POLITEHNICA UNIVERSITY OF BUCHAREST

Doctoral School of Electronics, Telecommunications and Information Technology

Decision No. 694 from 28-06-2021

Ph.D. THESIS SUMMARY

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CONTRIBUTIONS TO QUALITY OF SERVICE ASSURANCE IN 5G MULTI_DOMAIN SLICED NETWORKS THROUGH MANAGEMENT, ORCHESTRATION AND VIRTUALIZATION

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BUCHAREST 2021

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Chapter 1

Introduction

The cloud offers the chance to turn technology into a globally available utility, a dynamic asset that can automatically respond to demand spikes.With Cloud services actually evolved into a utility commodity, every company must now analyze the impact of Cloud and how it might help them gain a competitive advantage.

There is a demand of current applications for trafic management optimization, virtualization of shared resources and rapidly realtime network delivery. “This need has induced the conceptualization and adoption of new networking models, such as Software defined networking and (SDN) [1][2] and Network Functions Virtualization (NFV)[3][4].”

NFV promotes a decoupling between software and underlying hardware by implementing various network operations through software that were previously implemented by separate hardware and software.

Actual explorations in networking have started to concentrate on maximum usage of both SDN and NFV breakthrough technologies and their advantages.

However, because to the complexity of their connection and the variety of interconnected network parts involved, their inclusion poses certain difficulties. Their standardization is currently being researched, which complicates the execution of their complete framework and principles.[1]

5G mobile communications technologies are being acclaimed as a game-changing technology that can support a completely mobile and connected society by acting as a complete ecosystem. Design aspects for 5G architectures have been demonstrated [5][6].

The ability to slice the network is a powerful 5G capability. A controlled group of resources sub-sets, network functions/network virtual data functions at any place in

the world, control, management/orchestration, and service planes make up a Network Slice (NSL). A slice is a logical end-to-end network/cloud that operates on a shared underlying infrastructure (physical or virtual). Slices are separated from one another and can be handled and managed separately. Slices can be ordered or made to order.

The 5G network applications are mainly ultra-reliable and low latency communication (URLLC), enhanced mobile broadband (eMBB) and massive MTC (machine-type communication) and [7] and are implemented as special slices.

1.1 Thesis domain presentation

The main domain for this thesis is represented by focus on NFV technology and, moreover study and own contributions on two different NFV frameworks: „SONATA (Switchless Optical Network for Advanced Transport Architecture)”5Gtango and Open Source MANO (OSM) framework which are going to be studied and developed in the next chapters.

Based on these frameworks, the domain of the thesis concentrates mainly on the „Management and Orchestration (MANO) and Lifecycle Management and Integration (LCM)” and quality assurance of network slicing stacks for NFV. Following the text dedicated to challenges identifications the thesis develops personal contributions and experiments for VNFs, Network Services (NS) and service chains software configurations, concepts and tools.

Apart this, cloud computing, SDN and software modeling tools and systems in cloud are also included in the study.

1.2 Motivation of the thesis

The incentive of this thesis was first started from my professional background accompanied by interest in scientific research in NFV, virtualization and software in cloud computing.

Moreover, the opportunity to participate to an OSM hackfest [2019] and become a developer member in their community brought me the chance to work and contribute to bug fixes and new functionalities regarding charms in VNF.

1.3 Structure of the thesis

This thesis is organized as follows:

Chapter 2 „MANO-SONATA framework” presents the SONATA framework and its architecture and our **own contribution** to NFV experiments using this framework.

Chapter 3 „MANO-OSM framework” presents OSM and Openstack arhitecture and the main blocks used for the personal contribution on NFV, experiments using them.

Chapter 4 „Charms and Virtual Network Functions primitives” focuses on understanding charms and primitives and their roles in VNF construction.

Chapter 5 „Contributions to Quality of Service assurance in multi-domain network slicing through VNF and charms with OSM” focuses on **own solutions** for the purpose of testing and monitoring the network services quality in a network slicing scenario.

