Orchestrator*. There is no marketplace nor similar BSS/OSS system considered within the Telefonica released platform, which provides T-NOVA architecture and overall implementation with an added value (and clear differentiation) for the distinct stakeholders.

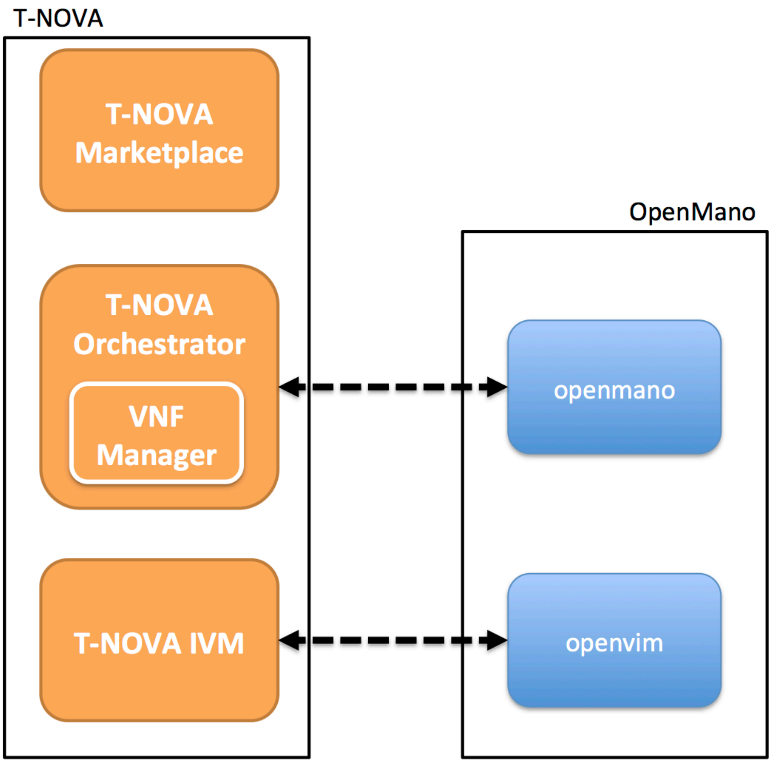

Figure 12. OpenMANO relation to T-NOVA components

Although OpenMano and some of the T-NOVA components implement similar management and orchestration features, there are still some conceptual differentiations between the frameworks. First of all, in OpenMano the term network service, as defined in the ETSI NFV ISG, is avoided, and instead they use the term network scenario, which refers to a network topology consisting of VNFs and the networks/links used to interconnect them. While from the logical perspective the concept is the same for the technical metrics within the SLAs, it becomes more difficult to manage the different business metrics applied over a given service (e.g. billing, pricing), which in T-NOVA is completely managed by the Marketplace and the Orchestrator.

Furthermore, OpenMano follows an NFVO-centric approach, with a very simplified VNF instance lifecycle management at the NFVO (i.e. very simplified VNF Manager). T-NOVA addresses the problem following a two-level orchestration approach. Therefore, for the entities catalogued as VNFs, the orchestrator follows a VNFM-centric approach (i.e. lifecycle management managed by the VNF Manager, interaction with the VIM, etc.); while for the entities catalogued as network services, the orchestrator follows a NFVO-centric approach.

It is still safe to say that OpenMano only covers a partial set of features in the NFV realm, while T-NOVA provides a complete holistic approach to the problem of both defining and creating services and VNFs, as well as managing and orchestrating them.

2.8. Vmware vCloud Solution for NFV

VMware offers vCloud Suite solution, that is an integrated offering for building and managing a VMware vSphere-based private cloud. Recently VMWare has released VMware vCloud for NFV that is a multi-vendor NFV cloud platform and supports over 40 Virtual Network Functions (VNFs) from over 30 ecosystem partners. The platform exhibits multi-tenancy/multi-vendor capabilities of the VMware platform (Figure 13) combined with highly developed operations support services that deliver FCAPS for the cloud and the open application programming interfaces (APIs) for integrating northbound to applications and service orchestration platforms.

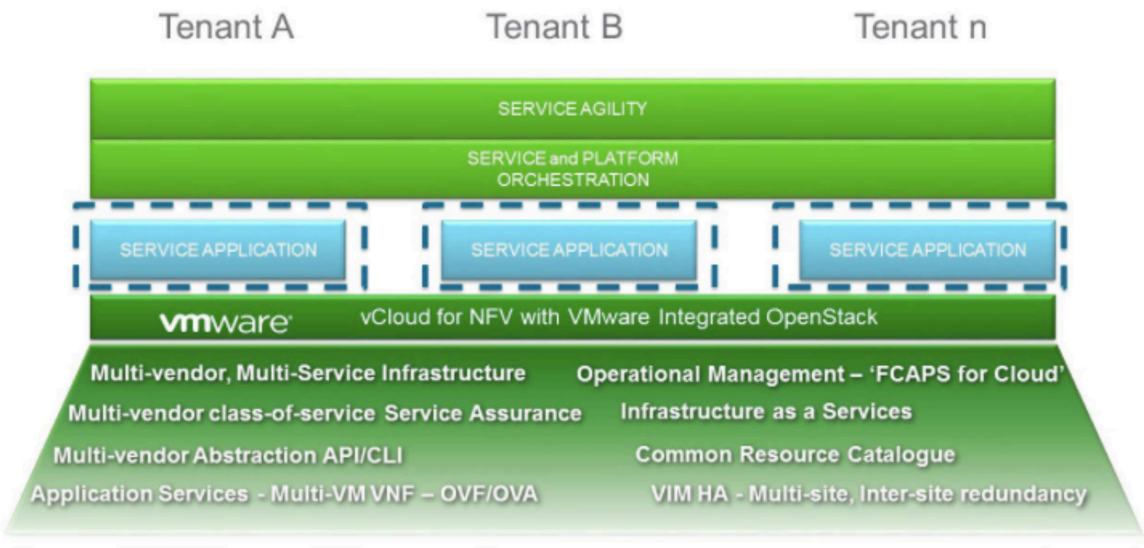

Figure 13 Multi-Tenant/Multi-Service NFV Platform

VMware vCloud for NFV features VMware vSphere®, the compute virtualization solution for the cloud; VMware NSX™, network virtualization platform that delivers the entire networking and security model from L2-L7 in software; VMware Virtual SAN, software-defined storage. Cloud Management APIs are provided through VMware vCloud Director, a management tool for Telco cloud architectures, and VMware Integrated OpenStack .

2.9. Project MCN

The Mobile Cloud Networking (MCN) [16] is a 3-year European co-funded (FP7) project, which started in November 2012 and will end in October 2015. At the time of writing of this document, the MCN consortium was preparing a 6 months extension request. The project approaches the integration between the Cloud and Telco worlds, making Operators benefit from the principles of virtualization.

2.9.1. Overview

The project focuses, in particular, on mobile operators. For this reason, the main target is to fully cloudify the whole components of a mobile network operation, namely (see Figure 14):

- the access (RAN - Radio Access Network);
- the core (EPC – Evolved Packet Core);
- the services (IMS – IP Multimedia Subsystem, CDN – Content Delivery Networks, DSS – Digital Signage);
- the Operational Support Systems (OSS) (Provisioning, Monitoring, SLA Management);
- the Business Support Systems (BSS) (CRM – Customer Relationship Management, Charging, Billing).

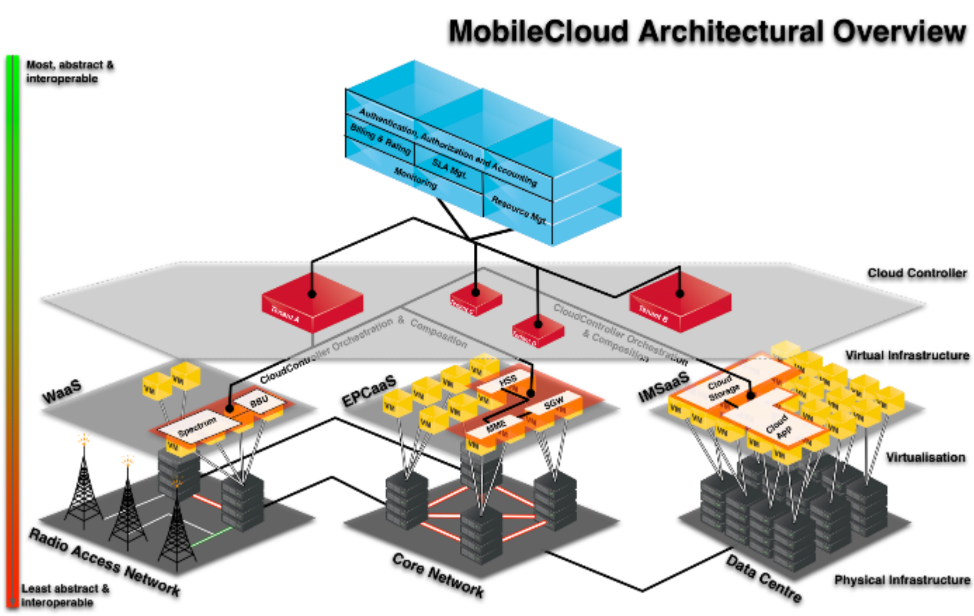

Figure 14. Mobile Cloud Networking Vision

Note: In the case of OSS/BSS case, the focus is two-fold. Firstly, support the operations and businesses of cloudified networks; secondly, the virtualization itself of the OSS/BSS platforms.

Beyond the virtualization, the project explores the “as a Service” (XaaS) concept, where the functions are provided as a full operational service. That means the customer of the service does not need to worry about implementation, deployment and dimensioning details of it. This approach allows an easy creation of “end-to-end (e2e)” services by composition of basic services. As an example, it can be considered the creation of an MVNOaaS service by the composition of RANaaS+EPCaaS+IMSaaS.

2.9.2. Motivations

The motivations for this project relate to the exploitation of cloud principles by the Telcos, such as flexibility, efficiency, pay as you go, or cost reduction. In particular, this can be explored by a sector that has been obliged to severely reduce margins and lose business that they traditionally controlled.

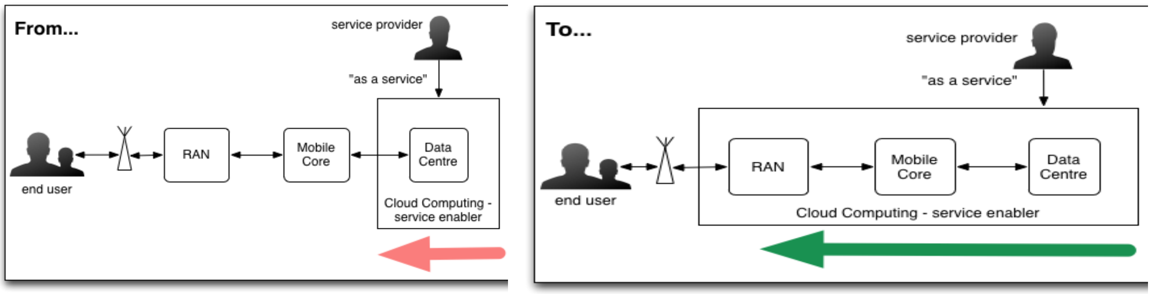

Figure 15. Extending the Concept of Cloud Computing Beyond Data Centres Towards the Mobile End-User

The primary motivations of the MobileCloud project are to:

- Extend the Concept of Cloud Computing beyond data centres towards the Mobile End-User.
  - o "One Service (atomic): Mobile Network + Computing + Storage"
  - o "On-Demand, Elastic, and Pay-As-You-Go"
- Enable a Novel Business Actor, the Mobile Cloud Provider
- Redesign the Mobile Network Architecture for Exploiting and Supporting Cloud Computing
- Deliver and Exploit the Concept of an End-to-End Mobile Cloud for Novel Applications

2.9.3. Architecture

Mobile Cloud Networking overall architecture design [17] is mainly governed by service oriented design principles. Every service in MCN has the same provisioning and lifecycle management pattern and architecturally follows the global MCN reference architecture.

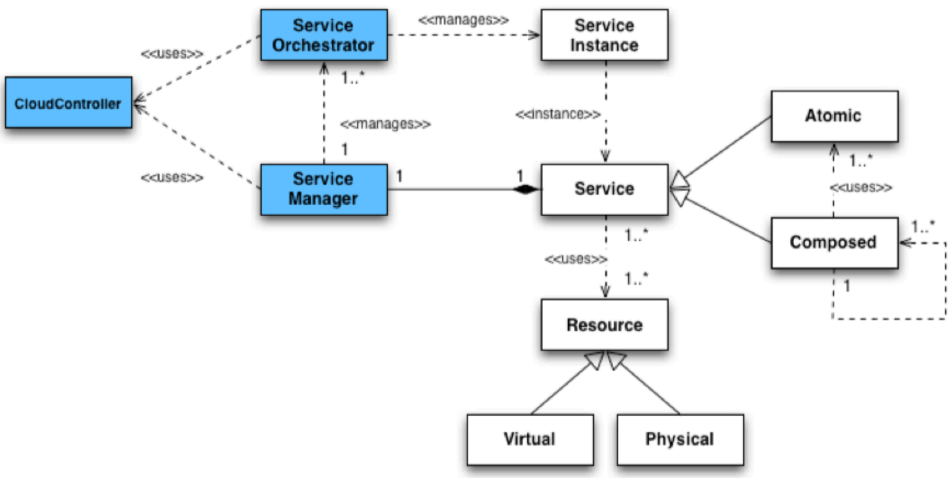

Figure 16. MCN Architectural Entities Relationship

A brief description of key components follows:

Service Manager: provides an external interface to the Enterprise End User (EEU) and is responsible for managing service orchestrators, it has business and technical management functions.

Service Orchestrator: it oversees the end-to-end orchestration of a service instance. It is responsible for managing the Service Instance and in particular its components (SIC), once it is created and running.

Cloud Controller: provide the signaling and management interfaces to enable the common (northbound), and technology-specific (southbound) control planes. It provides both atomic and support services required for realizing SO needs. The main MCN architectural entities that interact most with the Cloud Controller are the SM and SO.

Service Orchestrator implementation in MCN project is service specific as it depends on the domain knowledge of the respective NF it is implementing. Some of the prominent NFs being virtualized and managed as a service in MCN are – EPC, IMS, DNS, OSS/BSS (RCB), AAA, CDN, etc.

2.10. Project CONTENT

CONTENT (Convergence of Wireless Optical Network and IT Resources in Support of Cloud Services) is a 3-years European co-funded (FP7) project, which started in November 2012 and will end in October 2015.

CONTENT aims at offering a network architecture and overall infrastructure solution to facilitate the deployment of conventional Cloud computing as well as mobile Cloud computing intro`ducing new business models and facilitating new opportunities for a variety of business sectors.

2.10.1. Project Overview

The project focuses on developing a next generation converged network infrastructure to support the network of the future. The proposed infrastructure model will be based on the IaaS paradigm and will aim to provide a technology platform interconnecting geographically distributed computational resources, which can support a variety of Mobile Cloud services.

CONTENT will focus on a hybrid wireless solution based on Wi-Fi and LTE and a WDM access-metro network with frame-based sub wavelength switching granularity, incorporating active nodes that also support backhauling of the wireless access network. To support the IaaS paradigm, CONTENT will adopt the concept of physical resource virtualization across the technology domains. One of CONTENT's objectives is to offer a rationalized cost and energy efficient network infrastructure suitable to support Cloud and mobile Cloud services.

CONTENT project objectives are:

1. Seamless integration of wireless and wired optical access-metro network domains to provide end-to-end connectivity of computational resources with fixed and mobile users.
2. A cross-domain and technology virtualization solution allowing the creation and operation of infrastructure slices including subsets of the network and computational physical resources.
3. Support of dynamic end-to-end service provisioning across the network segments, offering variable QoS guarantees, throughout the integrated network
4. Cost and Energy Efficiency

2.10.2. Proposed CONTENT Architecture

CONTENT proposes a layered architecture with the aim to facilitate the main principles of its novel proposition i.e. cross-technology virtualization in support of optimised, seamless and coordinated cloud and mobile cloud service provisioning across heterogeneous network domains. During the 2nd year of the project, the CONTENT architecture has been updated. The individual architecture layers have been defined in considerably more detail taking into consideration an implementation oriented perspective.

The overall updated CONTENT architectural structure is illustrated in Figure 17 and includes the following layers:

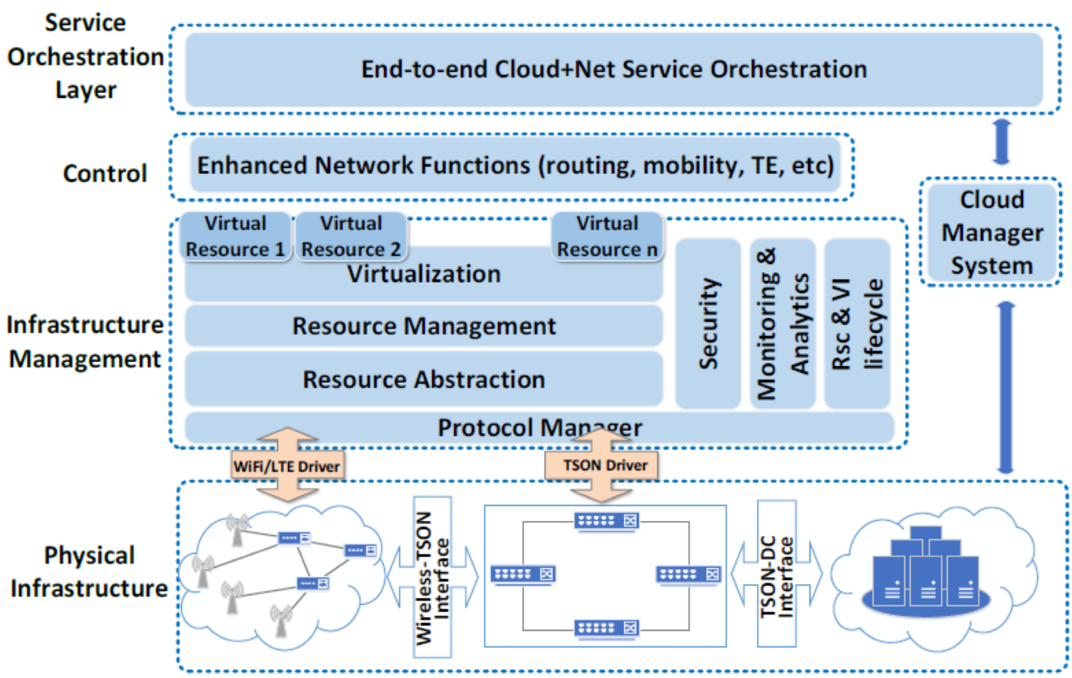

Figure 17. Overall CONTENT layered architecture

Physical Infrastructure Layer: including a hybrid wireless access network (LTE/WiFi) domain, and an optical metro network domain (TSON) interconnecting geographically distributed data centres, supporting frame-based sub-wavelength switching granularity.

Infrastructure Management Layer: is responsible for the management of the network infrastructure and the creation of virtual network infrastructures over the underlying physical resources. An important feature of the functionalities supported, is orchestrated abstraction of resources across domains, involving information exchange and coordination across domains. During the 2nd year of the project, the work on the IML focused on defining the implementation requirements and approach. The IML comprises mainly the infrastructure segment of the SDN architecture and the associated management. One of the most innovative aspects of the IML will be the reservation service, which is the service offered in order to compose and provide heterogeneous virtual infrastructures. A big part of the work during the second year focused on the development of the modules addressing the resource brokering and reservation mechanism.

A security component has been added to the overall system architecture within the infrastructure management layer since it's required from a functional perspective in order to ensure the highest level of security at any layer of the CONTENT stack.

Virtual Infrastructure Control Layer: responsible to provision IT and (mobile) connectivity services in the cloud and network domains respectively. The focus of the project is on the network side, where the control layer establishes seamless connectivity across heterogeneous technology domains (wireless access and optical metro) through a coordinated, end-to-end approach to support optimized performance, QoS guarantees as well as resource efficiency and sustainability.

Service Orchestration Layer: responsible for efficient coordination of the cloud and network resources, in order to enable the end-to-end composition and delivery of integrated cloud, mobile cloud and network services in mobile environments supporting the required QoE.

2.11. Project UNIFY

UNIFY (Unifying Cloud and Carrier Networks) project [18] has the goal of increasing the potential of virtualization and automation across the whole networking and cloud infrastructure. The project is focused on enablers of a unified production environment and will develop an automated, dynamic service creation platform, leveraging a fine-granular service chaining architecture. UNIFY proposes a service abstraction modeland a service creation language to enable dynamic and automatic placement of networking, computing and storage components across the infrastructure. It will develop an orchestrator with optimization algorithms to ensure optimal placement of elementary service components across the infrastructure. Moreover, UNIFY intents to research new management technologies and develop a Service Provider DevOps concept to address the dynamicity and agility of new services. It will investigate the applicability of a universal network node based on commodity hardware to support both network functions and traditional data center workloads. Therefore, the UNIFY consortium researches, develops and evaluates means to orchestrate, verify and observe end-to-end service delivery from home and enterprise networks through aggregation and core networks to data centers.

The project started in October 2013 and is in the course of finalizing the architecture.

2.11.1. Basic Concepts

Through the design of universal hardware architectures UNIFY aims at improving the intelligence and flexibility of the network and so open up opportunities for new converged fixed and mobile end-user service offerings, while also enabling advanced programmability and efficient virtualization, providing means to reduce the cost of new service creation and operation.