Chapter 6 „Conclusions” –summarizes the main lessons learnt within the Ph.D thesis activity and future possible developments.

Chapter 2

MANO Orchestration-ETSI and SONATA Framework

In this chapter ETSI MANO architectural framework is presented. Then, another NFV framework called „Switchless Optical Network for Advanced Transport Architecture” (SONATA) has been presented. This has been used at the beginning of my doctoral thesis. Also, a comparative view between SONATA and ETSI is offered and some experiments with SONATA are presented in this chapter.

2.1 Introduction to ETSI MANO/NFV Orchestration

In support of NFV administration and orchestration, ETSI has produced a reference architectural framework and specifications [8]. The framework is designed to help VNFs run across many hypervisors and computational resources.

In below Fig.2.1, the representation of the main „operational blocks of the ETSI NFV-Management and Orchestration (MANO)" is shown: [9]

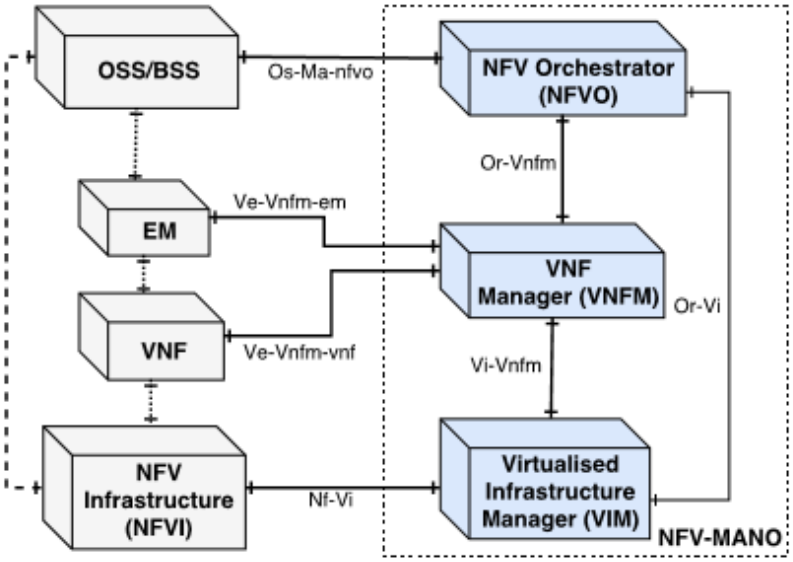


Fig.2. 1 *The NFV-MANO architectural framework [9]*

„Operation/ Business Support System (OSS/BSS):" handles with the supply and operation of service providers network services. Its integration is not complete in MANO arhitecture.

„Element Management (EM): component responsible for the traditional network management functions FCAPS (Fault, Configuration, Accounting, Performance, and Security) of a running VNF."

VNF: it is the operational part executed on a physical server and it represents the virtualization network function. For example, a firewall, a switch, a router etc. are examples of VNFs. Each individual VNF is associated with an EM.

„NFV Infrastructure (NFVI): representing all the hardware (compute, storage, and networking) and software components where VNFs are deployed, managed and executed."

MANO

„Network Function Virtualization Orchestrator (NFVO): it is the primary component, in charge of the orchestration of NFVI resources across multiple Virtual Infrastructure Managers (VIMs) and LCM of network services."

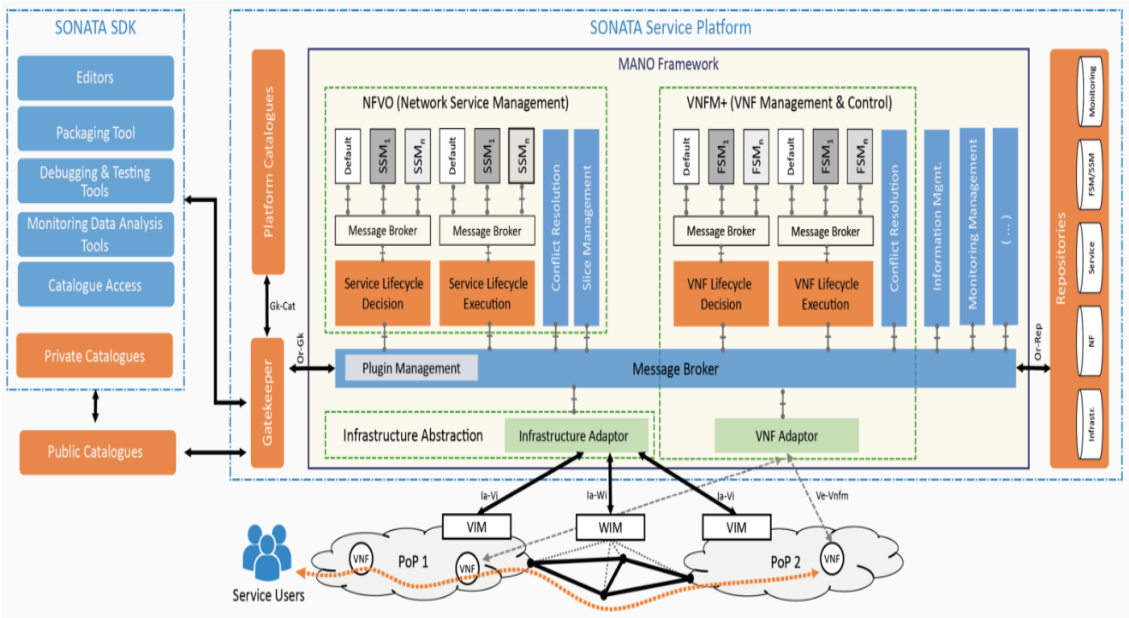
„VNF Manager (VNFM): performs configuration and VNF lifecycle management (e.g., instantiation, update, query, scaling, termination, migration) on its domain."Several VNF managers could exist in a particular system.

„VIM: block that provides controlling and managing the NFVI resources as well the interaction of a VNF with hardware resources. For example, OpenStack is a cloud platform and OpenDaylight and Open Network Operating System (ONOS) are SDN controllers."

2.2 SONATA Architecture

The SONATA framework is built on the ETSI NFV paradigm, but it includes extra instruments and tools to help developers reduce networked service time-to-market and NS costs.

As it can be seen in Fig.2.3, the general architecture of „SONATA framework contains the following components: Software Development Kit (SDK), the Service Platform (SP) and catalogues in which one can find different system artefacts."



SDK-Service Development Kit; SP- Service Platform; VIM- Virtual Infrastructure Management

Fig.2.2 *SONATA Framework [10]*

The source for the next paragraphs (2.2 and 2.3) is taken from [https://sonata-nfv.eu/content/sonata-project] in order not to reduce its scope and sense

„The SDK helps the third-party developers to create complex services composed of multiple VNFs, with a set of software tools and also supports service providers to deploy and manage their created NSs on multiple SONATA SPs."

„The Service Platform (SP) is responsible for management and control of network functions and services. It is a modular and customizable environment in which the platform operators can create specific platforms appropriate for their business model, by replacing components of MANO plugins."

„The Catalogues consist of network functions and services information like code, executables, configuration data and other requirements. These catalogues are divided into private, service platform and public catalogues".

2.3 SONATA Framework mapped to ETSI

VIM handles and manages virtualized resources (network, storage, and compute) in an operator's infrastructure domain in both SONATA and ETSI (NFVI-PoP). A VIM can manage one or more types of NFVI resources.

In comparison to the ETSI architecture, SONATA has a "gatekeeper component" that is responsible for evaluating the network services submitted into SP in the form of packages.