The service architecture will be based on a unified view of the infrastructure, covering both the traditional network and the data centre entities. The programmability framework envisaged by UNIFY will create unprecedented opportunity for innovation in the fields of cloud computing and networking. A lower technical barrier for sharing resources and services will unlock new business opportunities, which can be rapidly implemented on a unified production environment.

2.12. Project NetIDE

NetIDE is focused on delivering a single integrated development environment (IDE) to support the whole development lifecycle of network controller programs in a vendor-independent fashion. The project addresses the lack of a common approach to the development and deployment of SDN Controllers. This problem is being exacerbated by the increasing numbers SDN frameworks being proliferated such as Pox, Floodlight, Ryu, Trema, OpenDaylight, etc. Secondly there is a lack of integrated development support for SDN solutions. Finally there is a lack of critical services and tools for the network layer i.e. key services to support integration between development and testing of applications are still missing

The current NETIDE architecture is shown in Figure 18. Pyretic is the development language for the abstracted controller which is integrated with an NetIDE Interpreter via an Abstract API (IRF). The NetIDE Interpreter adds the targeted controller specific components such as REST API's etc. Pyretic is one member of the Frenetic family of SDN programming languages (also under development is Frenetic-OCaml: embedded and implemented in OCaml). Pyretic enables network programmers and operators to write succinct modular network applications by providing abstractions. Pyretic is both a programmer-friendly domain-specific language embedded in Python and the runtime system that implements programs written in the Pyretic language on network switches.

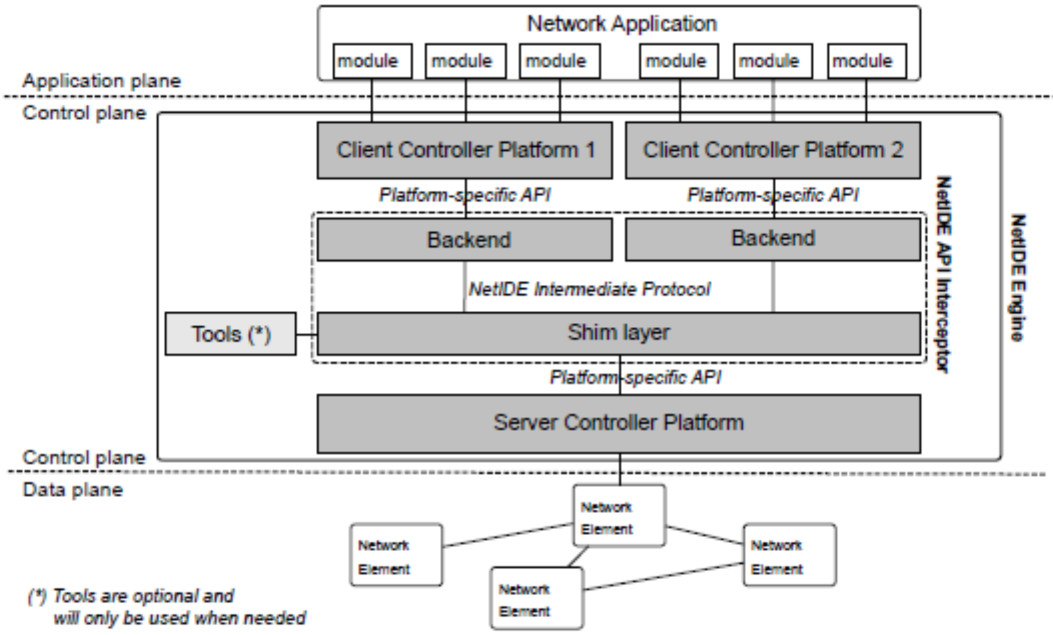

Figure 18. NetIDE Network Engine Architecture

The project has investigated various architectural solutions to remove controller level lock-in. The NetIDE solution to this problem is on a compatibility layer, called Network Engine. The Network Engine is a runtime system that provides a compatibility layer (called the NetDE API Interceptor) which is capable of translating Network Application calls for an SDN Controller platform specific call. The "Network Engine" has been approved as a project OpenDaylight's Berylium release which is due in February 2016. The "Network Engine" is modular by design and comprises of the following key functionality:

- An OpenDaylight plugin ("shim" in architecture diagram) sends/receives messages to/from subscribed SDN Client Controllers. This consumes the ODL Openflow Plugin

- An initial suite of SDN Client Controller "Backends": Floodlight, Ryu, Pyretic. Further controllers may be added over time as the engine is extensible.

The project has completed two releases of the Network Engine to date. The architecture of the initial release was based on the WINE concept (www.winehq.org) where Microsoft Windows applications (such as Microsoft Office) run on top of POSIX operating systems supported by the libraries and the APIs provided by WINE. In a similar way, Ryu (or Floodlight, or others) applications can run on top of the OpenDaylight (or others) framework using to the NetIDE App Engine modules and APIs. The second release introduced a number of new features in many of its components. In particular, both the Ryu backend and shim layer provided support for LLDPmessages, the Floodlight backend added the support for flowMod messages while the OpenDaylight shim layer provided support for LLDP packets and was updated to work with Opendaylight Helium sr3.

Another key focus in NETIDE has been the development of their integrated development environment based on plugins for Eclipse. The purpose of the IDE is to generate a platform-specific network simulator configuration (e.g., a Python-based Mininet configuration) from a topology model as shown in Figure 19. It then starts a virtual machine (VM) and configures it automatically according to the specified platform configuration. NETIDE has released a number of plugins for Eclipse which are available for download from the Eclipse Marketplace (https://marketplace.eclipse.org/content/netide). The plugins support the creation and editing of a network model.

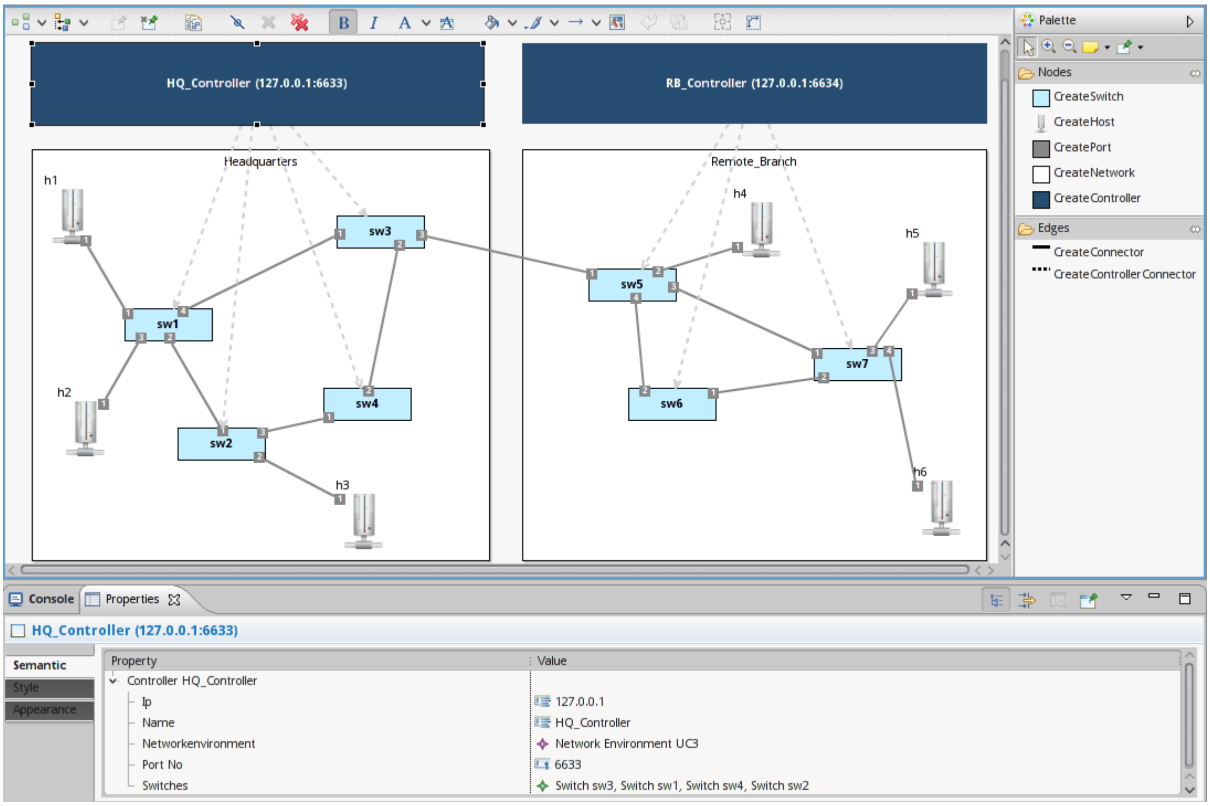

Figure 19. Network topology editor

Additionally the plugins support:

Network Programming Language Editors: Editors to implement Network Applications are already provided. Developers can use the PyDev to code Python-based applications for Pyretic, POX, or Ryu or Eclipse CDT to code C/C++-based applications for NOX.

Deployment Configuration: The deployment configuration for Network Applications and their simulation environment, in which Network Applications are linked to controllers in a topology model, is realised via an Eclipse launch configuration plug-in. This plug-in provides a user interface in which developers can choose a previously specified topology model. Then, they can choose a platform and the path of the Network Application code for each controller in the topology model.

Generator: The Mininet configuration generator plug-in reads the topology model and outputs a Mininet configuration and a Vagrantfile. The Mininet configuration consists of a python class representing the topology in which every switch is represented by the pattern

2.13. Consolidation and Discussion

The previous sub-sections surveyed a number of currently running projects (i.e. MCN, CONTENT, UNIFY and NetIDE), industry frameworks and solutions (i.e. HP OpenNFV, Qosmos/INTEL/TIETO, OpenMANO, OPNFV, vCloud) as well as efforts from Standardisation Bodies (i.e. ETSI NFV ISG, TMForum. It is important to say that T-NOVA partners are participating or at least follow closely those activities.

For T-NOVA the activities in the frame of ETSI NFV ISG are of primary importance. T-NOVA architecture (to be discussed in the following section) intends to align to the one proposed by the ETSI NFV ISG. Moreover, the ETSI architecture is also a general guide for most of the solutions, platforms and projects discussed.

Each project/platform/standard surveyed provided valuable inputs, specifically:

- ETSI NFV ISG
  - NFV reference architecture
  - Component functionalities
  - Interface definition
- TMF
  - Definition of the new virtualized operations environment (TMF ZOOM)
  - ETSI NFV MANO Gap Analysis
  - ETSI NFV MANO Relevant Specifications
- OPNFV, OpenMANO, HP OpenNFV and Qosmos/Tieto/Intel
  - Mapping of reference architecture to available SW/HW components/platforms
  - Service Lifecycle
  - Distributed Cloud architecture to support NFV deployment
  - High value VNFs for telcos
  - Key architectural components and interfaces
- MCN, CONTENT, UNIFY, NetIDE EU Projects

- Exploitation of Cloud for deployment of telco related functionalities
- Heterogeneous networks virtualisation
- End-to-end Cloud and Network Orchestration
- Interconnection of Telco Cloud and Carrier Networks
- Software abstraction and Programmability for SDN Controllers

The above background information has been discussed thoroughly in the respective Tasks of WP2 (2.3, 2.4, 2.5, 2.6) in order to provide guidelines and influence the design of the overall T-NOVA architecture produced within Task 2.2 and presented in the next chapter.

3. T-NOVA OVERALL ARCHITECTURE

3.1. Key Features of the T-NOVA System and Architecture Principles

Deliverable D2.1 (System Use Cases and Requirements) presented and analysed a set of high-level system requirements based on different use cases of the T-NOVA system. If a consolidation of all these high-level system requirements can be attempted, these can be distilled down to the following five key features/functionalities, which need to be implemented by the T-NOVA system:

F1. IT infrastructure virtualisation, supporting resource elasticity

IT assets are necessary for the hosting of VNFs. These assets need to be virtualised in order to be provided as-a-Service, and the associated resources must be scalable in order to optimise usage.

F2. Network infrastructure virtualisation, supporting resource elasticity

Network connectivity is required for both the interconnection of the VNF/VNFCs among the various NFVI PoPs as well as for the customer's access points. Network links need to be virtualised in order to be provided as-a-Service, and the associated resources must be scalable in order to optimise usage.

F3. Automated service provisioning, monitoring, scaling and optimisation

Although an NFV service can be manually deployed, a key feature of T-NOVA is service automation. Following deployment, the service will need to be monitored, scaled and optimised also in an automated manner.

F4. Service advertisement and brokerage

In order to increase the benefits from the automated service provisioning for the customer, a service advertisement as well as a Brokerage framework needs to be in place. The latter is required to facilitate the involvement of multiple actors in the T-NOVA ecosystem.

F5. SLA, billing and accounting support

SLA, billing and accounting support is expected to accelerate market uptake of the T-NOVA system since it enables to actually generate revenue from its deployment and operation.

In addition to the aforementioned key features, in order to maximise the impact of T-NOVA results and accelerate the market uptake of the project achievements to the highest possible extent, we identify the following five high-level architectural principles which need to be respected during the architecture design and implementation phase:

P1. High TRL / Short time-to-market

NFV is generally considered a close-to-market technology, and T-NOVA project outcomes target to TRLs equal to or higher than 6, meaning that at the end of the project the system should be stable and well operational in a lab environment under realistic traffic/load conditions, fulfilling all functional and non-functional requirements.

P2. Openness (architecture, interfaces)

Adopting an open architecture with open interfaces based on industry standards maximises cross-vendor interoperability and maximises project impact.

P3. Modularity and Flexibility

A modular design based on independent components allows multiple alternative configurations (including partial deployment), making the system flexible so as to fulfil diverse actors' needs.

P4. Resilience

In order to meet (or even approach) carrier-grade requirements, the system should quickly recover from faults, outages and malfunctions.

P5. Affordability

The procurement, application and deployment of the T-NOVA solution as a management framework should involve minimal CAPEX investment. For this purpose, it should adapt as much as possible to existing IT and network infrastructures.

3.2. T-NOVA Architecture Overview

Based on the required functionalities as well as architectural principles as mentioned in the previous section, it is possible to derive an overall, high-level view of the architecture of the T-NOVA system.

The first step should be to map the aforementioned key features to functional blocks.

F1. IT infrastructure virtualisation, supporting resource elasticity

State-of-the-art data-centre IT virtualisation technologies, including modern cloud platforms can fulfil most of the functionalities required for T-NOVA. The typical IT virtualisation structure can be followed, based on *compute*, *storage*, DC *network* and *hypervisor* domains. On top of these, a unified management framework conforming to contemporary cloud management paradigms can be foreseen, where the compute/storage/DC network and hypervisor domains are jointly managed achieving the automated provision, management and optimisation of IT IaaS services. In order to align with ETSI terminology, we call this management entity *Virtualised Infrastructure Management (VIM)*. A VIM manages and controls the infrastructure of a data centre in which VNFs are deployed. The latter is called *NFVI Point of Presence (NFVI-PoP)*

F2. Network infrastructure virtualisation, supporting resource elasticity

Intra-data-centre network assets are controlled by the *VIM*, as described in the previous paragraph. Contemporary Software Defined Network (SDN) technologies significantly facilitate software-driven and vendor-agnostic network management and are thus commonly employed in modern data centres, so it is realistic to assume that the intra-DC network is SDN-enabled. For the wide-area network, a separate management entity needs to exist, managing:

- connectivity between NFVI-PoPs and customer network services
- connectivity between DCs/NFVI-PoPs,
- traffic steering to establish the end-to-end network service.

We identify this management entity as *Wide Area Network Infrastructure Connection Management (WICM)*.

F3. Automated service provisioning, monitoring, scaling and optimisation

The establishment of an end-to-end T-NOVA service normally requires the knowledge of the available resources, the planning of the service and the interaction with the VIMs and the WICMs managing the infrastructure assets that will be involved. All these operations need to be carried out by a higher-level management entity, one per Service Provider, which jointly orchestrates the underlying infrastructure. This is the role of the *T-NOVA Orchestrator*, which should incorporate functional modules dealing with *Resources Orchestration, Network Service Orchestration* as well as *VNF Management*. In order to fulfil its role, the Orchestrator should also maintain internal catalogues containing information about available and established Network Services, available VNFs and deployed instances of both, as well as infrastructure resources. At the same time, a Repository for hosting the VNF images and associated metadata should be foreseen (*NF Store)*, from where the VNF images are retrieved for deployment as instances into the infrastructure.

F4. Service advertisement and brokerage

A dedicated, customer-facing module should be foreseen, dedicated to *Brokerage* functionalities. Apart from pricing and trading policies, the Brokerage function should have access to Service and VNF catalogues as well as to the NF Store.

F5. SLA, billing and accounting support

In the same context, dedicated modules should also be foreseen for i) *Accounting* ii) *SLA Management* and iii) *Billing*. These components should collect resource usage data, monitor the status of the established SLAs and bill the customer accordingly. All service-related information can be presented through a unified *Dashboard*, which can also facilitate interactions with service brokerage procedures.

By assembling all the aforementioned components, which were identified as necessary, a high-level view of the T-NOVA system architecture can be derived, as shown in Figure 20.

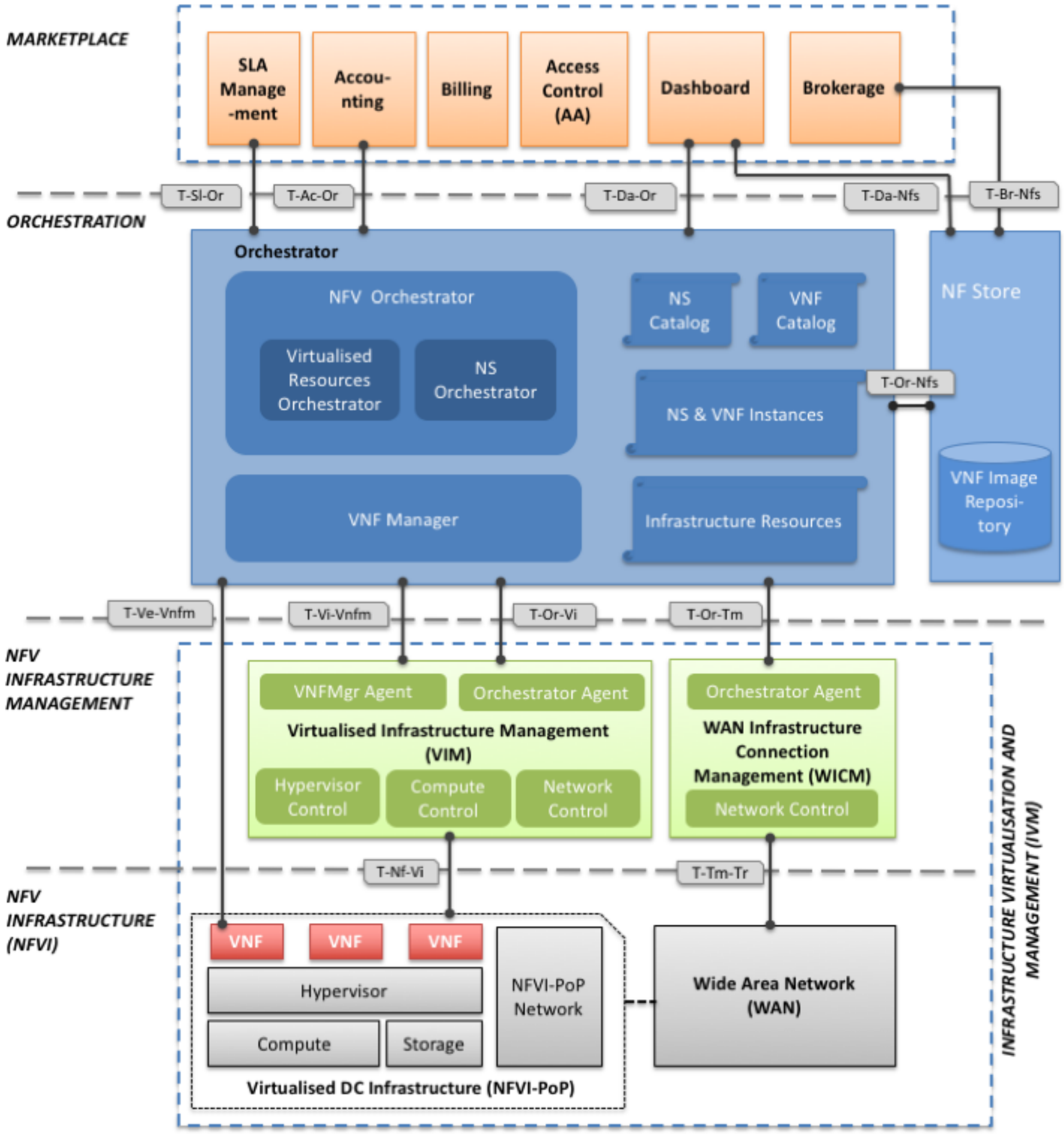

Figure 20. High-level view of overall T-NOVA System Architecture

The T-NOVA architecture can be hierarchically organised into four architectural layers:

- The *NFV Infrastructure (NFVI)* layer includes the physical and virtual nodes (commodity servers, VMs, storage systems, switches, routers etc.) on which the services are deployed.
- The *NFVI Infrastructure (NFVI) Management* layer comprises the infrastructure management entities (VIM, WICM). In the sections as well as the deliverables to follow, the NFVI and management layers are conceptually grouped under the name *Infrastructure Virtualisation and Management (IVM).*
- The *Orchestration* layer is based on the T-NOVA Orchestrator and also includes the NF Store

- Finally, the *Marketplace* layer contains all the customer-facing modules which facilitate multi-actor involvement and implement business-related functionalities.

The sections to follow present a first overview of the aforementioned layers and their components, while a more detailed description is to be found in Deliverables D2.31 and D2.41.

With regard to interfaces, it must be noted that in 7 mostly depicts reference points – which may contain one or more actual interfaces- between architectural layers, each reference point label starts with "T-" to differentiate from interfaces defined in ETSI NFV ISG documents (and in specific Vi-Vnfm, Or-Vi, Ve-Vnfm, Nf-Vi) – although in many cases the functionality of the reference point will be almost aligned to the ETSI definitions.

Following this initial architectural overview, Table 1 suggests how the T-NOVA approach will effectively fulfil the architectural principles identified in the previous section.

Table 1. Fulfilment of architectural principles

Architectural Principle	Proposed Approach
P1. High TRL / Short time-to-market	Rely on established and well-tested platforms as basis for developing some functionalities (e.g. VIM, WICM, account/billing etc.), to achieve rapid prototyping.
P2. Openness (architecture, interfaces)	Release architecture and interface specifications as public domain and rely on widely used communication protocols (e.g. HTTP REST) and data formats (e.g. XML, JSON)
P3. Modularity and Flexibility	Develop each entity as an independent, self-contained software module. Allow multiple architectural variants by defining several options in the information models.
P4. Resilience	Exploit technologies from the cloud domain for VM migration. Exploit SDN management for rapid traffic redirection. Establish a multi-level proactive monitoring framework.
P5. Affordability	Rely on and extend/build open-source software which can be installed on commodity servers. Ensure as wide as possible compatibility with existing infrastructure (e.g. support both SDN and non-SDN network elements) in order to minimise infrastructure upgrade costs.

3.3. High-level Description of T-NOVA Main Architectural Entities

3.3.1. Marketplace

T-NOVA introduces the concept of Marketplace in the Network Function Virtualization framework, with the aim of promoting the VNF service offerings and facilitating the commercial activity and fluent interaction among the different business stakeholders interacting with the T-NOVA system, which were previously identified when exploring NFV use cases in Deliverable D2.1.

The T-NOVA marketplace is a distributed platform placed on top of the orchestration level, which besides providing the Graphical User Interface, it supports the following general functions for T-NOVA stakeholders:

- The Customers will be able to browse and select VNFs service offerings that best match their needs, as well as negotiate SLAs and exchange their billing information with the Service Provider, keeping track of all the services purchased.
- The Service Provider will be able to acquire VNFs, interacting with different Network Function suppliers by means of a brokerage/trading module in order to compose network services as bundles of VNFs not only for its own needs but also to offer the composed Network Services to its customers. Therefore, also SLA and billing information between SP and FPs will be managed.
- Several Network Function developers (Function Providers) will be able to publish their VNF to trade them by means of T-NOVA marketplace.

Based on the T-NOVA requirements gathered in Deliverable D2.1 we identify that the modules in 8 should be present at marketplace level:,

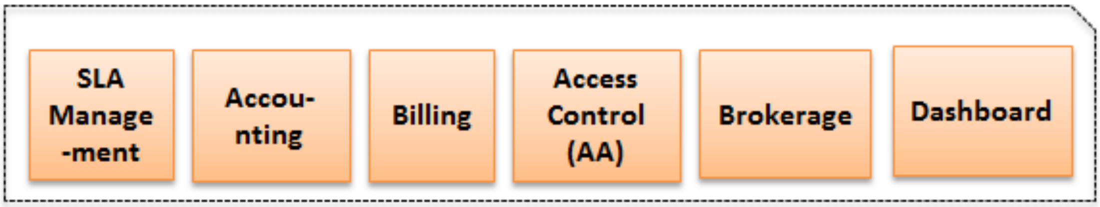

Figure 21. Marketplace components

- **Access control**: this component provides authentication and authorization functionalities to manage the access to T-NOVA by the different stakeholders. In other words, it regulates who is allowed to access the T-NOVA system and what is it allowed to do.
- **Accounting module**: this module is in charge of registering all business relationships (subscriptions and SLA evaluations) and making the related information available for the billing system.
- **Dashboard**: it is the graphical front-end displaying monitoring/utilization/status information about the provisioned T-NOVA services. It will have different views for each of the stakeholders accessing the T-NOVA marketplace.
- **Brokerage module**: it is the component that receives requests for VNFs, and will present the most suitable offerings; depending on the applicable trading-policies the necessary actions to get the best price for each VNF will be carried out.

- **SLA management module**: it is the component that will register all the SLA agreements among the involved parties, checks if the SLAs have been fulfilled or not, and informs the accounting system for the pertinent billable items.
- **Billing system**: It is the component that produces the bill for a customer on behalf of the Service Provider (SP). A bill will be produced for the SP on behalf of its own suppliers (FPs).

Further information about the functionalities and internal architecture of each marketplace module, as well asthe internal marketplace interfaces among these modules and other minor intermediate modules (e.g. a business service catalogue and service selection component) are defined under T2.6 and will be explained in Deliverable D2.42.

As shown in Figure 22, the marketplace is connected on one hand to the orchestrator by means of 3 main external interfaces, and the dashboard and brokerage module are connected to the Function.

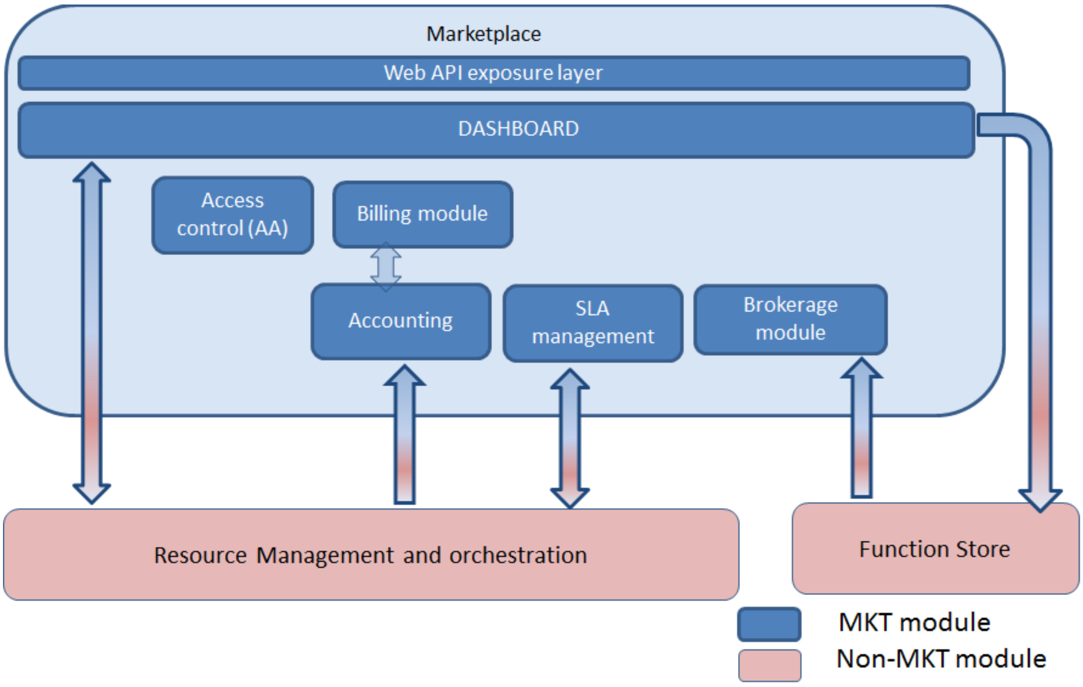

Figure 22. Marketplace external interfaces

3.3.2. Orchestrator

The T-NOVA Orchestrator is the core component of the T-NOVA architecture framework and it aims to address Network Services (NSs) and Virtual Network Functions (VNFs) lifecycle management operations over distributed and virtualized network/IT infrastructures.

3.3.2.1. Reference Architecture

The Orchestrator reference architecture, as well as the interfaces with the external Functional Entities (FEs) is depicted in Figure 23. In detail, the orchestrator interacts with the Marketplace, which is the FE responsible for establishing the business and operational management of T-NOVA. Besides the Marketplace, the Orchestrator also interfaces with the Virtualized Infrastructure Management (VIM), for managing the data center network/IT infrastructure resources, as well as with the WAN Infrastructure Connection Management (WICM) for the WAN elements connectivity management. Finally, the Orchestrator interacts with the VNF itself, which is located in the T-NOVA Infrastructure Virtualized Management (IVM) layer, to ensure its lifecycle management.

Internally, the T-NOVA Orchestrator is composed by two main elements and a set of repositories. One of the core elements is the NFV Orchestrator (NFVO), acting as the front-end with the Marketplace and orchestrating all the incoming requests towards the other elements of the architecture. Further details about the NFVO and the associated incoming requests are given in section 3.3.2.2.1. To support the NFVO operation procedures, a set of repositories are defined to describe the available VNFs and NSs, the instantiated VNFs and NSs, as well as the available resources in the virtualized infrastructure. Further details about the orchestrator repositories are provided in section 3.4.2.3.3. Finally, the NFVO also interacts with the VNF Manager, responsible for the VNF-specific lifecycle management procedures, as described in section 3.4.2.3.2.

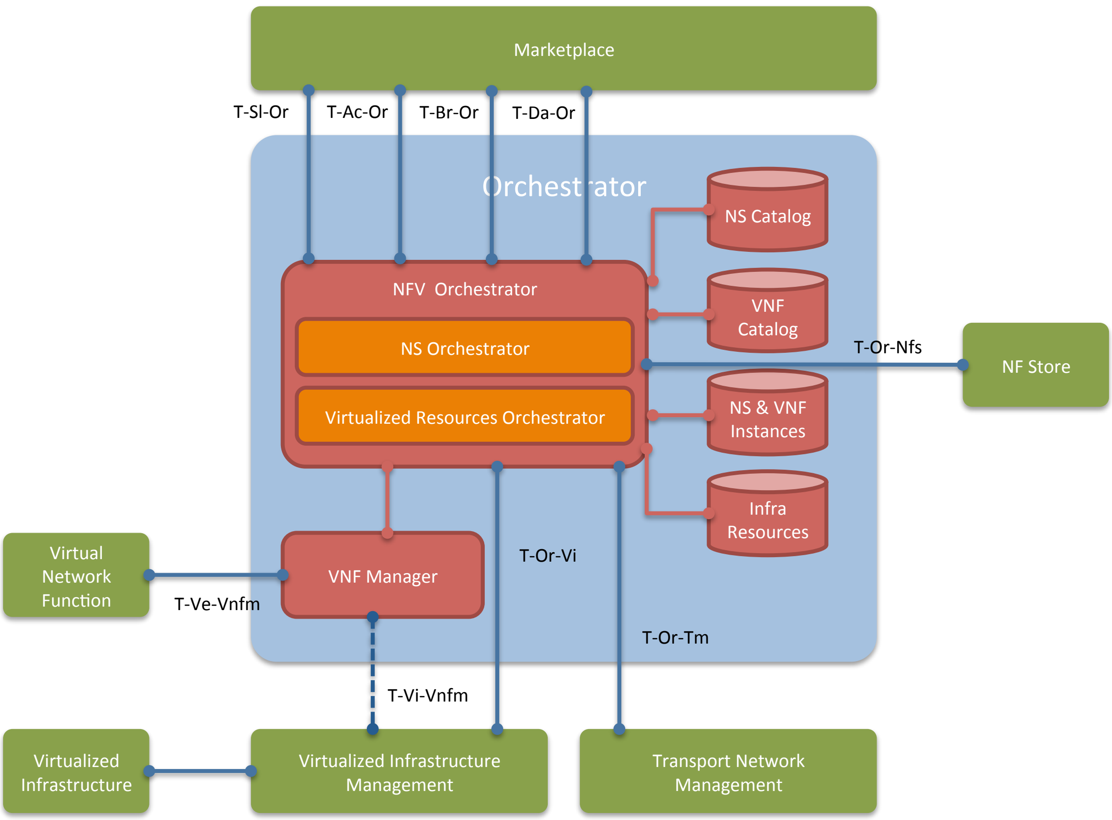

Figure 23. T-NOVA Orchestrator Reference Architecture and Interactions

3.3.2.2. Functional Entities High-level Description

3.3.2.2.1 NFV Orchestrator

The main function of the NFV Orchestrator (NFVO) is to manage the virtualized Network Services (NSs) lifecycle procedures. Since the NSs are composed by Virtual Network Functions (VNFs) and Physical Network Functions (PNFs), the NFVO is able to decompose each NS into the constituent VNFs and PNFs. Nevertheless, although the NFVO has the knowledge of the VNFs that compose the NS, it delegates their lifecycle management to a dedicated FE designated by VNF Manager (VNFM).

Furthermore, besides orchestrating the virtualized service level operations, therefore abstracting the service specificities from the business/operational level – in this case the T-NOVA Marketplace – the NFVO also manages the virtualized infrastructure resource level operations. Hence, it coordinates the resource allocation to specific NSs and VNFs according to the availability of the virtualized infrastructures, also known as data centers.

To address the two main functionalities above mentioned, the NFVO is architecturally split in two modules, namely the Network Services Orchestrator (NSO) and the Virtualized Resources Orchestrator (VRO), further described below.

Network Services Orchestrator

The Network Service Orchestrator (NSO) is one of the components of the NFVO with the responsibility to manage the NS lifecycle management procedures (e.g. on-boarding, instantiation, supervision, assurance, scaling and usage accounting). Towards this objective, it interacts with the T-NOVA Marketplace (northbound interface) external entity as well as with the following T-NOVA Orchestrator internal components:

- **Repositories**: collect information (e.g. deployment descriptors, dependencies, software images, SLAs, etc.) about the NSs/VNFs and storage of NSs/VNFs instances;
- **Virtualized Resources Orchestrator (VRO)**: request management actions related with the virtualized resources, either within the data center scope (e.g. compute, storage and network) and/or on the transport network segment;
- **Virtual Network Function Manager (VNFM)**: request of lifecycle management actions related with the VNFs.

Virtualized Resources Orchestrator

The Virtualized Resources Orchestrator (VRO) is the resource layer management entity of the NFVO main block. Its main responsibility is to orchestrate/manage the virtualized infrastructure resources distributed across multiple data centers, in particular, map the incoming NS requests to the virtualized infrastructure resources, as well as coordinating the resources allocation and placement for each Virtual Machine (VM) that composes the VNF (and the NS). Moreover, the VRO is also the entity interacting with the WAN elements for connectivity management purposes.

The following virtualized resources are managed by the VRO:

- **Compute**: virtual processing CPUs and virtual memory;
- **Storage**: virtual storage;
- **Network**: virtual links intra/interconnecting VNFs within the Data Center Network (DCN).

The VRO interacts with the following blocks:

- **Network Services Orchestrator (NSO)**: receive resources reservation/allocation requests for a specific NS, for all the constituent VNFs;
- **Repositories**: collect information about the VNF software components and resources, as well about the infrastructure resources availability;
- **Virtualized Infrastructure Manager (VIM)**: enforce resource reservation/allocations and collect monitoring information about the virtual links interconnecting the VNFs;
- **WAN Infrastructure Connection Manager (WICM)**: enforce resource decisions allocations and collect monitoring information about Wide Area Network elements;
- **Virtual Network Function Manager (VNFM)**: receive resources reservation/allocation requests.

3.3.2.2.2 Virtual Network Functions Manager (VNFM)

The VNF Manager (VNMF) is responsible for the lifecycle management of the VNF. This includes the following:

- Instantiate: create a VNF on the virtualized infrastructure using the VNF on-boarding descriptor;
- Configure: configure the instantiated VNF with the required information to start the VNF (can already include some customer-specific attributes/parameters);
- Scale: increase or decrease the VNF capacity by adding/removing VMs (out/in horizontal scaling)
- Update: modify configuration parameters;
- Upgrade: change software supporting the VNF;
- Terminate: release infrastructure resources allocated for the VNFs.

The VNFM interacts with the following components:

- **Network Services Orchestrator (NSO)**: receive VNF instantiation requests for a specific NS and provide VNF monitoring information;
- **Repositories:** collect information about the VNF internal components and resources;
- **Virtualized Resources Orchestrator (VRO)**: request reservation/allocation/release of virtualized infrastructure resources for the VNF;
- **Virtual Network Function (VNF)**: configure VNF specific information and receive VNF related monitoring information;
- **Virtual Infrastructure Management (VIM)**: collect monitoring information about the virtualized infrastructure resources allocated to the VNF.

3.3.2.2.3 Repositories and Catalogues

To support the T-NOVA Orchestrator lifecycle management operations, the following catalogues are defined:

- **NS Catalogue:** represents the repository of all the on-boarded NSs in order to support the NS lifecycle management:
    - NS Descriptor (NSD): contains the service description, including SLAs, deployment flavours, references to the virtual links (VLDs) and the constituent VNFs (VNFFG);
    - Virtual Link Descriptor (VLD): contains the description of the virtual network links that compose the service (interconnecting the VNFs);
    - VNF Forwarding Graph Descriptor (VNFFG): contains the NS constituent VNFs, as well as their deployment in terms of network connectivity;
- **VNF Catalogue:** represents the repository of all the on-boarded VNFs in order to support its lifecycle management;
    - VNF Descriptor (VNFD): contains the VNF description, including its internal decomposition in Virtual Network Function Components (VNFCs), deployment flavours and references to the virtual links (VLDs);
    - Software images of the VMs located in the IVM layer;
- **NS & VNF Instances:** represents the repository of all the instantiated NSs and VNFs, which can be updated/released during the lifecycle management operations;
- **Infrastructure Resources:** represents the repository of the available/reserved/allocated NFVI resources as abstracted by the VIM across operator's infrastructure domains. Furthermore, it also includes the resources available/reserved/allocated in the WAN segment.

3.3.3. Infrastructure Virtualisation and Management

The concept of virtualisation has been a cornerstone in the rapid evolution and adoption of cloud computing. This model of abstracting the physical compute resources into virtual resources has been broadly adopted in the IT domain and is now also being embraced in the networking domain, by introducing Virtual Network Functions (VNFs). Application workloads run on top of hardware thanks to a hypervisor layer that decouples software and hardware through partitioning hardware and share it among different applications. For network applications such as the deployment of VNFs careful consideration must be given to all elements of the infrastructure environment to ensure the required performance particularly for intensive packets processing workloads or applications that support large numbers of simultaneous connections. In this context the availability of certain features within the CPU, driver performance, efficient virtualisation of resources, physical distribution of virtual nodes etc. can have a significant influence on performance.

For this reason, the T-NOVA Infrastructure Virtualisation Management (IVM) domain (consisting of the NFVI and NFVI Management layers) will comprise a mixture of physical and virtual nodes and will be used to develop, implement and showcase T-NOVA services. The IVM will be fully integrated with the T-NOVA Orchestrator to ensure that requirements for the deployment and lifecycle management of T-NOVA VNFs can be carried out in an appropriate and effective manner. The IVM will be flexible enough to support a variety of use cases beyond those explicitly identified in T-NOVA (see Deliverable D2.1). As mentioned previously, infrastructure virtualization plays a key role in achieving this vision in T-NOVA. Virtualisation and management of the virtualised resources extends beyond the compute and storage to include network infrastructure in order to fully exploit the capabilities of the T-NOVA architecture.

3.3.3.1. IVM Architecture

Using both the NFVI and MANO architectures as references the proposed architecture for the T-NOVA IVM is presented in Figure 24.

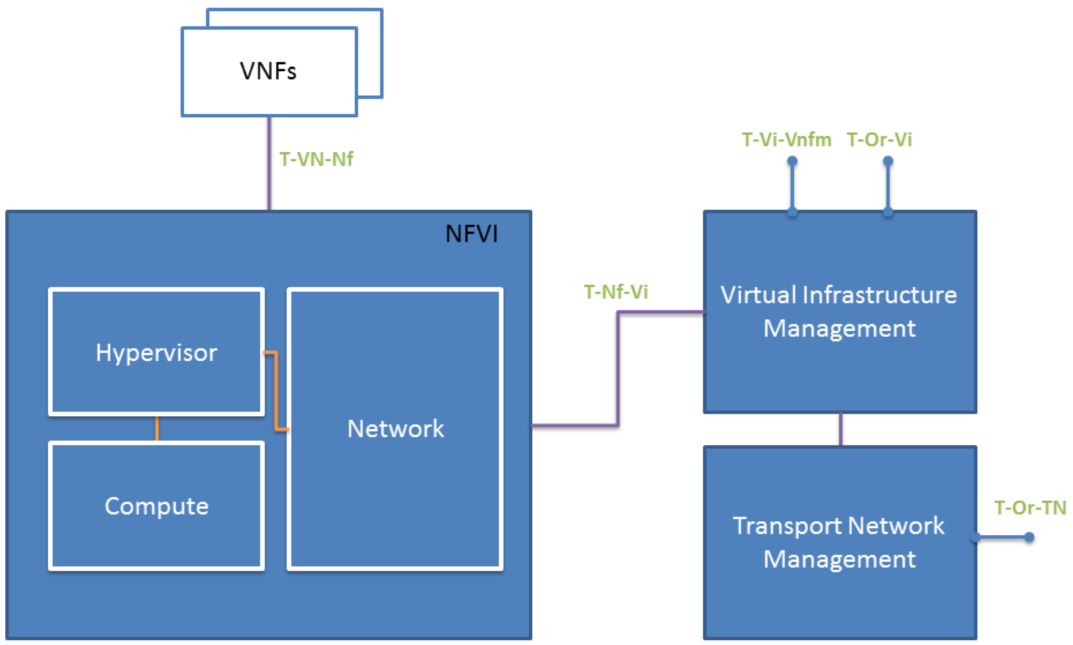

Figure 24. High-level architecture of T-NOVA IVM.