As a result, SONATA adds personal extensions and contributions to improve and speed up multiple tenancy assistance, as well as permit and authorize resource slicing. (see Fig.2.4)

In comparison to the ETSI model, SONATA introduces SDK as a new architectural component. With a collection of software tools, the SDK enables third-party developers to design sophisticated services made of several VNFs, as well as service providers to deploy and manage their generated NSs across multiple SONATA SPs.

SDK includes tools for generating network functions, simulating service trials, debugging and monitoring, and supporting DevOps network service operations.

2.4 NFV experiments using SONATA Framework

In this section several NFV experiments developed by the thesis' author are presented . Given the complexity of the SONATA framework, these experiments and own contribution have the primary objective to understand and proof the operability of various VNFs in different topologies using SONATA framework.

The experiments have been:

- **Virtual Firewall** - Main objectives (related to basic functionality) : create a virtual firewall which has the purpose to block the traffic between two hosts
- **Virtual Routers Graph Experiment**- Main objectives: create a small network of virtual routers which will forward traffic through a network graph between three hosts from three different subnets.
- Another experiment is to create a **network topology** whose purpose is to instantiate several VNFs with SONATA platform. These VNFs roles are : hosts, routers, firewall, proxy, http server - all virtual.

The tests above used the complex SONATA SDK framework to demonstrate the framework's true functionality and versatility. Some simple situations have been purposefully designed with the goal of highlighting and testing the main operability of the tools.

Chapter 3

MANO Orchestration- OSM framework

In this chapter, another orchestration framework, i.e., Open Source MANO (OSM) has been examined and exploited. The argument is that OSM integrates and contains the previous framework SONATA as a project but also as functionalities.

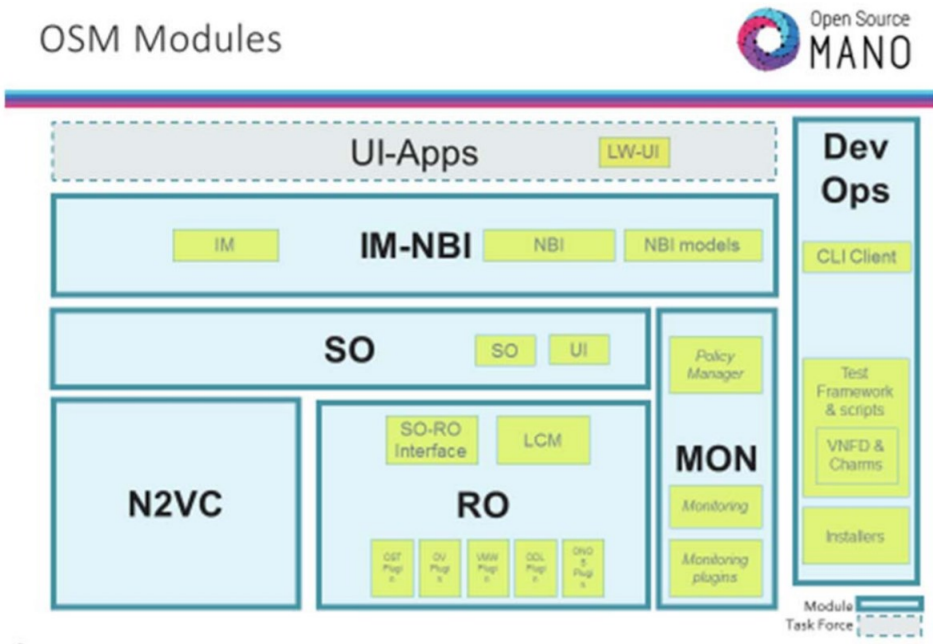
The general objectives of this chapter and group of experiments are:

- Description of the OSM architecture, understanding and installation of OSM framework
- Understanding and installation of Openstack
- Develop network services with OSM and Openstack platform

- Go deeper (by descriptor structure) into what means NFV along with VNF and NS examples and experiments.