For the T-NOVA architecture the decision was taken to separate the *VIM* function from the Orchestration layer, whereas ETSI considers management and orchestration (MANO) as a single domain. The reason is twofold: first, there already exist several quite mature technological frameworks which can implement most of the VIM functionalities – which is not the case for the Orchestrator. Second, it is a matter of cardinality; the T-NOVA architecture considers a single Orchestrator but multiple VIM instances, one per NFVI-PoP.

The VIM acts in unison with the NFVI under the control of the Orchestrator through two specific interfaces:

- Virtual Network Function Management – VIM Interface (T-Vnfm-Vi)
- Orchestrator –VIM Interface (T-Or-Vi)

These interfaces enable the Orchestrator and its VNF Manager to manage the VIM and subsequently the resources under the control of the VIM.

The T-NOVA architecture, following the ETSI WG INF (focused on the specification of the NFVI), identifies three domains in order to disaggregate the complexity of the required capabilities into logical functional domains. The domains are as follows:

- *Compute domain*, which operates at the lowest level, also in the computing and storage slices. It comprises the generic high volume servers and storage. The underlying physical elements are abstracted by the hypervisor allowing aggregation of these resources across many discrete servers and assignment of them to VNF's.
- *Hypervisor domain*, which operates at a virtual level, encompassing the computing and storage slices. It provides abstraction of the hardware to the VNF. This supports capabilities such as portability and scalability of the VNF. The hypervisor also is responsible for the allocation of the compute domain resources to the VMs and also provides a management interface to the orchestration and management system which supports the loading and monitoring of VMs and VNF. The hypervisor is also responsible for network connectivity between VM's hosted on the same physical server as well as those hosted on different physical servers.
- *Network domain*, which operates both at virtual level and the hardware level, of the Data Centre's (NFVI-PoP) network slice. It comprises all the generic high volume switches interconnected into a network which can be configured to supply infrastructure network services.

In addition to the VIM, the analysis of the system requirements of T-NOVA, including the needs of interconnecting distributed NFVI-PoPs and establishing end-to-end services, highlights the necessity for a *WAN Infrastructure Connection Management* (WICM) capability for the set-up, teardown and management of network traffic between points of presence (PoP) e.g. inter-data centre connectivity supporting VLAN tunnelling over WAN. Released specifications to date by ETSI have not identified this as a primary concern. However, they do include an interface (i.e. Ex-Nf) which acts as an interface between the NFVI domain and external networks. The T-NOVA WICM domain implements and interface to the Orchestrator in order to obtain appropriate management.

A detailed description of the function, purpose and requirements for each domain will be presented in Deliverable D2.31.

3.4. High-Level Description of Interfaces

This section presents an overview of the main reference points of the T-NOVA architecture, their purpose and the information which is exchanged. The relevant reference points of the ETSI NFV architecture are also identified, although the correlation/overlap between T-NOVA and ETSI may vary.

3.4.1. Marketplace – Orchestrator Interfaces

As aforementioned, there are four interfaces between the Marketplace and the Orchestrator. A first approach to the information to be exchanged by means of these interfaces is provided below. Further details and requirements for these interfaces are carried out in tasks T2.3, T2.5 and T2.6, and will be included in deliverables D2.31 and D2.41.

These interfaces are summarized in Table 2 and they all have some partial overlap with the ETSI Os-Ma interface, which connects the MANO and OSS/BSS domains.

Table 2. Interfaces between the T-NOVA Orchestrator and the Marketplace

Interfacing entities	T-NOVA Reference Point name	ETSI NFV Relevant Reference Point	Description and Comments
Dashboard-Orchestrator	T-Da-Or	Os-Ma	This Dashboard sends the Orchestrator all the service composition information triggered by the SP as well as the service instantiation order by the customer. The Orchestrator sends the Dashboard all the service monitoring information.
SLA management module-Orchestrator	T-Sl-Or	Os-Ma	The SLA management module sends the Orchestrator the SLA agreement. The Orchestrator communicates SLA-related metrics to the management module so that the latter can check SLA compliance
Accounting module-Orchestrator	T-Ac-Or	Os-Ma	The Orchestrator sends the Accounting module all the service track information.

3.4.1.1. Dashboard-Orchestrator (T-Da-Or)

This interface will convey the information that a given SLA is ready to be applied, together with its parameters (from the SLA management module to the Orchestrator), or has been breached (from the Orchestrator to the SLA management module). We emphasize that, since the Orchestrator has to follow the SLA related metrics, in order to try to escalate the service and keep the SLA, the SLA management module will only be notified in the case of a SLA breach.

3.4.1.2. SLA management module-Orchestrator (T-Sl-Or)

This interface will convey the information that a given SLA is ready to be applied or has been breached (from the Orchestrator to the SLA management module), as well as that SLA agreement (its parameters -- from the SLA management module to the Orchestrator). We emphasize that, since the Orchestrator has to follow the SLA related metrics, in order to try to escalate the service and keep the SLA within agreed levels of service, the SLA management module will only be notified in the case of a SLA breech.

3.4.1.3. Accounting module-Orchestrator (T-Ac-Or)

This interface will convey all the resource usage information (from the Orchestrator to the Accounting module), so that the Customer can later be billed accordingly. No information is expected to flow from the Accounting module to the Orchestrator.

3.4.2. Marketplace – Function Store Interface

3.4.2.1. Dashboard-Function Store (T-Da-Nfs)

This interface will convey the information provided in the Dashboard in order to publish a new VNF in the NF Store as well as the modification and withdrawal of the VNFs.

3.4.2.2. Brokerage-Function Store (T-Da-Nfs)

This interface is used by the brokerage module to retrieve the information about the VNFs available for composing a new Network Service.

3.4.3. Orchestrator – Network Function Store Interfaces

The interface between the Orchestrator and FS (T-Or-NFs), supports a set of key functions within T-NOVA. The interface has no mapping to the ETSI MANO architecture, as the FS is a T-NOVA specific entity not considered in ETSI MANO. This interface allows the orchestrator to be notified about VNFs that have been recently added, removed, or modified in the FS. Furthermore, it also allows the orchestrator to retrieve VNF related information, such as virtual machine images, VNF metadata, including name, id, pricing information, requirements and VNF capabilities.

The Orchestrator interacts with the Network Function Store for gathering information about the VNF and gets the images and metadata description of the VNF that are made available to the system.

The interface is further described by T2.3 for the Orchestrator side and by T2.5 for the NF Store side, in deliverables D2.31 and D2.41, respectively.

Hereunder a summary of the primitives is presented.

Interface T-Or-Nfs:

Orchestrator side:

- Notification of modification in the NF Store
- Delivery of VNF image and VNF metadata
- Removal/Deletion of the VNF from the NF Store

Function Store side:

- Request for delivering the new or updated VNF image and VNF metadata.

Table 3. Interfaces between the T-NOVA Orchestrator and the FS

Interfacing entities	T-NOVA Reference Point name	ETSI NFV Relevant Reference Point	Description and Comments
NFV Orchestrator –Function Store Interface	T-Or-Nfs	None	This interface allows the NFV Orchestrator to receive VNF advertisements (new VNF added to FS, VNF removed from FS, VNF modified) and to also receive VNF related information (e.g. virtual machine images, VNF metadata, including name, id, pricing information, requirements and VNF capabilities)

3.4.4. Orchestrator – VNF Interfaces

The interface between the Orchestrator and VNF supports a set of key functions within T-NOVA. The Ve-Vnfm interface directly maps to the interface identified in the ETSI NFV architecture, as outlined in Table 4. On the one hand, this interface allows the VNFM to configure the VNF and possibly perform a set of control operations (e.g. start, stop) as well as other VNF lifecycle related operations. On the other hand it allows the VNFM to deliver detailed information on the status (e.g. running state, error state) and performance of the VNF (function/VM level information) so that it can act accordingly to the SLA in place.

The Orchestrator directly interacts with the VNFs during their running phase. This interaction happens in the "Management" and "Termination" status of the VNF lifecycle.

The services provided with this interface are summarized hereunder:

Management status

- set-up: initialization of the VNF, e.g. configuration of the VNF network interfaces
- start and stop: request to the VNF to start or stop providing the service.
- Monitoring: the VNF can provide to the orchestrator monitoring information useful to the orchestrator for deciding about scaling the VNF or the service.

Termination status

- Terminate: request to release the resources allocated to the VNF and shut-down of the VNF itself

Table 4. Interfaces between the T-NOVA Orchestrator and VNFs

Interfacing entities	T-NOVA Reference Point name	ETSI NFV Relevant Reference Point	Description and Comments
Virtual Network Function Manager– Virtual Network Function Interface	T-Ve-Vnfm	Ve-Vnfm	This interface allows the VNF Manager to configure the VNF, collect monitoring/performance data, and be notified about faults within the VNF.

3.4.5. Orchestration Layer – VIM Interface

The interfaces between the Orchestration Layer and VIM support a number of key functions within the T-NOVA. As shown in the IVM high level architecture section 3.3.3, two specific interfaces have been identified and map to the interfaces identified in the ETSI NFV Architectural Framework as outlined in Table 5. The first one is the Virtual Network Function Management – VIM Interface (T-Vi-Vnfm) and is responsible for the exchange of infrastructure monitoring information allocated to the VNF either through explicit request by the VNF Manager or through periodic reporting initiated by the VIM. The types of data exchanged over this interface include detail information on the status, performance and utilisation of infrastructural resources such CPU, storage, memory etc. Data will also encompass networking information relating to a specific a VNF such as NIC level network traffic from the hosting VM or inter VM network traffic if a VNF is deployed across more than one VM. Finally VNF performance data will also be exchanged over this interface (In the case of performance data its builds on monitoring data with the addition of context such as the expected operational target for a service, or involves utilising data from various levels within VNF software to understand what is happening with a particular service e.g. performance may relate to end-to-end actions of a VNF service such as (secure) VM-to-VM communications, QoS etc. VNF performance may also be related to effectiveness of configuration changes or optimisations relative to the baseline performance of a VNF service. Collectively the data will be used by the VNF Manager within the T-NOVA Orchestrator to track VNF service performance and to ensure SLA compliance.

The second interface identified is the Orchestration – VIM interface (T-Or-Vi). This interface is responsible for handling requests from the NFV Orchestrator with respect to the full life cycle of a NS service. Typical examples of requests sent over this interface would include instantiation (preceded by on-boarding), scaling, termination etc. This interface will also be used by the NFV Orchestrator to reserve/allocate resources as well as to pass resource configuration to VIM such as definitions of VMs and network requirements such as the specification of the interconnections between VNF instances (i.e. network topology), e.g. HEAT templates in an OpenStack Cloud environment. Specific types of monitoring information will also be exchanged over this interface such as data related to the network connections between VNF instances either within a data centre or intra data centre connections which are physically dispersed. This interface is also used by the VIM to report back to the Orchestrator the outcome of all requests received.

Table 5. Northbound Interfaces of the T-NOVA IVM

Interfacing entities	T-NOVA Reference Point name	ETSI NFV Relevant Reference Point	Description and Comments
Virtual Network Function Management – VIM Interface	T-Vi-Vnfm	Vi-Vnfm	This interface allows the VNF Manager to request operations related to the NS lifecycle; and/or for the VIM to report the characteristics, availability, and status of VNF related infrastructure resources.
Orchestrator – VIM Interface	T-Or-Vi	Or-Vi	This interface allows the Orchestrator to request reservation/allocation of resources and NS related lifecycles operations; and for the VIM to report the characteristics, availability, and status of infrastructure resources.

3.4.6. Orchestrator – WAN Infrastructure Connection Management Interfaces

The WAN Infrastructure Connection Manager (WICM) provides management capabilities of the network segments that are external to NFVI-PoP, and can be generally designated as Wide Area Network (WAN). The T-NOVA Orchestrator – Wide Area Network Interface (T-Or-Tm) supports requests from the Orchestrator to provide connectivity services typically for inter data centre (over MAN and/or WAN) or connection to customer connectivity services (which may range from simple Internet access to enterprise network service models such as L2/L3 VPN). Furthermore, the interface supports retrieving monitoring information with respect to the provisioned connectivity services. This interface is also used by the WICM to report back to the Orchestrator the outcome of all requests received.

Table 6. Interfaces between the T-NOVA WICM and the Orchestrator

Interfacing entities	T-NOVA Reference Point name	ETSI NFV Relevant Reference Point	Description and Comments
Orchestrator – Wide Area Network Interface	T-Or-Tm	Or-Vi	This interface between WICM and the Orchestrator is used to manage the set-up, tear down and monitoring of network segments that are external to the NFVI-PoPs.

3.4.7. VIM – NFVI Interfaces

The interface between the VIM and the NFVI is used to a) communicate management decision to the NFVI layer and b) to provide to the VIM awareness about the status of the NFVI, including resource usage and availability. The T-Nf-Vi reference point can be broken down into three separate interfaces, allowing the control of the Compute, Hypervisor and NFVI-PoP network, as shown in Table 7.

Table 7. Interfaces between the T-NOVA VIM and NFVI

Interfacing entities	T-NOVA Reference Point name	ETSI NFV Relevant Reference Point	Description and Comments
VIM – Hypervisor Interface	T-Nf-Vi/H	[Nf-Vi]/H	This interface dispatches management decisions from the VIM to the Hypervisor and communicates back the Hypervisor status and monitoring metrics.
VIM – Compute Interface	T-Nf-Vi/C	[Nf-Vi]/C	This interface dispatches management decisions from the VIM to the Compute domain and communicates back the Compute domain status and monitoring metrics.
VIM – Network Interface	T-Nf-Vi/N	[Nf-Vi]/N	This interface dispatches management decisions from the VIM to the NFVI-PoP Network domain and communicates back Network status and monitoring metrics.

3.5. ETSI NFV ISG Compliance and Mapping

ETSI NFV ISG is undoubtedly the most relevant standardization initiative to the T-NOVA scope. The ISG has produced a number of high-level specification documents, which have been considered as input during the Requirement and Specification activity (Task 2.1). From those documents, the most relevant to the architecture definition process is the NFV Architectural Framework – ETSI GS NFV 002 V1.1.1 (2013-10) [19]. Besides this document, the ISG has recently released a series of draft documents that provide a more detailed view regarding the Architecture components and their interactions.

These documents are in draft status but they still serve their purpose as work-in-progress documents giving a view on how the discussion on the NFV architecture evolves. These documents are:

- GS NFV INF 001 V0.3.6 (2014-01) - NFV Infrastructure Overview [6]
- GS NFV INF 001 V0.3.6 (2014-01) - NFV Infrastructure Architecture; Architecture of Compute Domain [20]
- GS NFV INF 004 V0.3.1 (2014-05) - NFV Infrastructure Architecture; Architecture of the Hypervisor Domain [21]
- GS NFV INF 005 V0.3.1 (2014-05) - NFV Infrastructure Architecture; Architecture of the Network Domain [22]
- GS NFV INF 007 V0.3.1 (2014-05) - NFV Infrastructure Architecture; Interfaces and Abstractions [23]
- GS NFV SWA 001 v0.2.0 (2014-05) – Virtual Network Functions Architecture, [24]
- GS NFV MAN 001 v0.6.1 (2014-07) - NFV Management and Orchestration, [11]

The initial analyses of those documents along with valuable inputs from the partners that currently participate in the standardisation body's activities have heavily influenced the design of T-NOVA overall architecture. T-NOVA will follow closely the ISG activities, with the ultimate aim to provide contributions based on the findings and developments during its lifecycle. It is very important to state that T-NOVA architecture although aligned with the reference architecture of NFV ISG, is designed with the requirement that it needs to be implemented in the course of the project - and in this sense its scope needs to be focused on specific use cases.

The subsection below provides a view on how the T-NOVA workplan maps to the ETSI NFV reference architecture.

3.5.1. ETSI ISG NFV impact in T-NOVA

The T-NOVA architectural vision is in general alignment with the current set of both finalised and draft ETSI documents and with the current technical approach of the three main WGs, INF, SWA and MANO. In specific:

- For WP2 which is related to Use Cases, Requirements and Architecture definition and specification:
    - Task 2.3 orchestrator key requirements and architecture clearly point to the NFVO Functional Entities currently being worked in ETSI NFV MANO WG,
    - Task 2.4 infrastructure key requirements and architecture clearly point to the NFVI and Functional Entities currently being worked in ETSI NFV INF WG,
    - Task 2.5 virtual network functions key requirements and architecture clearly point to the VNF Functional Entities currently being worked in ETSI NFV SWA WGs.

Similarly:

- WP3 Implementation of the T-NOVA Orchestrator and associated interfaces, strongly correlates with MANO WG

- WP4 implements the Infrastructure Virtualisation and Management layer comprising the NFVI and the VIM. T-NOVA assigns the Infrastructure Management (i.e. VIM/WICM) to a separate WP, due to the multiplicity of the cardinality that this architectural component withholds in the proposed infrastructure. The work here corresponds to both ETSI NFV MANO WG (partially) and to ETSI NFV INF WG.
- WP5 Implementation of the VNF framework as well as the Function Store and the actual VNFs, is aligned with ETSI NFV SWA WG.

Task 2.6 and WP6, which introduce the Marketplace concept which along with Function Store in T2.5/WP5 are the novelties proposed by T-NOVA aiming at opening the NFV market to third party developers for the provision of VNFs. Currently this concept falls outside the technical view of ETSI NFV.

The next figure illustrates the above mentioned mapping between ETSI ISG NFV Functional Entities and the Work Packages / Tasks of the T-NOVA workplan.

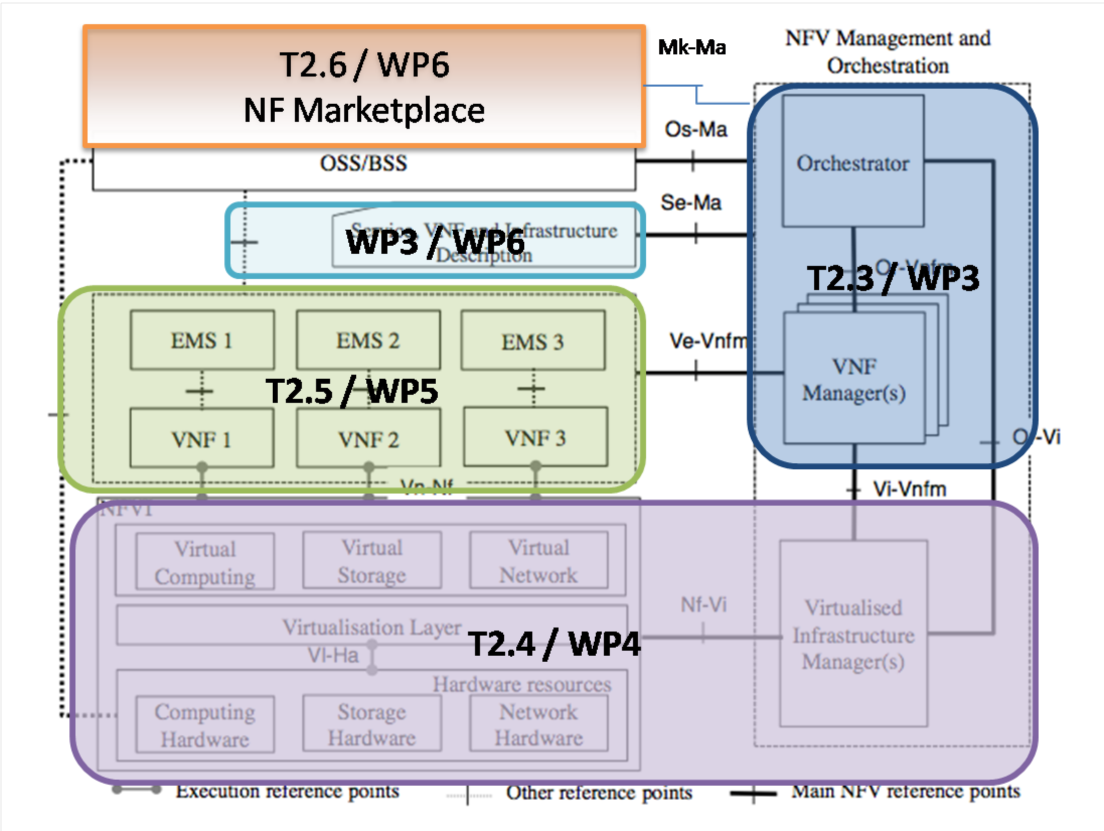

Figure 25. T-NOVA scope mapping into ETSI NFV reference architecture

The following table (

Table 8) summarises on the mapping of T-NOVA to ETSI view related to the most prominent architecture components.

Table 8. Mapping of T-NOVA to ETSI architectural component

Architectural Component	ETSI View	T-NOVA View
Virtualised Network Function (VNF)	A VNF is a virtualization of a network function in a legacy non-virtualized network.[8]	T-NOVA and ETSI views are completely aligned. In T-NOVA the VNF are considered as single or multiple VMs deployed in Compute Nodes.
NFV Infrastructure	The NFV Infrastructure is the totality of all hardware and software components, which build up the environment in which VNFs are deployed, managed and executed. It can span across several locations, The network providing connectivity between these locations is regarded to be part of the NFV Infrastructure.[9]	T-NOVA also aligns its definition to that of ETSI. The proposed overall architecture, as well as the detailed w.r.t the NFVI (subject of Task2.4/WP4) supports the existence of multiple NFVI-PoPs at several locations as part of the NFVI, interconnected by transport network links.
Hardware Resources	Includes the physical IT (i.e. computing and storage) and network resources available at the NFVI. IT resources are considered to be provided by COTS equipment. Network resources include network elements such as switches and routers along with interconnecting links. Two types of networks are considered for the NFVI: NFVI-PoP Network: providing the networking required to interconnect the IT resources along with external network connectivity Transport Network: providing interconnection between NFVI-PoPs	T-NOVA is also aligned w.r.t the hardware resources supported. Besides IT resources that will be based on COTS hardware, networking resources will be provided by hardware network elements and physical links.