3.1 Related Work -OSM high-level overview

From an arhitecture point of view, OSM is clearly a modular one(Fig.3.1) and has progressed gradually acquire cloud native design principals. An important feature for the OSM efficency and its community grow is the adaptive modularity of new functionalities.



***„Fig.3. 1** OSM Release Five Architecture Progression [12]"*

„N2VC- Network Service to VNF Communication"; „*RO*- Resource Orchestrator";

„MON- Monitoring"; „*Service Orchestrator* (SO) is responsible for end-to-end service orchestration and provisioning"; „*IM-NBI* - information model and northbound interface";

The information model and northbound interface are referred to as the IM-NBI.

The *Service Orchestrator (SO)* is used to orchestrate and deliver a service from beginning to end. In SO, the VNF description and the NS catalogs are reserved.

The *Resource Orchestrator (RO)* module can distribute networking services across many VIMs (VMware, OpenStack, OpenVIM, and so on). From ETSI MANO, these two components, SO and RO, can be identified as NFVO. [13]

The Network Service to VNF Communication (N2VC) Module is in charge of the VNF Configuration and Abstraction (VCA) layer's plugin framework.

The VNF Configuration and Abstraction (VCA) layer is in charge of allowing VNFs and/or Element Managers to send and receive configurations, actions, and notifications.

3.2 OSM Framework Architecture

Since there are many details about OSM framework and those are presented in the main thesis, at this subsection, the summary will contain pictures and information about OSM Architecture Release Five and Information Model VNFs and NSs.

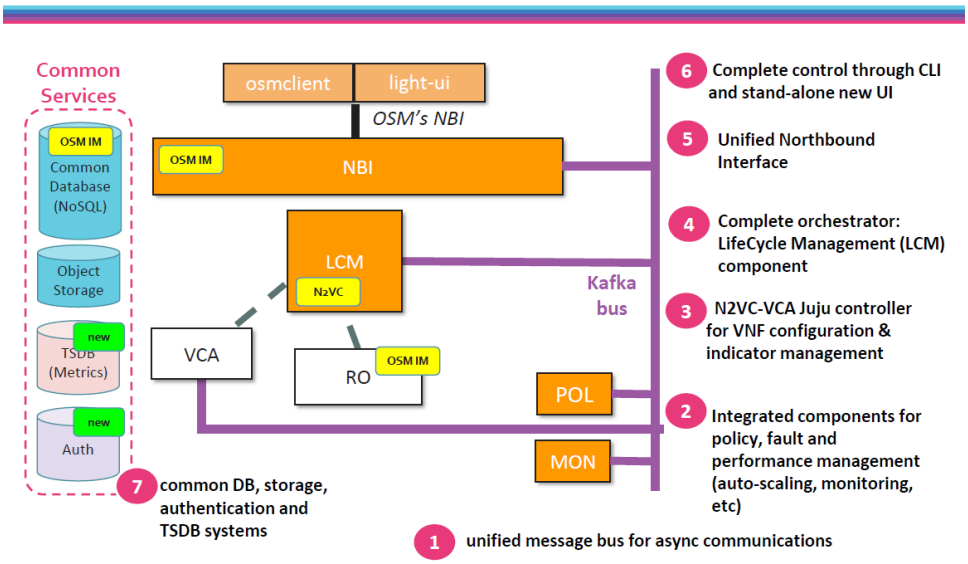
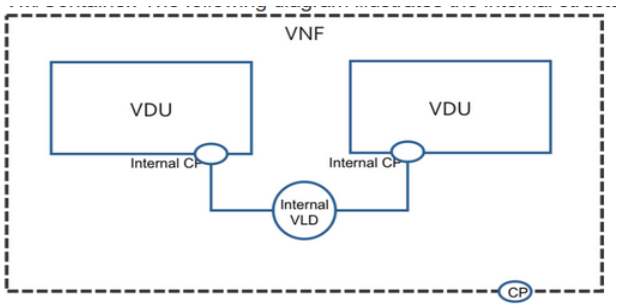