[8] ETSI GS NFV 002 V1.1.1, Section 7.2.2, pp14

[9] ETSI GS NFV 002 V1.1.1, Section 7.2.4.1, pp15.

Virtualisation Layer and Virtualised resources	The virtualization layer abstracts the hardware resources and decouples the VNF software from the underlying hardware, thus ensuring a hardware independent lifecycle for the VNFs. The NFV architectural framework does not restrict itself to using any specific virtualization layer solution. To ensure operational transparency, the operation of the VNF should be independent of its deployment scenario.	Our solution is aligned to ETSI view, with the latter being more generic with respect to the actual implementation choices. The virtualization layer will be based on currently available virtualization enabler frameworks (e.g. OpenStack) using open source hypervisors for the abstraction of the IT and network resources within the compute nodes. With respect to the network domain, the network hardware will be virtualized by the virtualisation layer in order to be able to virtualize network paths that provide connectivity to between VMs running VNF instances.
Virtualised Infrastructure Manager(s)	Virtualized Infrastructure Management comprises the functionalities that are used to control and manage the interaction of a VNF with computing, storage and network resources under its authority, as well as their virtualization. Multiple Virtualized Infrastructure Manager instances may be deployed	T-NOVA is completely aligned to the specification of VIM by ETSI. For T-NOVA multiple VIM instances are considered, one for each NFVI-PoP.
Orchestrator	Orchestration and management of NFV infrastructure and software resources, and realizing network services on NFVI	Orchestrator will be the component that will allow the orchestration and management of the NFVI, by orchestrating the software and hardware resources for the provision of NFaaS
VNF Manager(s)	Manages the VNF lifecycle.	Total alignment to ETSI view.
Operation and Business Support Systems (OSS/BSS) – Marketplace	ETSI view does not provide any more insight on the OSS/BSS of the operator apart from the definition of an interface.	Although the OSS/BSS system is not in the scope of T-NOVA, the proposed Marketplace component of the overall architecture contains partially some OSS/BSS modules (i.e. Billing, Accounting, SLA monitoring, AAA) that will be implemented/adapted. Additionally the notion of the Marketplace is

		considered an added value, compared to the ETSI view.
Network Function Store	In ETSI view this component does not exist. Most of the VNF related metadata information is included in Service VNF and Infrastructure Description component. There is no component in the ETSI NFV proposed overall architecture that acts as a repository of the VNF images and templates.	The NF Store will be the architectural component, proposed by T-NOVA that will withhold metadata information and description related to the VNFs, along with the actual images of the VNFs submitted by the Function Providers (NF repository).

4. Service Lifecycle and sequence of interactions

This section presents the mapping of the Use Cases (UCs) that were initially described in Deliverable D2.1 (System Use Cases and Requirements), Section 5.2. For each UC the section attempts to illustrate how the involved components of the T-NOVA overall architecture are involved and how they interact with each other. The interactions are only described in a high-level manner; forthcoming deliverables will provide a more detailed insight on the workflow for achieving each system Use Case.

4.1. UC1: Advertise VNFs

Background / Rationale

This UC is related to the interactions required for a FP to publish and advertise a VNF.

Actors/Roles

FP

Pre-conditions

There is an offline exchange of authorisation information and certification for each FP, subject to bilateral discussions between the FP and the SP, acceptance of the Terms of Service etc.

Procedure

1. The FP is authenticated to the T-NOVA system.
2. The FP uploads the VNF package, including all the relevant description metadata. The metadata include configuration options, keywords, generic description of the VNF, VNF expected performance, resources requirements, pricing, etc,
3. The submitted VNF is certified in order to increase security and integrity of the VNF package. It should be noted that all the steps involved in the VNF deployment should include verification of the certification.
4. The VNF is assigned a unique ID and it is included in the advertised offerings.
5. The FP monitors the status and other statistical data (popularity, voting, comments etc.) of the published VNFs.

The sequence diagram for this UC is illustrated in the figure below (Figure 26).

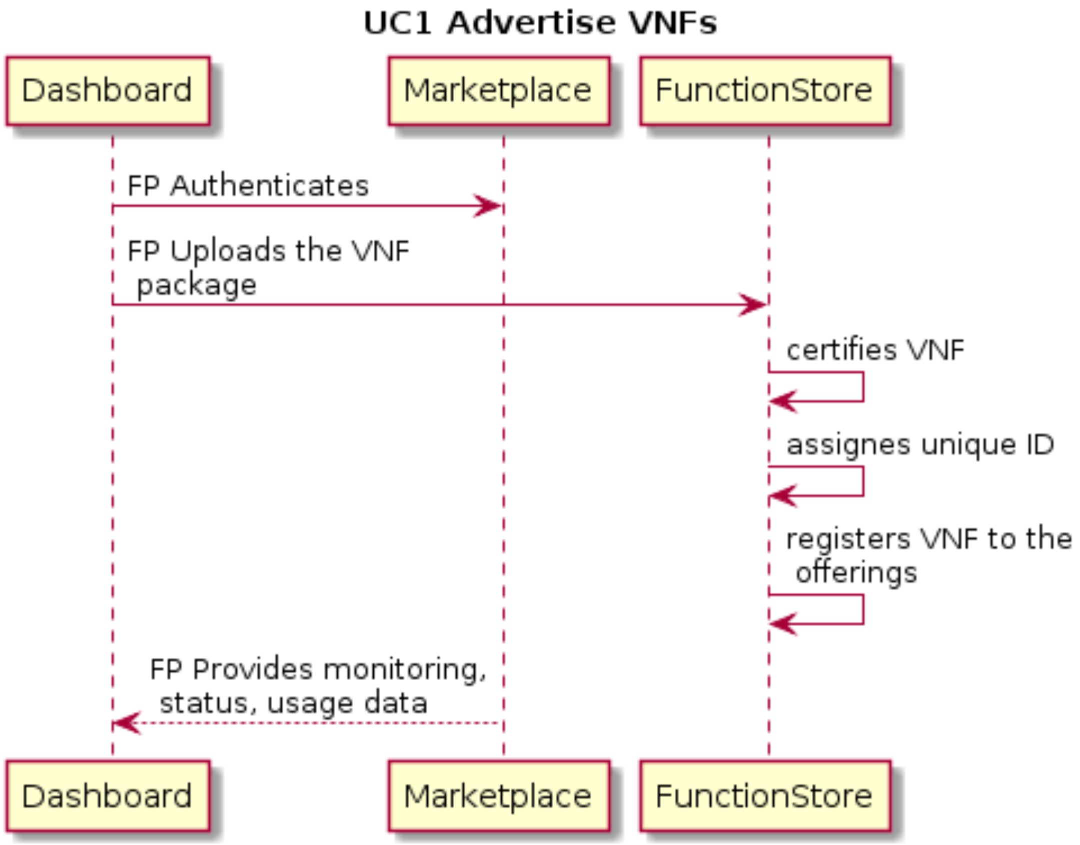

Figure 26 UC1 Advertise VNFs Sequence Diagram

4.2. UC2. Compose NFV services and describe service offerings

Background / Rationale

This use case intends to specify the interactions that take place during the VNF composition phase. According to ETSI NFV (ETSI NFV ISG, 2013), "VNF composition, is the process whereby a group of lower-level VNFs is used to define a higher-level VNF". There might be a need for decomposition also. An example would be: The FP offers several smaller functions modules as part of a Security Appliance i.e. Firewall, IPS, IDS. These basic VNFs can be composed in a single Security-oriented VNF, reducing the need for complex service chaining and Network Forwarding Graph calculations. Furthermore, T-NOVA SP will be able to compose and end-to-end network services that will mean a VNF Forwarding Graph and the connectivity between the two end points.

Stakeholders involved

SP, FP, Customer, (Broker). (NIP)

Pre-conditions

UC1 takes place. At least one VNF has been advertise by a Function Provider

Procedure

1. The SP identifies the VNFs that will be part of the NS that it will be offered (either as a new offering or based on customer request optionally).
2. UC 2.1 takes place: bid/trading process between SP and FPs to acquire NFs.
3. The Service Provider creates and publishes SLA descriptions concerning their own pre-composed service offerings and customer's obligations creating an offering: service description, SLA specification, price.
4. UC2.2 takes place: customer selects an offering and SLA is signed.
5. The customer provides the needed information for service configuration such us its network access point.
6. Resources are mapped, NFVI-PoPs are identified and the network graph is computed by the SP matching the SLA.

The figure below presents the sequence diagram for this UC2 encapsulating also the UC2.1 and UC2.2.

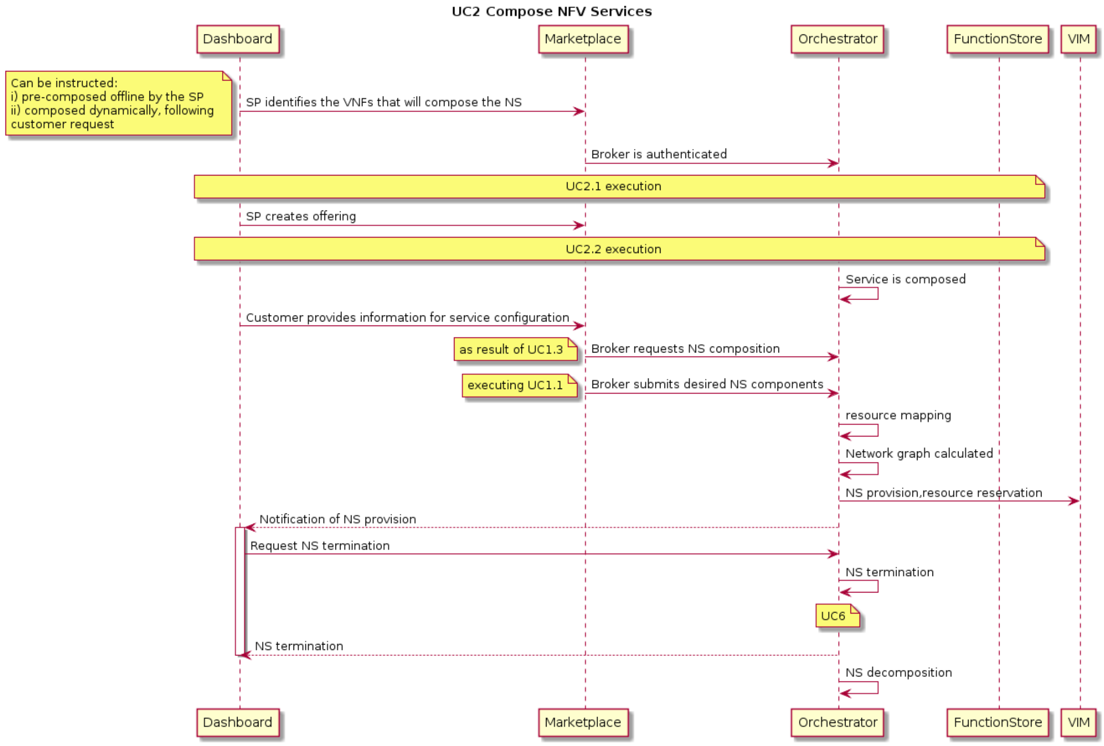

Figure 27 UC2 NFV Service Composition Sequence Diagram

4.2.1. UC2.1 Bid / trade

Background / Rationale

This use case describes the procedure that is required to perform VNFs trading among the involved Stakeholders.

Stakeholders involved

SP, FP (Broker), Business Service Catalogue (BSC)

Pre-conditions

The T-NOVA SP has been authenticated into the T-NOVA system and set the specifications/requirements of the service that they want to exploit. The BSC has returned a list of all potential VNFs offerings to the SP. The SP is redirected to a trading process, where he will bid with the various FPs for leasing their provided VNFs.

Procedure

1. The SP provides to the Broker the VNF request and the initial price.
2. The Broker informs the FPs regarding the request and the initial price
3. FP sends their bids for the functions (Price + SLA specification)
4. The Broker informs the bid results.
5. The SP acknowledges the results.
6. The Broker indicates the VNF's price, which is provided by the FP that won the bidding, to the SP.
7. The SP accepts the price and SLA.
8. The SP receives the VNF.
9. (Price will be stored in the accounting module, and SLA agreement in the SLA management module).

The sequence diagram for this UC is illustrated in the figure below.

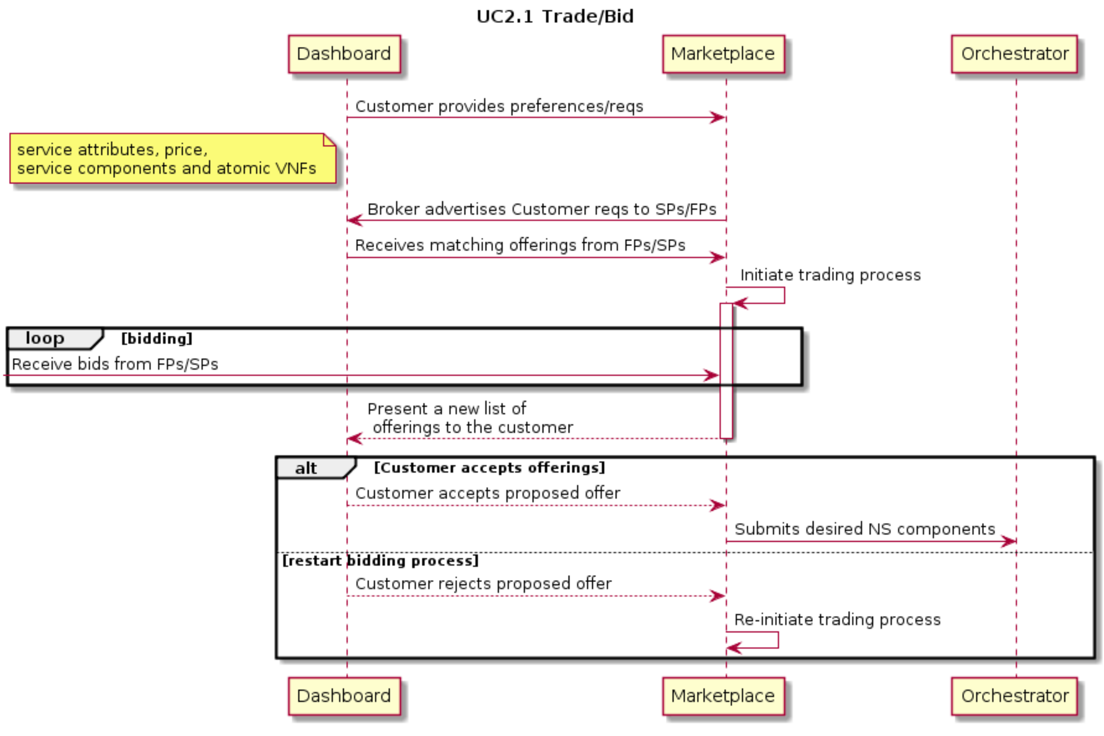

Figure 28 UC2.1 Bid/Trade Sequence Diagram

4.2.2. UC2.2 Browse / select offerings: service + SLA agreement + pricing

Background / Rationale

This use case defines how the customer selects the service among the offerings provided by the SP (service, SLA and pricing), and how the SLA agreement is established among the different involved parties. A contract is established between the Customer and Service Provider, and another between Service Provider and Function Provider (also Infrastructure Provider, if a separate actor), containing (among other things) target service metrics.

Stakeholders involved

Customer, SP

Pre-conditions

A T-NOVA customer has authenticated into T-NOVA system and has performed a request.

The SP has described service offerings including SLA specifications.

Procedure

1. The Customer browses through the different available offerings and the SLAs associated to each service as well as the associated pricing. *(In case the service required by the customer is not already offered, a new service composition will take place (UC1) as well as an associated bid/trading mechanism is performed by the Broker (UC2.1))*
2. The Customer selects specific service, SLA and pricing. This can be a bargain-like transaction or simply a combo-list selection of predefined choices.
3. The SP verifies that the Customer profile allows the acquisition of the specific functions corresponding to the selected service.
4. The SP negotiates the appropriate SLAs with the Function Provider (and Infrastructure Provider). This is possible either statically in UC2 or dynamically during brokerage (UC2.1).
5. The Customer accepts SLA and pricing (Pricing Module) and other applicable conditions.
6. The SLAs agreed are registered in the system.

The following figure illustrated the sequence diagram for this UC.

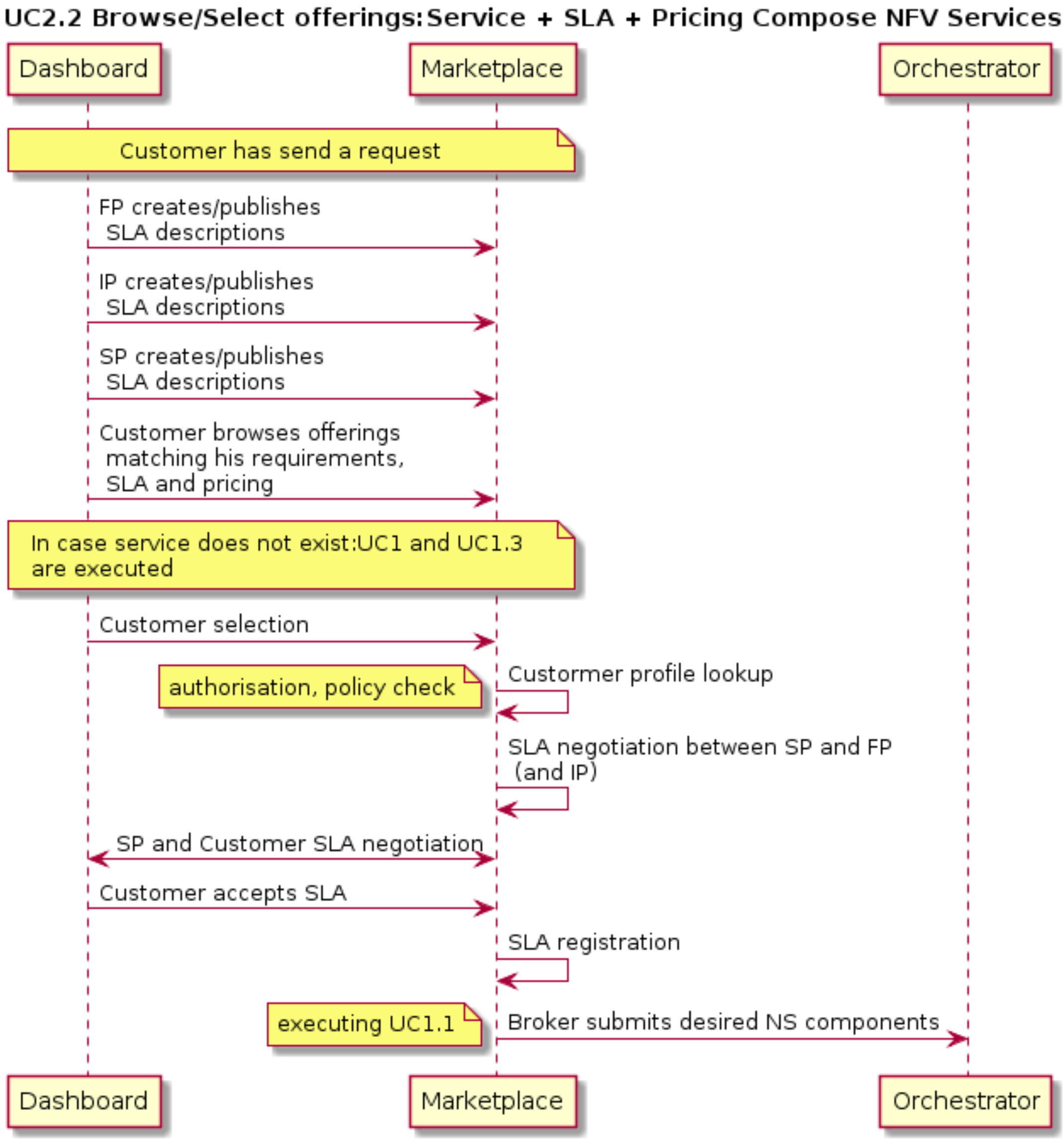

Figure 29 UC 2.2 Browse/Select offerings Sequence Diagram

4.3. UC3 Provision NFV services

Background / Rationale

The T-NOVA Service Provider instantiates the appropriate infrastructure resources according to the customer request in order to fulfil the SLA.

Stakeholders involved

Customer, SP

Pre-conditions

The T-NOVA Customer has selected the service components and relevant parameters (UC1). The IT and network infrastructure resources required to deploy the service are in place.

Procedure

1. Mapping and deployment of the resources are executed (see UC2.1).
2. The SP configures the components of newly created instance(s) of the service.
3. The SP starts the service, verifies that service is up and running (including connectivity to customer network service) and notifies the customer.

The following figure is presenting the sequence diagram of this use case.