***Fig.3.2** OSM Architecture - Release Five [14]*

Because of its modularity and flexibility, OSM aims to reduce integration needs. A "well-known Information Model (IM) aligned with ETSI NFV is capable of modeling and automating the whole lifecycle of Network Functions" is included in this scope:

• VNFD (Virtual Network Function Descriptor) and VNFR (Virtual Network Function Record)

A VNF can be composed by several „Virtual Deployment Units (VDU)". „The VNFD connects (VDUs) using the internal Virtual Links (VLs)". Each VDU represents a VM/Container". The fig. 3.4 illustrates an example of a VNFD internal structure :



VDU- Virtual Descriptor Unit; *VLD*- Virtual Link Descriptor; *CP*- Connection point

Fig.3.3 *„Structure of a VNF represented in Virtual Network Function Descriptor- example" [14]*

NSD (Network Service Descriptor), NSR (Network Service Request) (Network Service Record)

The Network Service Descriptor [NSD] specifies a collection of interconnected VNFs that can be used to create a network service with numerous VNFs. In addition, as seen in fig.3.5, NSD additionally defines the NS-level configuration information.

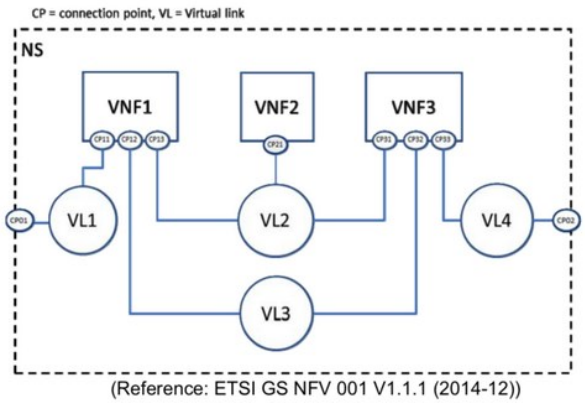


Fig.3.4 *Network Service Descriptor -example[14]*

3.3 NFV experiments using OSM framework

This section presents NFV experiments performed by the author, whose scope is to create different layouts in OSM and highlight the functionality of different VNFs and NS. These experiments have been realized at 5th OSM Hackfest, Barcelona Feb 4-8/2019 (a report have been offered to university as well, see Anexa 7). ***The***

contribution is personal but the servers and VIMs have been offered by OSM community during the hackfest.

The following objectives have been defined as targets :

- Installation of OSM Release Five
- Understanding and configuration of VIM accounts in Openstack
- Understand and create VNFs and NS
- Define Virtual Descriptor Unit (VDU) and multi-VDU in order to go deeper in the VNF configuration
- Create VNF/NS packages

Chapter 4

Charms and Virtual Network Functions Primitives

This section continues the work from Chapter 3 with a section on getting to know and dealing with VNFs, as well as instances of proxy charm and an example of an OSM issue bug and its resolution throughout charms.

The overall objectives of this study and set of experiments are:

- To achieve notions about what means Day0- fundamental intialization; Day1- service intialization and Day2- executable operations, all three needed for VNFs instantiation and management setup
- Understanding what VNF primitives and charms are and how are they integrated
- Develop and demonstrate an example of proxy charm with OSM

The main functional components used are:

- OSM, Openstack, Juju
- Images for VIM

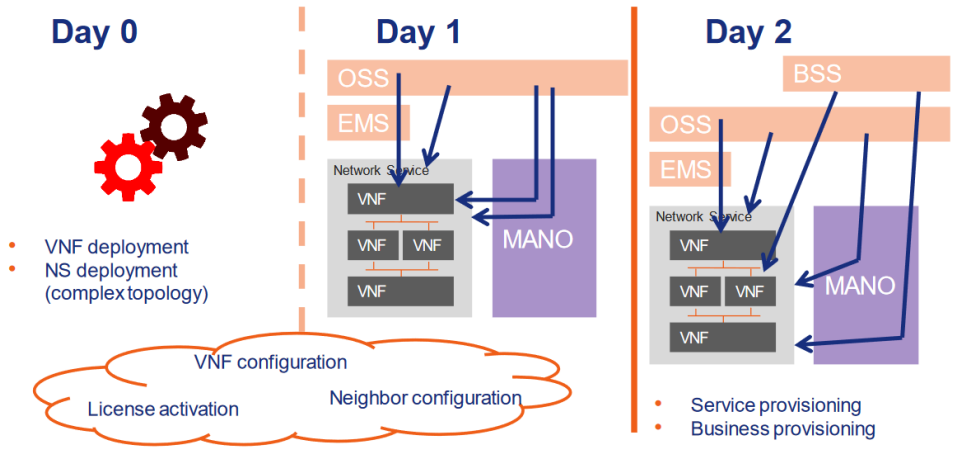
4.1 Related work and architecture

This subsection is dedicated for "day 0, day 1, day 2 „VNF constructs and configurations. In the same time, introduction to „VNF primitives and charms and also network slicing" is accomplished. All these components are part of OSM framework. (see Fig.4.1)

Day 0 is essential in order to take a good care of the arhitecture plan and the needed resources (CPUs, storage space, RAM).

The software that was drawn up in „Day-0" stage is developed and deployed in „Day-1". In „Day-1" step, the configuration of VNF needs to deliver the scheduled service it was meant for.

At Day 2, the software can start to grow consistent to the changes and the customer behaivour. Besides all of this, maintenance and support are also introduced.



*„**Fig.4.1** High Level Overview Day 0, 1, 2 VNF [15]"*

4.2 Juju, VNF primitives and Charms

A charm [16] is a piece of software that executes scripts against a set of targets. When charms are created with Juju, they are used either within an application or on the same system as the application.

Juju [16] a controller, models and charms and is speialized free tool in sense of elasticity model for operating software in the cloud.

Proxy charm is a concept that was borned in OSM to have a piece of software installed in a VNF: the charm runs in OSM, in LXD container and they connect to application with module remotely." (see fig.4.3)

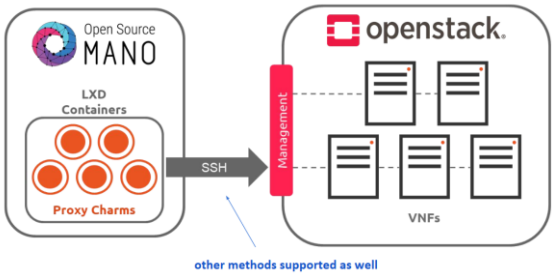


***Fig.4.2** „Proxy Charms in OSM" [16]*

4.3 Example of proxy charm for VNF

Among the steps from OSM Hackfest Barcelona, this section contains the thesis author's personal contributions.

This section demonstrates how to structure the VNF Package's necessary components for correct instantiation and management setup, so they may be used later in the process.

Being a member of OSM developer's team, I have noticed at some point a common bug regarding charm implementation. This is related to their workload status. Throughout their existance, charms can go through different states (like maintenance, active or blocked) either if it is specified from outside or not. Some issues or faults may emerge during the charm implementation process. The common issue noticed, based on what it was presented so far, is related to „ssh access from Day-1 stage". For this particular moment, there is important to have only „workload status active" and to exclude the rest ones which can randomly appear.

So, a python script has been developed with my contributuion in order to assure the „workload status is set to active only when SSH proxy is properly configured."