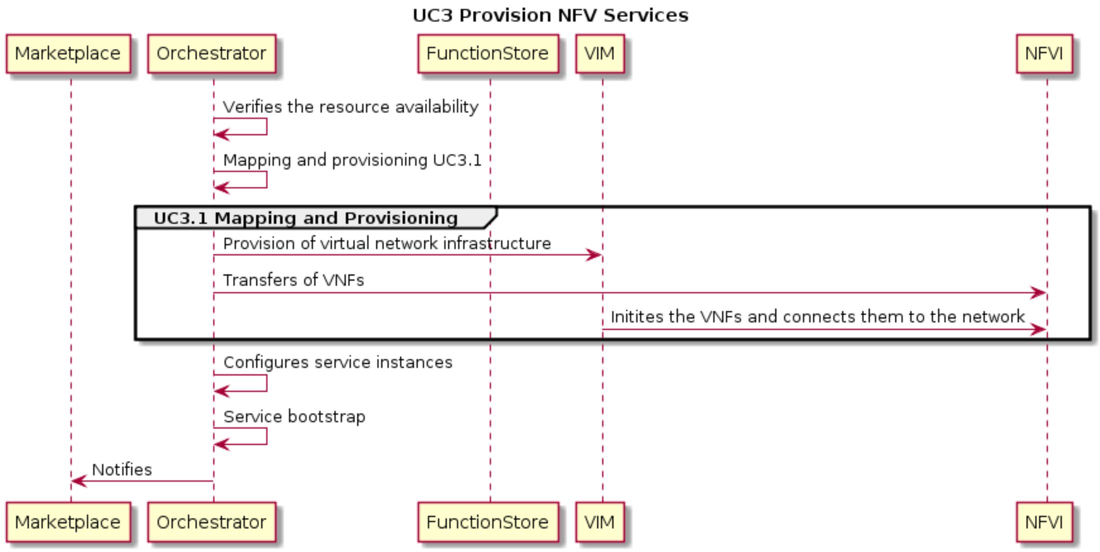

Figure 30 UC3 Provision of NFV Services Sequence Diagram

4.3.1. UC3.1. Map and deploy service

Background / Rationale

The VNFs are mapped into appropriate resources and then provisioned on the NFV infrastructure. The use case may be executed in two different situations – upon a new service request by the customer (UC2), or as a result of a service reconfiguration or rescaling (UC3).

Stakeholders involved

Customer, SP

Pre-conditions

The infrastructure resources required to fulfil the customer request are supposed to be available.

Procedure

1. The requested service is mapped into specific infrastructure (network and compute) resources, taking into account several applicable objectives (e.g. security, reliability, cost minimization, SLA fulfilment).
2. The images of the requested VNFs are transferred to the appropriate NFVI-PoPs to be deployed.

3. Virtual network is established (or reconfigured if already established, in the case of service reconfiguration) in the NFVI-PoP(s) (includes the inter-NFVI-PoP connectivity, if necessary)
4. VNFs are instantiated and connected to the virtual network.
5. The virtual network is relayed to the external connectivity service provided by the SP to the customer (if applicable and not already connected).

4.4. UC4 Reconfigure/Rescale NFV Services

UC4 (and UC4.x) is focused on the adaptation of the resources allocated to a specific service, towards SLA fulfilment and resource usage optimisation. For all UC4.x Use Cases, the precondition is the execution of UC3 and auto-scaling support of the involved VNF Service.

4.4.1. UC4.1 Scale-Out / In VNF Service

This UC comprehends the modification (scale-out or scale-in) of the number of instantiated VNF images used by a given NS.

The sequence diagram for this UCs is illustrated in Figure 31.

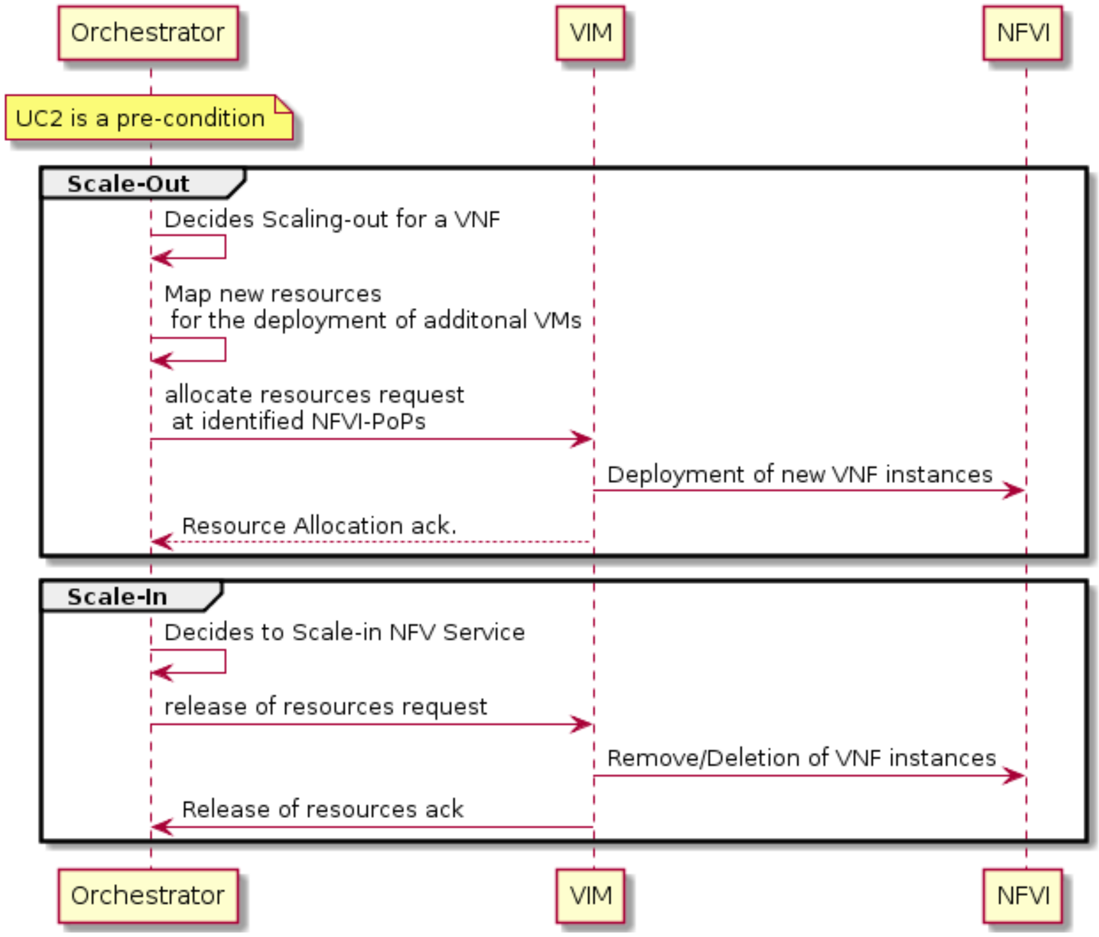

Figure 31. UC4.1 Sequence Diagram

4.4.2. UC4.2 Scale-Up /Down VNF Service

UC3.2 involves the increase or decrease of the computing/network resources allocated to a single VNF instance. During the second year of the project it has been studied whether support for this UC would eventually reach to an actual implementation. It seems that the current limitation in the selected hypervisors in the IVM layer tender the applicability of this UC. However the UC is included here as a possible UC for the T-NOVA platform for future reference.

The sequence diagram for this UCs is illustrated in Figure 32.

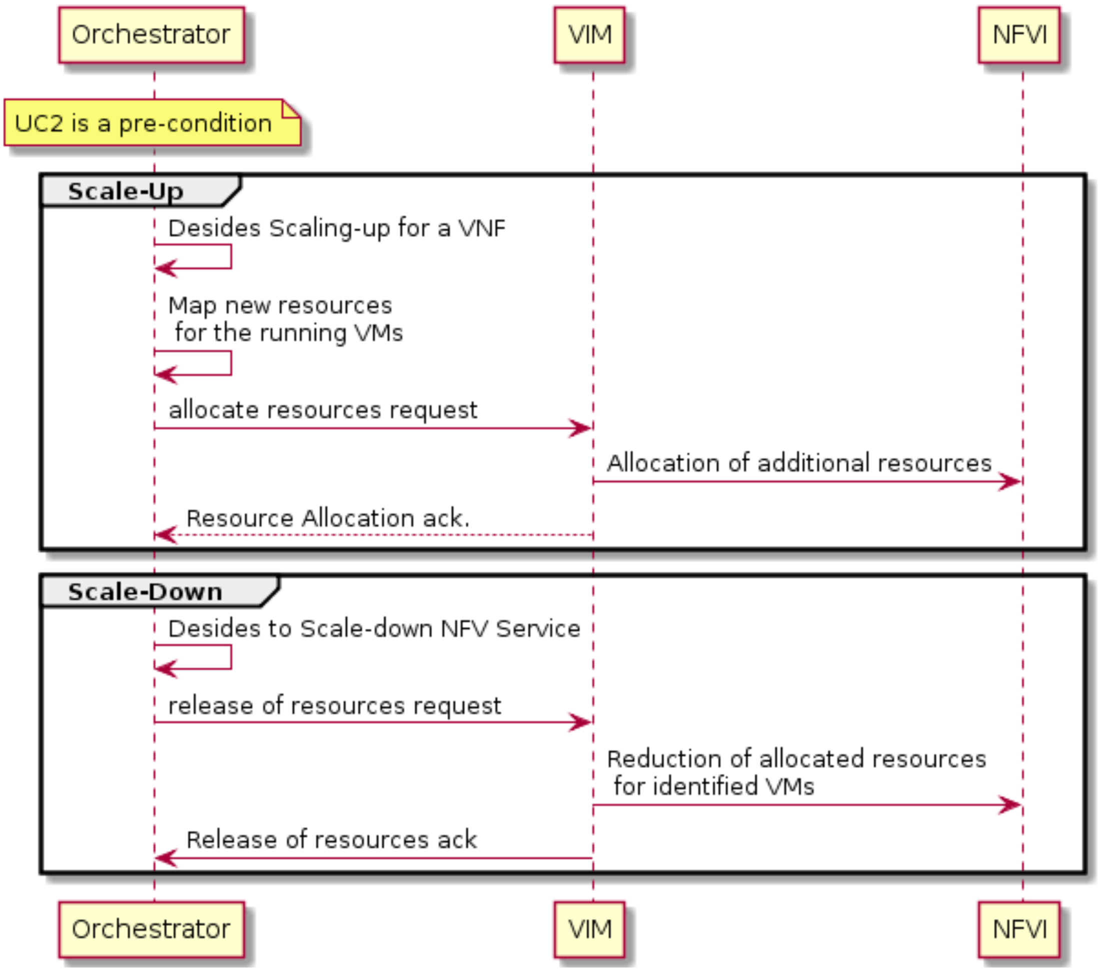

Figure 32. UC4.2 Sequence Diagram

4.4.3. UC3.3. Reconfigure VNF Service

This UC realises the reconfiguration of VNF Service parameters. It can be automatically triggered, scheduled at a given time or manually launched by the SP and/or the Customer.

The sequence diagram for this UC is illustrated in Figure 33

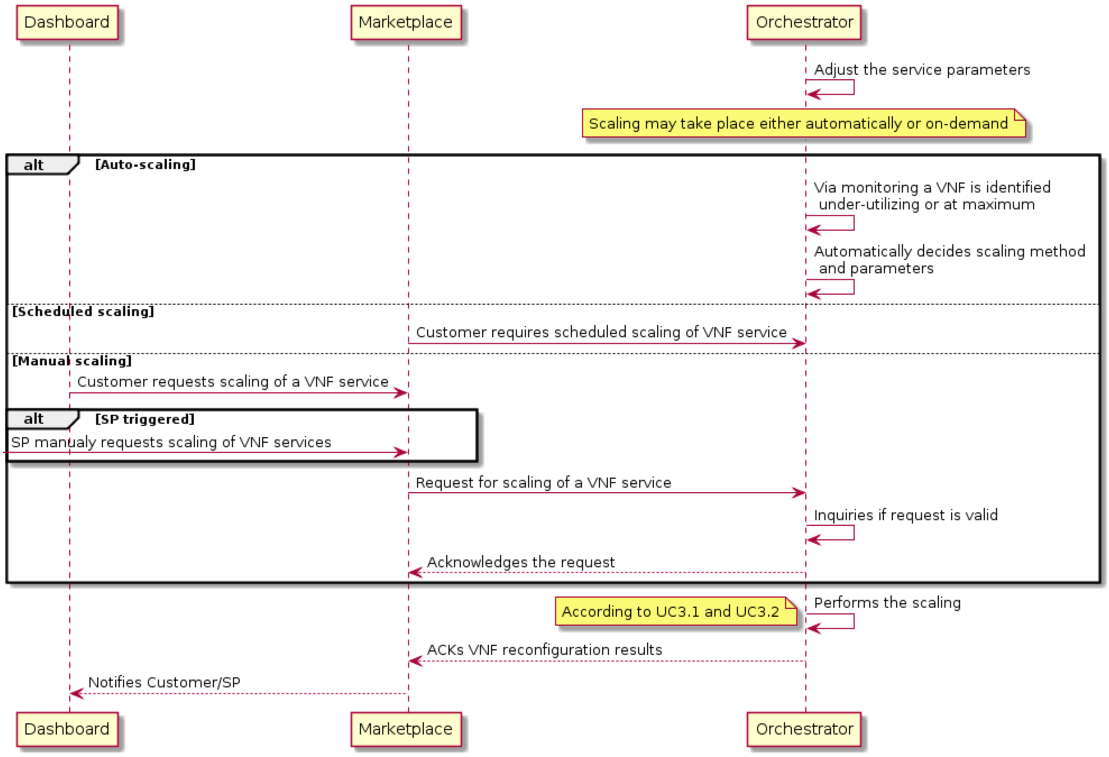

Figure 33. UC3.3 Sequence Diagram

4.5. UC5. Monitor NFV Services

Background / Rationale

The resources consumed by a T-NOVA service as well as its overall status are constantly monitored and monitoring metrics are presented to SP and to the Customer.

The established T-NOVA service is monitored in order to:

- Provide awareness to SP and Customer about service status;
- Provide awareness to SP about infrastructure utilisation;
- Check conformance to SLA;
- Facilitate billing;
- Detect (and possibly prevent) faults and anomalies;
- Trigger reconfiguration/rescaling decisions (UC3).

Stakeholders involved

Customer, SP

Pre-conditions

The service is established and is active (UC2)

Procedure

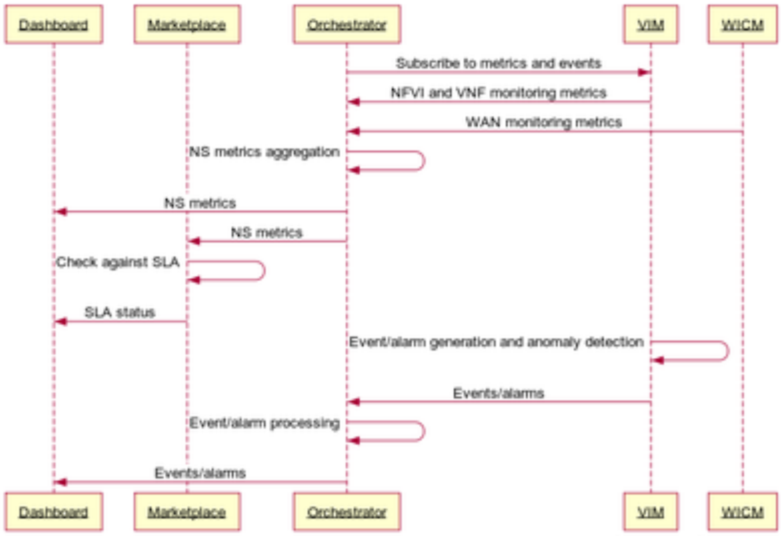

Figure 34 UC5 Sequence Diagram

1. The Orchestrator subscribes to specific service metrics and events
2. The VIM periodically sends NFVI (virtual and physical elements) and VNF monitoring metrics to the Orchestrator
3. Monitoring metrics are aggregated to form an integrated picture of the T-NOVA service.
4. Service metrics are presented to the SP and Customer.
5. Service metrics are checked against the SLA (see UC4.1).
6. SLA status is presented to the SP and Customer
7. Anomalies are detected (also possibly forecasted) and alarms are generated.
8. Alarms are presented to SP and Customer.

4.5.1. UC 4.1 Monitor SLA

This UC defines the workflow for the evaluation of the agreed SLA among the stakeholders. The UC also considers the reaction to be taken according to the results.

The sequence diagram for this UCs is illustrated in Figure 35

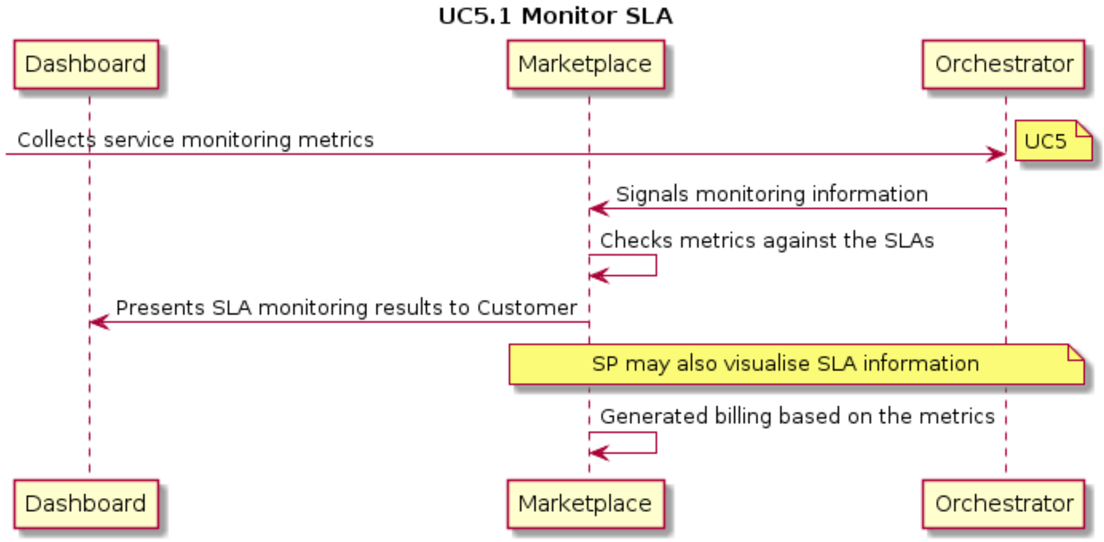

Figure 35. UC4.1 Sequence Diagram

4.6. UC6 Bill NFV Service

Background / Rationale

This use case defines the billing procedure for a T-NOVA Customer, and the billing procedure for SP by the FP (and NIP/CIP) based on accounting and SLA fulfilment.

Stakeholders involved

Customer, SP, FP, (NIP, CIP)

Pre-conditions

A Customer is assigned a bill cycle valid for all his subscriptions (a SP is also assigned a bill cycle).

A Customer has requested and selected T-NOVA services, , possibly with different corresponding pricing conditions and SLAs (UC 2.2).

The service(s) has(ve) been deployed (UC 3).

The bill cycle for T-NOVA Customer is about to close.

Procedure

Billing to Customer:

1. Accounting information (which includes services subscribed and usages for all services, prices, and billable SLA items) is collected. This is done on a per cycle and per SP basis.
2. The appropriate bills are generated, considering the accounting information.
3. The billing information is presented to the Customer.

Billing to SP:

1. Accounting information (which includes services subscribed and usages for all services and billable SLA items) is collected. This is done on a per cycle and per FP (and IP) basis.
2. The appropriate bills from FP (and IP) to the SP are generated, considering the accounting information.
3. The billing information is presented to the SP.

The sequence diagram for this UCs is illustrated in Figure 36.

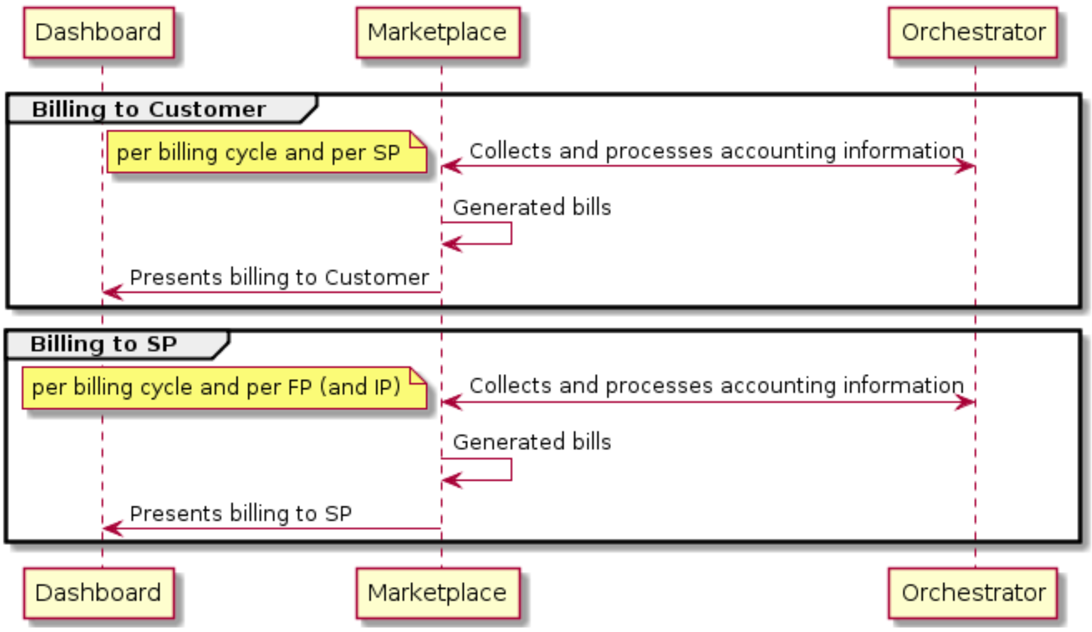

Figure 36. UC5 Sequence Diagram

4.7. UC7 Terminate NFV services

Background / Rationale

This use case defines the procedures related to (1) termination of a provisioned NFV service, either by Customer or SP and (2) removal of a VNF from the catalogue of available and advertised services.

Stakeholders involved

Customer, SP, FP

Pre-conditions

- A VNF has been uploaded and published.
- A T-NOVA service has been deployed.

Procedure

Case 1: A Customer is terminating an active/provisioned NFV Service

1. The Customer is authenticated.
2. The Customer browses the active services, chooses the NFV service and requests its termination.
3. The VNF instances are terminated and the service is torn down.

4. All billing/charging activities related to this service are terminated.
5. SP and Customer are informed.
6. NFV related data (monitoring data, billing data, etc.) are archived for further use.

Case 2: A Service Provider is terminating an active/provisioned NFV Service for a specific Customer

1. The SP is authenticated.
2. The SP browses the active services, chooses the NFV service and requests its termination.
3. The VNF instances are terminated and the service is torn down.
4. All billing/charging activities related to this service are terminated.
5. SP and Customer are informed.
6. NFV related data (monitoring data, billing data, etc.) are archived for further use.

Case 3: A Service Provider removes a T-NOVA Service from the service catalogue

1. The SP is authenticated.
2. The SP selects an NFV service from the list of offered services.
3. The SP removes/deactivates the specific service.
4. The NFV service is removed from the list of offered services.
5. The FP is informed.

The sequence diagram for this UCs is illustrated in **Error! Reference source not found.**

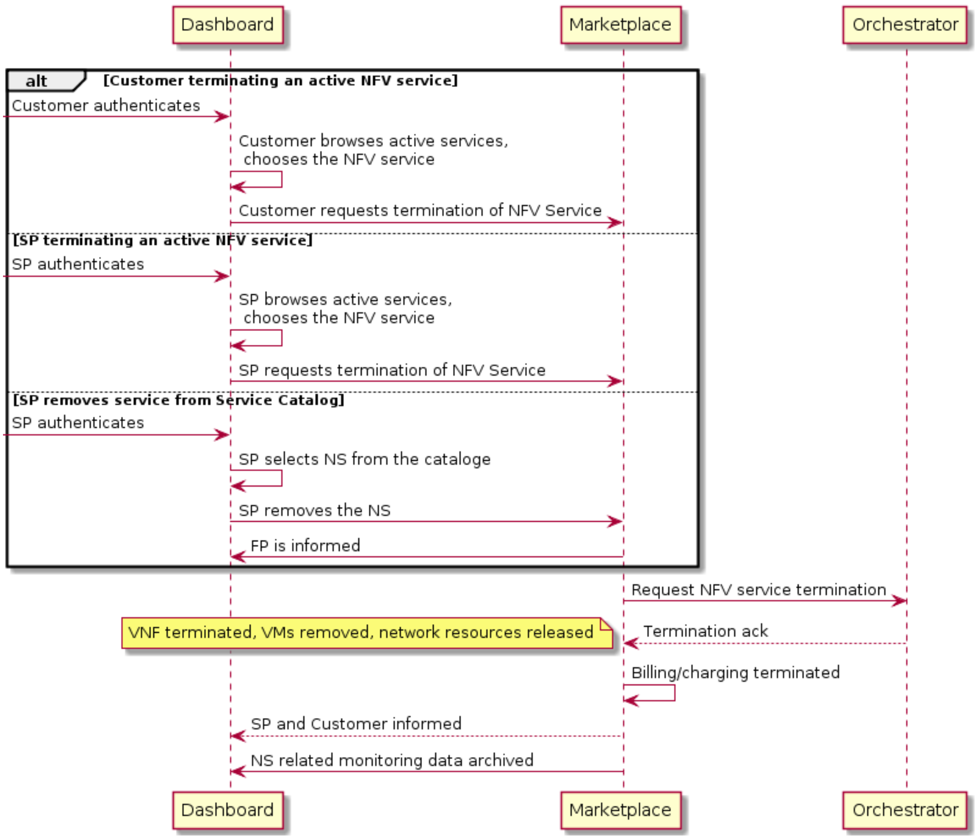

Figure 37 UC7 Sequence Diagram

5. T-NOVA 5G RELEVANCE

This section discusses the relationship of T-NOVA with the European (but also global) target vision towards a "5G" telco infrastructure. First, some relevant H2020 research projects belonging to the 5G PPP Phase 1 –to which T-NOVA is already establishing relationship- are overviewed. Following, the degree to which T-NOVA is contributing towards achieving the 5G PPP KPIs is discussed.

5.1. H2020 (5G PPP Phase 1) relevant running projects

5.1.1. SONATA

The SONATA (Service Programming and Orchestration for Virtualised Software Networks - http://www.sonata-nfv.eu) project, has been recently launched (1st July 2015), aiming to contribute to a more flexible programmability of 5G networks by means of the implementation of: 1) a novel Service Development Kit (SDK) and ii) service execution platform based on a modular NFV Orchestrator.

The outcome of the development kit will be NFV forwarding graphs of composed services that will be automatically deployed with a customizable Orchestrator compatible with common existing Virtual Infrastructure Managers (VIM) in the market.

The combination of the toolkit to facilitate the service composition and the service platform in a flexible manner implements an extended NFV DevOps model between service developers and telecom operators.

For service development, SONATA aims to provide service patterns and description techniques for composed services. The SDK will be developed by integrating catalogue access, editing, debugging, and monitoring analysis tools with service packaging for shipment to an operator. For deployment, SONATA provides a novel service platform to manage service execution. The platform complements the SDK with functionality to validate service packages. Moreover, it improves on existing platforms by providing a flexible and extensible orchestration framework based on a plugin architecture. It is expected that by means of SONATA platform the service developers can provide custom algorithms to steer the orchestration of their services: for continuous placement, scaling, life-cycle management and contextualization of services. These algorithms are overseen by executives in the service platform, ensuring trust and resolving any conflict between services.

As SONATA project has just been launched, no architecture has been released yet. Based on SONATA objectives, we can see an envisaged interplay with T-NOVA in relation to the service orchestration platform. The T-NOVA orchestrator can be the starting point for SONATA to build its novel modular orchestrator able to offer enhance orchestration features such as more elaborated service patterns for service description, validation of service packages and enhanced custom algorithms to steer the orchestration, among others.

5.1.2. 5GEx

The 5GEx project will start on October 1st, 2015. Its core objective is to enable a unified European infrastructure services market, through the integration of multiple operator environments and multiple technology frameworks. This integration must allow the provisioning of new cross-domain and cross- technology services, in a fast and automated way.

The key outcomes pursued to reach this objective are:

- A full-fledged technology framework, consisting of a reference architecture, a set of mechanism, algorithms and components (most prominent of which is a multi-domain orchestrator, sitting on top of legacy single-domain orchestrators and controllers);
- A reference implementation of the end-to-end system, with deployment of a proof-of-concept prototype;
- A Sandbox Exchange, to validate the concept through experimenting on a selected set of use cases; it will reside on a set of testbeds, made available by the telecom operators participating to the project, interconnected and integrated among them;
- The definition and validation of a novel business layer, including a business information model, economic and market-addressed mechanisms to promote efficiency of multi-domain services;
- The contribution to relevant standard forums and Open Source communities.

Another key concept in 5GEx is the convergence among network, connectivity and computational resources, to deliver more complete services leveraging existing cloud computing and NFV platforms, along with the available network resources.

The multi-domain orchestrator is the core technical element of the 5GEx architecture. It is expected to include a number of subcomponents, namely:

- A runtime engine, for cross-domain management of network links and virtual machines;
- An exchange of functions, for cross-domain management of service components;
- An exchange of information and control, for providing capabilities like cross-domain SLA management, resource mapping, service and VNF management.

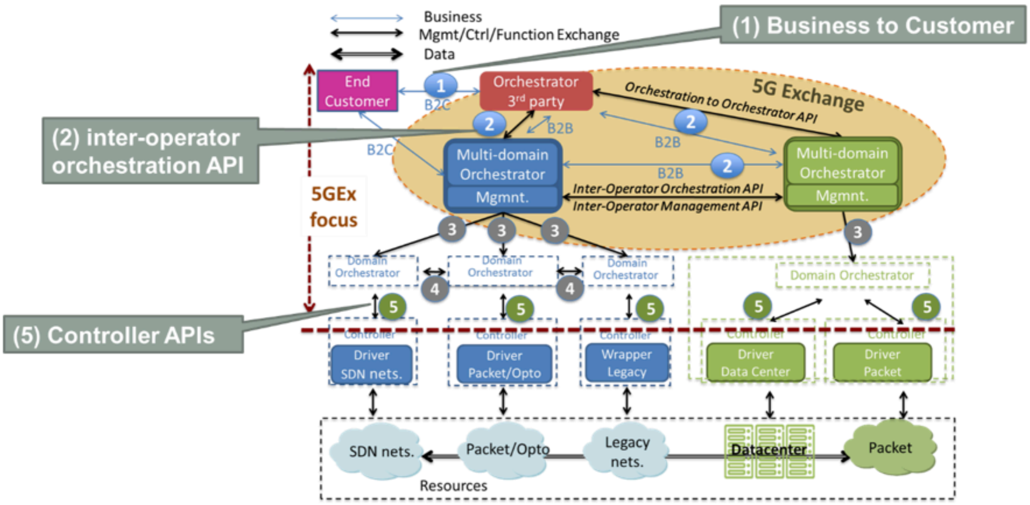

Figure 38. 5GEx concept

In terms of interaction with T-NOVA, the most evident possible commonality could be given by the T-NOVA Orchestrator. It can be involved in two ways:

- As an initial technical model/baseline for the design of 5GEx multi-domain orchestrator; if the design choices in 5GEx will be compliant, the microservice architecture chosen for the T-NOVA Orchestrator could also allow a partial reuse, by picking the components which can adapt to and benefit the 5GEx architecture;
- Furthermore, the T-NOVA Orchestrator can be one of the domain orchestrators selected as targets for the design of 5GEx API, and for its reference implementation/testing/experimentation. The timing of respective project plans could not allow a bidirectional interaction; however T-NOVA can try to incorporate inputs coming from 5GEx into the definition of its Orchestartion interfaces, at least as recommendation for future evolutions.

T-NOVA can provide additional inputs to 5GEx as far as the specification of B2C interface for the multi-domain orchestrator is concerned. Although 5GEx is not expected to implement a full marketplace layer, it should specify a northbound API for end users to access the multi-domain service catalogue. T-NOVA marketplace can be a good reference to look at, for deriving functional and non-functional requirements of this interface.

5.1.3. SESAME

SESAME (Small Cells coordination for multi-tenancy and edge services), is Horizon 2020 project that targets innovations around three central elements in 5G: the placement of network intelligence and applications in the network edge through Network Functions Virtualisation (NFV) and Edge Cloud Computing; the substantial evolution of the Small Cell concept, already mainstream in 4G but expected to deliver its full potential in the challenging high dense 5G scenarios; and the consolidation of multi-tenancy in communications infrastructures, allowing several operators/service providers to engage in new sharing models of both access capacity and edge computing capabilities.

SESAME proposes the Cloud-Enabled Small Cell (CESC) concept, a new multi-operator enabled Small Cell that integrates a non-x86 lightweight execution platform (i.e., the microserver). The deployed CESCs are clustered constituting the Light Datacenter (LightDC) concept exploite for deploying Virtual Network Functions (VNFs), supporting powerful self-x management and executing novel applications and services inside the access network infrastructure. The Light DC will feature low-power processors and hardware accelerators for time critical operations and will build a high manageable clustered edge-computing infrastructure. This approach will allow new stakeholders to dynamically enter the value chain by acting as neutral host providers in high traffic areas where densification of multiple networks is not practical. The optimal management of a CESC deployment is a key challenge of SESAME, for which new orchestration, NFV management, virtualisation of management views per tenant, self-x features and radio access management techniques will be developed.

In terms of relevance and interaction with T-NOVA, the primary synergy areas are:

- Exploitation of the T-NOVA orchestrator. T-NOVA orchestrator components (named TeNOR) will be offered as Opensource, allowing reuse of certain functionalities e.g. Service Mapping and extension of those in order to fit into the dynamic clustered environment of SESAME
- Reuse of descriptor structures used in T-NOVA in order to base and expand those that will be developed by SESAME.
- Finally, T-NOVA VNFs will also be Opensource so particular components will be reused in order to provide a number of VNFs used for the pilots and proof of concepts of the project.

Additional T-NOVA components that will be considered, although infrastructure monitoring is not main focus of SESAME project, is the monitoring framework for monitoring and supervision of the running VNF instances across the LightDC environment.

5.1.4. SUPERFLUIDITY

SUPERFLUIDITY is a Horizon 2020 project focused on addressing shortcomings in today’s mobile networks which include long provisioning times, overprovisioning of resources to meet variable demand; reliance on rigid and cost-ineffective hardware devices and the complexity emerging from increasing heterogeneity in the network. Sources of heterogeneity include traffic, services and access technologies from multiple vendors. The project aims to address these issues by adopting the following strategies:

- Flexibility, via an architectural decomposition of network components and network services into elementary, reusable primitives.
- Simplicity, via a cloud-based architecture, getting rid of access-specific gateways and integrating heterogeneous JBOAs (“just a bunch of accesses”) within a converged cloud-network infrastructure ranging from the core all the way to the network edge.

Agility, via virtualization of radio and network processing tasks.

- Portability and viability, through platform-independent abstractions, permitting reuse of network functions across multiple heterogeneous hardware platforms, while allowing for the vendors' need for closed platforms or closed source implementations.
- High performance beyond the state of the art, via software acceleration, specialization and adaptation to hardware accelerators, while making these mechanisms transparent to network service designers so that they can focus on the development of novel services and not performance optimization.

The project takes the position that NFV on its own is insufficient to solve the convergence problems of 5G networks. Superfluidity takes the perspective that the infrastructure required to support 5G services needs to be more heterogeneous than just X86 commodity servers. The project considers both custom ASICs and heterogeneous components such as TCAMs, FPGAs, GPUs added to x86 machines to increase the performance of certain networking workloads as the basis for a converged infrastructure approach. Secondly, they also consider cases where some functions run much more efficiently in hardware (e.g., packet switching, or wireless protocol implementations with strict packet timings); in these cases, Superfluidity consider the best option to be the creation of an API that abstracts this complexity and allows external control and innovation. The overall approaches being adopted by the Superfluidity project is to accommodate and leverage hardware heterogeneity in a "divide and conquer" architectural paradigm for 5G networks. This is a departure from the 2/3/4G architectural approach based on monolithic network components/entities and their interfaces, and promote an approach where components are "constructed" via the programmatic composition of elementary "building blocks".

Within the T-NOVA project, resource heterogeneity has been considered and identified as a necessary requirement within the NFVI-PoP (see deliverable 2.32). In addition the T-NOVA infrastructure repository subsystem identifies and exposes heterogeneous resources such as PCIe co-processor cards to the T-NOVA Orchestrator components. Deliverable 3.2 relates with Superfluidity task on block abstraction model, since it includes APIs to expose parametric details of infrastructure profiles. T-NOVA Deliverable 4.1 will provide on insights on the service performance on virtualised infrastructures which are likely to be of relevance and interest to the Superfluidity partners and will used to inform Intel's activities in the Superfluidity aligned task. The Superfluidity project also has a task on Optimal Function Allocation which has potential alignment with T-NOVAs task 3.3 on the development of a resource mapping algorithm. Both tasks have the common goal of matching network services to the available hardware infrastructure. Finally the Superfluidity task on the Provisioning and Control Framework aligns with the Orchestration development activities in WP3 of T-NOVA.

5.2. Addressing of 5G PPP Key Performance Indicators (KPIs)

In the frame of the 5G Private-Public Partnership (5G PPP), as established between the European Commission and the 5G Association, a set of Key Performance Indicators has been agreed upon[10], which should set the targets for a future 5G system. These KPIs address crucial limitation of current telco systems, mostly in terms of capacity, scalability and tolerance.

In this context, all projects which are seen to contribute to the 5G vision (not only 5G PPP Phase 1 projects, but also the last “wave” of FP7 projects) should clearly address some (or all) of these targets. T-NOVA, whose scope clearly falls within the 5G vision for infrastructure softwarisation, addresses these KPIs as summarized in the table below.

5G PPP KPI	**T-NOVA contribution**
1000 times higher mobile data volume per geographical area.	(not relevant)
10 to 100 times more connected devices.	T-NOVA increases telco infrastructure scalability by allowing core network functions to be virtualised and deployed in multiple instances, in a distributed fashion
10 times to 100 times higher typical user data rate.	(not relevant)
10 times lower energy consumption.	T-NOVA can consolidate tens or even hundreds of VNFs into commodity servers, thus achieving significant energy saving. The placement algorithms developed in T3.3 are seen to contribute towards this goal.
End-to-End latency of < 1ms.	T-NOVA can support deployment of edge VNFs very close to the end user (e.g. vCaches, vCPEs as foreseen in the project workplan), which significantly contribute to lower the service response time.
Ubiquitous 5G access including in low density areas.	(not relevant)

[10] https://5g-ppp.eu/kpis/

6. CONCLUSIONS

This document presents an updated approach to the high-level overall architecture of the T-NOVA system, the entities and the main interfaces/reference points. All T-NOVA partners contributed to this endeavour, achieving consensus among the consortium members on the initial architectural vision.

Several integrated NFV architectures proposed by industrial consortia, R&D projects and standardisation bodies were taken into account. T-NOVA inherited and adapted several concepts and architectural principles from the surveyed proposals in order to come up with a layered system architecture which fulfils all user requirements set out in D2.1, is reasonably complex and feasible to implement, being compatible with existing state-of-the-art IT and network infrastructures. In addition, the proposed architecture is compliant with the current technical approach as well as the terminology of ETSI ISG NFV, introducing at the same time several extensions to it.

Using an iterative approach, the feedback received from the detailed subsystems' design and specification as well as from the early phases of implementation helped to refine and amend the overall architecture, as it is eventually specified in the present document.

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LIST OF ACRONYMS

Acronym	Explanation
AAA	Authentication, Authorisation, and Accounting
API	Application Programming Interface
CAPEX	Capital Expenditure
CIP	Cloud Infrastructure Provider
CSP	Communication Service Provider
DASH	Dynamic Adaptive Streaming over HTTP
DDNS	Dynamic DNS
DDoS	Distributed Denial of Service
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
DoS	Denial of Service
DoW	Description of Work
DPI	Deep Packet Inspection
DPDK	Data Plane Development Kit
E2E	End-to-End
EU	End User
FP	Function Provider
GW	Gateway
HG	Home Gateway
HTTP	Hypertext Transfer Protocol
IP	Internet Protocol
IP	Infrastructure Provider
ISG	Industry Specification Group
ISP	Internet Service Provider
IT	Information Technology
KPI	Key Performance Indicator
LAN	Local Area Network
MANO	MANagement and Orchestration
MVNO	Mobile Virtual Network Operator
NAT	Network Address Translation

NFaaS	Network Functions-as-a-Service
NFV	Network Functions Virtualisation
NFVI	Network Functions Virtualisation Infrastructure
NFVIaaS	Network Function Virtualisation Infrastructure as-a-Service
NIP	Network Infrastructure Provider
NS	Network Service
OPEX	Operational Expenditure
OSS / BSS	Operational Support System / Business Support System
PaaS	Platform-as-a-Service
PoC	Proof of Concept
QoS	Quality of Service
RTP	Real Time Protocol
SA	Security Appliance
SaaS	Software-as-a-Service
SBC	Session Border Controller
SDN	Software-Defined Networking
SDO	Standards Development Organisation
SI	Service Integrator
SIP	Session Initiation Protocol
SLA	Service Level Agreement
SME	Small Medium Enterprise
SP	Service Provider
TEM	Telecommunication Equipment Manufacturers
TRL	Technology Readiness Level
TSON	Time Shared Optical Network
UC	Use Case
UML	Unified Modelling Language
vDPI	Virtual Deep Packet Inspection
vHG	Virtual Home Gateway
VM	Virtual Machine
VNF	Virtual Network Function
VNFaaS	Virtual Network Function as a Service
VNPaaS	Virtual Network Platform as a Service

vSA	Virtual Security Appliance
vSBC	Virtual Session Border Controller
WAN	Wide Area Network
WICM	Wide-area Network Infrastructure Connection Manager
WP	Work Package

ANNEX A. TERMINOLOGY

This annex contains a reference of all main T-NOVA architectural entities as well as some general terms used throughout the deliverable.

The terms marked with an asterisk (*) have been aligned with ETSI NFV ISG terminology.

A.1. General Terms

Name	Virtualised Network Function (VNF)*
Description	A virtualised (pure software-based) version of a network function

Name	Virtualised Network Function Component (VNFC)*
Description	An independently manageable and virtualised component (e.g. a separate VM) of the VNF

Name	T-NOVA Network Service (NS)
Description	A network connectivity service enriched with in-network VNFs, as provided by the T-NOVA architecture.

Name	Network Function Virtualisation Point of Presence (NFVI-PoP)*
Description	A physical location where VNFs can be deployed. It can refer to large, centralised data centres or light-DCs distributed in the network.

Name	NFV Infrastructure (NFVI)*
Description	The totality of all hardware and software components which build up the environment in which VNFs are deployed

A.2. MarketPlace Domain

Name	Marketplace
Description	The set of all tools and modules which facilitate the interactions among the T-NOVA actors, including service request, offering and provision, trading, service status presentation and configuration, SLA management and billing

Name	SLA Management Module

Description	The Marketplace functional entity which establishes and stores the SLAs among all the involved parties (Customer , SPs, and FPs, and checking if the SLAs have been fulfilled or not will inform the accounting system for the pertinent billable items (penalties or rewarding).

Name	Accounting Module
Description	The Marketplace functional entity which stores all the information needed for later billing for each user: usage resources for the different services, SLAs evaluations, etc.

Name	Billing Module
Description	The Markeplace functional entity that produces the bills based on the information store in the accounting module.

Name	Access Control Module
Description	The Marketplace functional entity which administers security in a multi-user environment, managing and enabling access authorization/control for the different T-NOVA stakeholders considering their roles and permissions.

Name	Dashboard
Description	The Marketplace functional entity which provides the web-based user front-end, exposing in a graphical manner all customer-facing services of the Orchestrator.

Name	Brokerage Module
Description	The Marketplace functional entity which enables the interaction among actors for service advertisement, request and brokerage/trading.

A.3. Orchestration Domain

Name	Orchestrator*
Description	The highest-level infrastructure management entity which orchestrates network and IT management entities in order to compose and provision an end-to-end T-NOVA service.

Name	Resources Orchestrator*

Description	The Orchestrator functional entity which interacts with the infrastructure management plane in order to manage and monitor the IT and Network resources assigned to a T-NOVA service.

Name	NS Orchestrator*
Description	The Orchestrator functional entity in charge of the NS lifecycle management (i.e. on-boarding, instantiation, scaling, update, termination) which coordinates all other entities in order to establish and manage a T-NOVA service.

Name	VNF Manager*
Description	The Orchestrator functional entity in charge of VNF lifecycle management (i.e. installation, instantiation, allocation and relocation of resources, scaling, termination).

Name	NS Catalog*
Description	The Orchestrator entity which provides a repository of all the descriptors related to available T-NOVA services

Name	VNF Catalog*
Description	The Orchestrator entity which provides a repository with the descriptors of all available VNF Packages.

Name	NS & VNF Instances Record*
Description	The Orchestrator entity which provides a repository with information on all established T-NOVA services in terms of VNF instances (i.e. VNF records) and NS instances (i.e. NS records)

Name	NF Store
Description	The T-NOVA repository holding the images and the metadata of all available VNFs/VNFCs

A.4. Infrastructure Virtualisation and Management Domain (IVM)

Name	Virtualised Infrastructure Management (VIM)*

Description	The management entity which manages the virtualised (intra-NFVI-PoP) infrastructure based on instructions received from the Orchestrator

Name	WAN Infrastructure Connection Management (WICM)
Description	The management entity which manages the wide area network for interconnecting service endpoints and NFVI-PoPs e.g. geographically dispersed data centres

Name	VNF Manager Agent*
Description	The VIM functional entity which interfaces with the Orchestrator to expose VNF management capabilities

Name	Orchestrator Agent *
Description	The VIM/WICM functional entity which interfaces with the Orchestrator to expose resource management capabilities

Name	Hypervisor Controller*
Description	The VIM functional entity which controls the VIM Hypervisors for VM instantiation and management

Name	Compute Controller*
Description	The VIM functional entity which manages both physical resources and virtualised compute nodes

Name	Network Controller @ VIM*
Description	The VIM functional entity which instantiates and manages the virtual networks within the NFVIPoP, as well as traffic steering

Name	Network Controller @ WICM
Description	The WICM functional entity which instantiates and manages the virtual networks within the wide-area transport network, as well as traffic steering

ANNEX B. ARCHITECTURE EXTENSIONS

This annex contains a description of how the T-NOVA architecture can be extended in order to adapt to different scenarios, according to diverse value chain configurations and stakeholders' needs. It must be noted that these architectures are out-of-scope of the project implementation. However, the aim of this section is to demonstrate the elasticity, and adaptability of the T-NOVA framework, as a future-proof architecture for VNF deployment and management.

B.1. BSS/OSS Interfaces

This scenario depicts how the T-NOVA reference architecture can be easily integrated with the current BSS/OSS systems that network operators and/or service providers may have already deployed in their facilities. The aim of this integrated scenario is to depict how the current reference architecture can be deployed in actual environments and being integrated in the different BSS/OSS systems of the stakeholder.

Integration of novel solutions with already existing systems becomes a key item to be considered when moving towards actual deployments.

- **Business value**: Integration of the novel T-NOVA framework with existing deployed solutions. Facilitates the migration from current systems to T-NOVA-like framework
- **T-NOVA roles**: T-NOVA Broker, T-NOVA SP, T-NOVA Infr. Provider

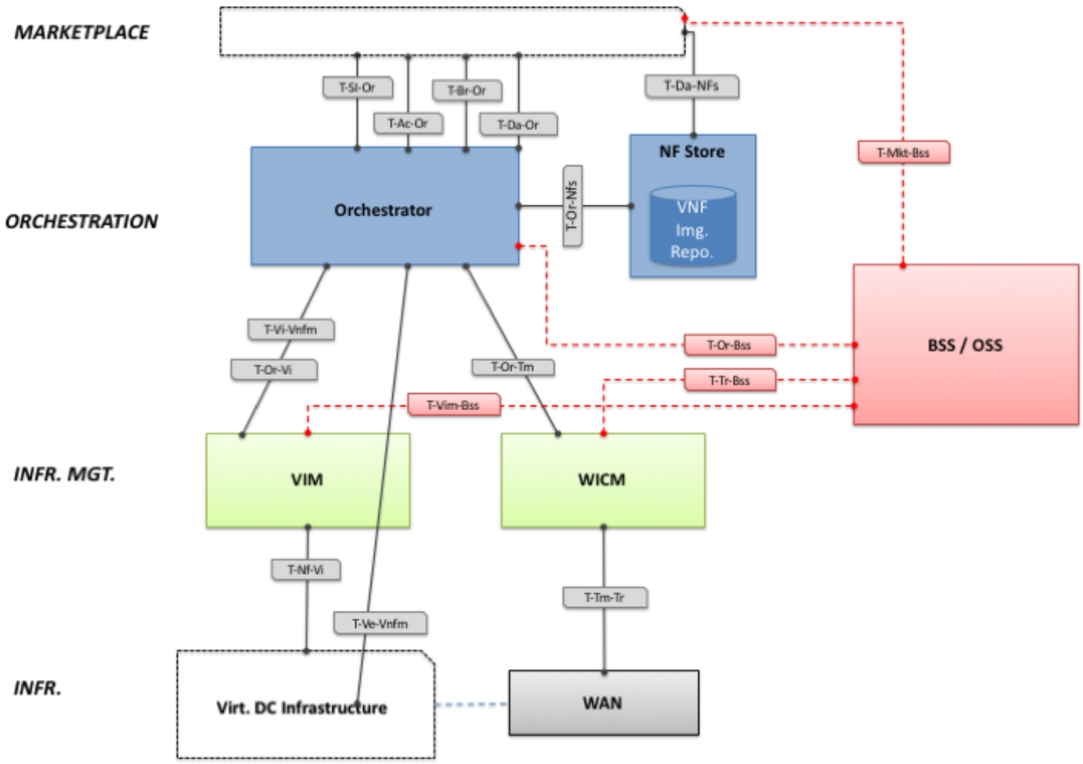

Figure 39. Architecture extension for interfacing with BSS/OSS

B.2. Multiple NFVI-PoP providers

This alternative case comprehends a simple extension of the reference architecture. In this case, some of the VIMs and the corresponding infrastructure are owned by a distinct infrastructure provider.

This case considers that SLAs at the infrastructure level between the distinct providers are in place. However, in order to ensure the correct deployment of VNFs and the correct service provisioning workflows execution, it is required that the BSS/OSS systems of both providers communicate.

Furthermore, since the third-party infrastructure provider is completely independent, the VIM' may not be compliant with the T-NOVA VIM functionalities. Thus, it may be the case that the corresponding T-Or-* interfaces must be adapted in order to integrate both infrastructure segments.

- **Business value**: Include different infrastructure providers (with differentiated VIMs) into a T-NOVA-like scenario for service provisioning and VNF management. Integration of T-NOVA with existing different virtualisation solutions.
- **T-NOVA roles involved**: T-NOVA Broker, T-NOVA SP, T-NOVA Infr. Provider

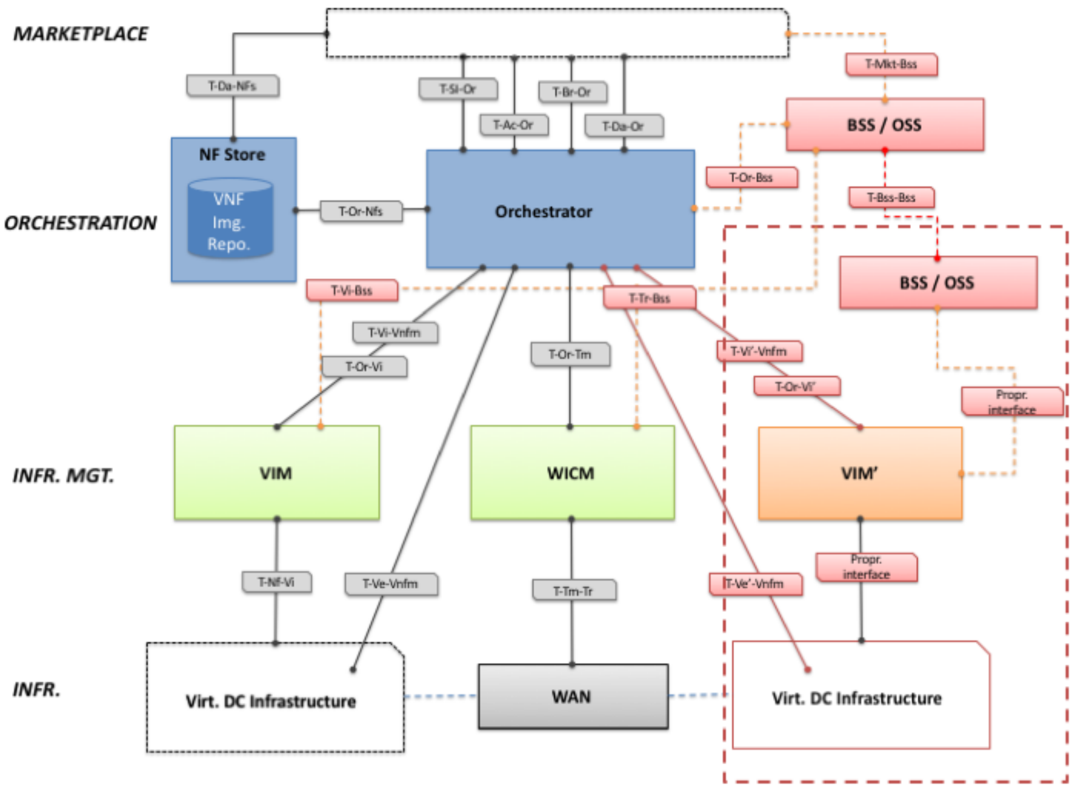

Figure 40. Architecture extension to support multiple NFVI-PoP providers

B.3. Multiple T-NOVA SPs, Single Broker

This basic case comprehends the scenario where there are several service providers, not federated among them (i.e. horizontally disjoint), and there is one single broker which interacts with all of them. Considering that the broker is an intermediary business entity that facilitates trading between the customer and the service providers, this scenario only depicts a typical case where a single broker is capable of providing services using several SPs below them.

- **Business value:** Increase the service offering from the T-NOVA broker towards the T-NOVA consumer, since services can now be provisioned over the infrastructure offered by two (or more) SPs.
- **T-NOVA roles:** T-NOVA Customer, T-NOVA broker, T-NOVA SP

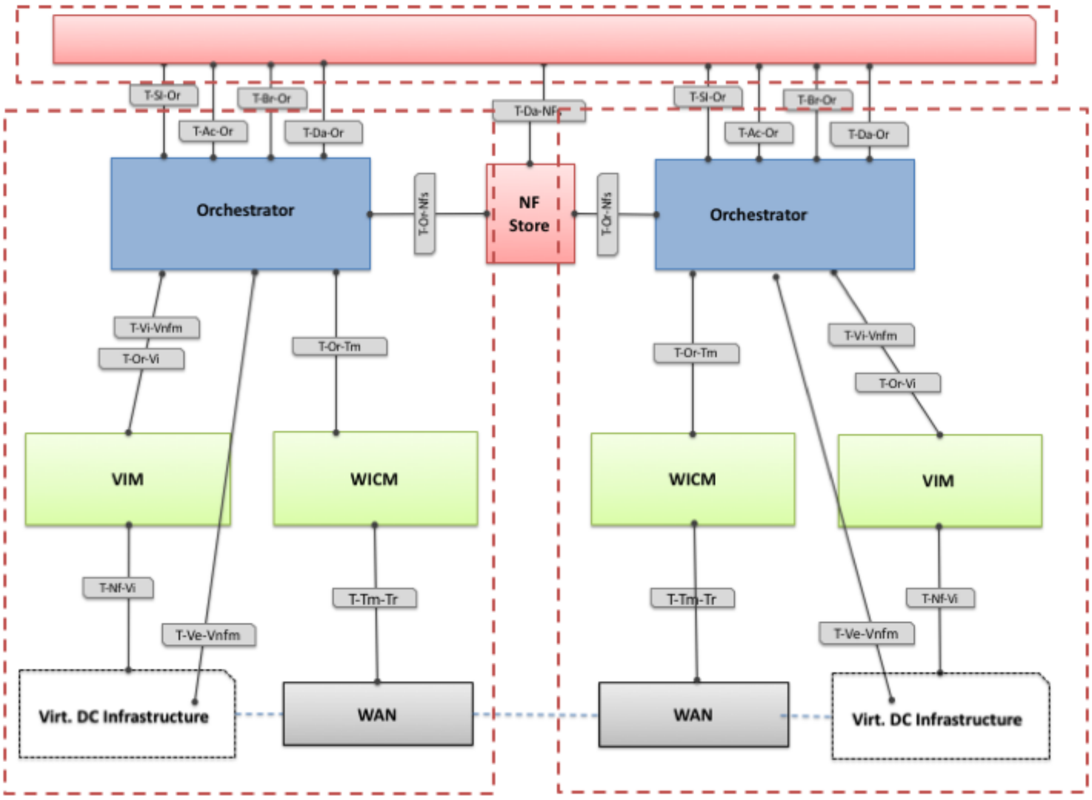

Figure 41. Architecture extension to support multiple SPs under a common broker

B.4. Multiple T-NOVA SPs (Orchestrator Federation)

This scenario comprehends the case where there are several vertically integrated service providers (i.e. two differentiated service providers, that are also capable of playing the broker role and thus they are capable of combining multiple applications into one sellable service). Typically, there would be no communication between the different service providers, since they are direct competitors.

However, in actual production environments, there are several business agreements between service providers. Those agreements respond to different business needs (e.g. increase service portfolio). In order to enable the service provider federation through the T-NOVA architecture, it is envisaged that a new interface shall be added between the corresponding orchestrator components *T-Or-Or*.

This new interface shall include all the information exchange procedures, as well as authentication and authorization between the different service providers.

Through this federation of service providers, the service offerings of each SP would be increased through the addition of new services that can be deployed through the functions of the other service provider in a transparent way.

- **Business value**: Increase the possibility of the T-NOVA to sell its services to the T-NOVA broker by means of utilizing resources from the federated SP
- **T-NOVA roles**: T-NOVA SP

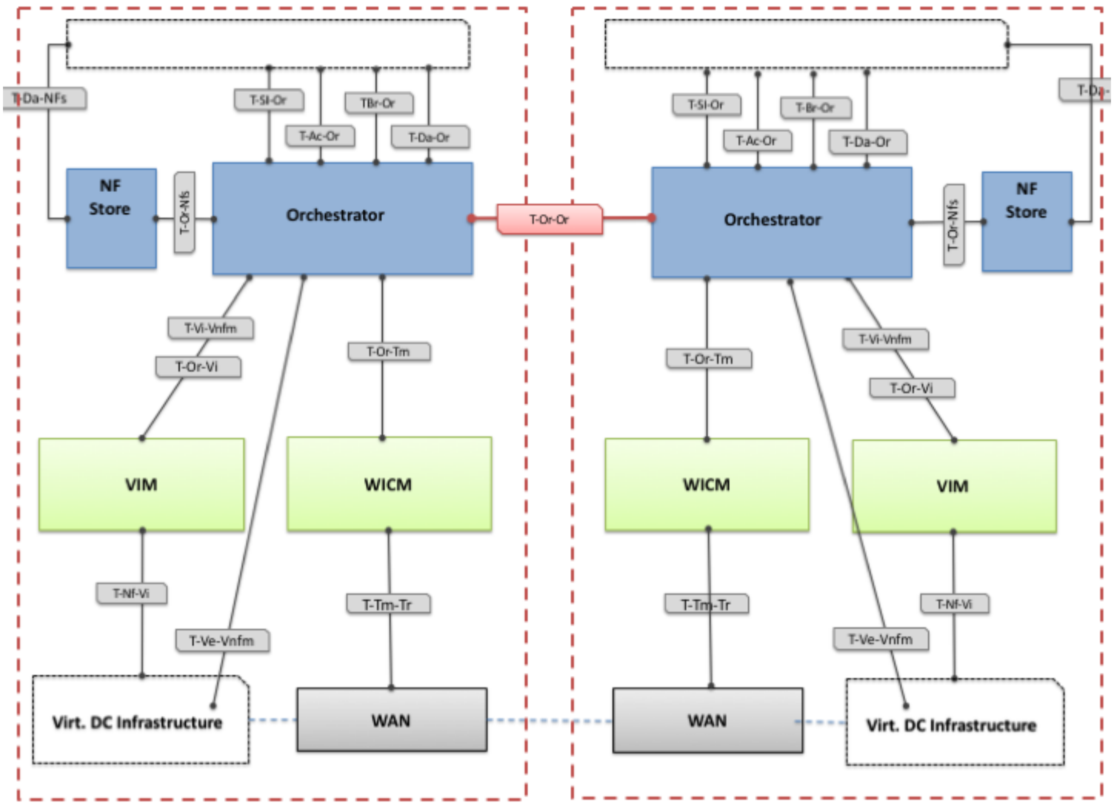

Figure 42. Architecture extension for SP federation

B.5. Multiple brokers over the same SP

This scenario corresponds to a situation where two or more independent brokers utilize the same SPs in order to offer the different services to the T-NOVA customers.

From the broker perspective, there is no change in their business operation. From the service provider perspective, it aims at maximizing theirrevenues by means of serving two or more (the maximum number of) brokers.

- **Business value**: T-NOVA SP revenues maximized by means of increasing the number of SP customers (i.e. T-NOVA broker)
- **T-NOVA roles**: T-NOVA broker, T-NOVA SP

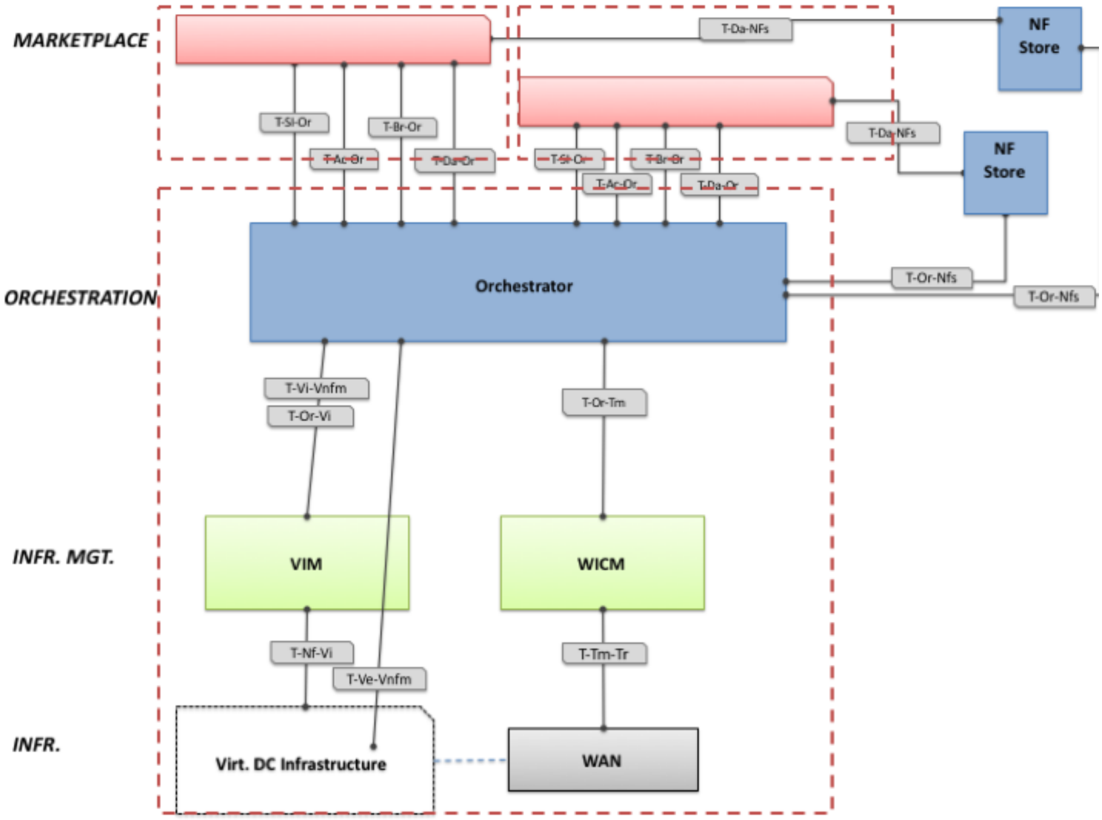

Figure 43. Architecture extension for multiple brokers under the same SP