In figure 4.7 there is the personal contribution and the implemented script:

```python
from charmhelpers.core.hookenv import (
    action_get,
    action_fail,
    action_set,
    status_set,
)
from charms.reactive import (
    clear_flag,
    set_flag,
    when,
    when_not,
)
import charms.sshproxy


@when('sshproxy.configured')
@when_not('simple.installed')
def install_simple_proxy_charm():
    """Post-install actions.

    This function will run when two conditions are met:
    1. The 'sshproxy.configured' state is set
    2. The 'simple.installed' state is not set

    This ensures that the workload status is set to active only when the SSH
    proxy is properly configured.
    """
    set_flag('simple.installed')
    status_set('active', 'Ready!')


@when('actions.touch')
def touch():
    err = ''
    try:
        filename = action_get('filename')
        cmd = ['touch {}'.format(filename)]
        result, err = charms.sshproxy._run(cmd)
    except:
        action_fail('command failed:' + err)
    else:
        action_set({'output': result})
    finally:
        clear_flag('actions.touch')
```

Fig.4.3 *Fixed typo in simple proxy charm [17]*

Chapter 5

Testing and Monitoring QoS in proposed architecture service model network slicing

This chapter brings out the main scientific contributions based on how to test and monitor the quality of service (QoS) of network services or service chains in multi-domain network slices. A proposed arhitecture based on OSM and another trobleshoot platform is made. The software simulations are accomplished with charms and primitives and things which have been already presented in previous chapters.

The overall objectives of this chapter are:

- Present the network slicing in general and specific network slicing problems while using OSM framework
- Analyse the challenges of QoS perspective in network slicing
- Propose a scientific slice scenario along with a practical solution for the assurance of QoS.
- The functional components and tools used are the following:
- OSM, Openstack, VmWare, Juju
- „Infrastructure as a Service/Platform as a service (IaaS/PaaS) platform service" assurance solution
- „Charms –software written in Python"

5.1 "Concepts and use-cases in 5G network slicing"

Network slicing is a term used to describe how to divide and create multiple virtualized and logic networks over multi-domian infrastructures. A network slice can include certain services and applications. SDN and NFV are chosen to work together to conduct orchestration, administration, and control, as well as analytics and automationtools.

Network slicing can deliver radio, cloud, and networking resources to application providers and vertical segments that do not have physical network infrastructure. As a result, service differentiation is enabled by tailoring network operations to match the needs of customers based on the type of service. [18]

The main considerations that OSM implemented from ETSI NFV framework , in terms of network slicing are :

a. The possibility to do the network service composition inside a slice. This means a way to allocate to a neighbour slice several network services and that those network services will be connected inside the slice.

b. The second important thing is the concept of sharing NST (Network Slice Templates). This sharing has aspirations for realization of resource and connecting different slices

In terms of deployment, here are the main steps:

- every slice is built as a group of network services connected by networks or Virtual Links Descriptors (VLDs)

- the classification of slice built by request is determined with simple input parameters
- to fullfill the NST requirements, VNFD and NSD are needed (details can be found at 5.3.1)
- before the netslice instantiation, the VNF and NS packages need to be added
- creation of a NSI

OSM, in terms of day-2 primitives at network slice level, outline them to NS and VNF primitives.

5.2 Quality of Service assurance perspective and its challenges in Network Slicing

This section is intended to introduce general concepts of „Quality of service (QoS) and Quality of Experience (QoE) in 5G network slicing" and also challanges which may appear in their implementation for customer satisfaction. It is an own brief description made from research of actual papers on this subject, as well as specific projects: SliceNet, SONATA/5GTANGO, 5GNORMA and OSM.

5G networks must have the following QoS capabilities [19] to meet the demands of complicated QoS of various applications and services:

- Past QoS-related events may be automatically and accurately reconstructed;
- Current QoS-related events may be accurately identified to trigger automatic mitigation or proposed immediate actions; and
  Future QoS-related events may be accurately predicted.

5.3 Contribution for testing and monitoring QoS in a service model network slicing

In this section, it is made a brief analisation and comparation of active and passive monitoring methods in a network.

Based on this, the main idea of this thesis is to show an example of a live testing and monitoring for specific KPIs from a service model slicing scenario.

Furthermore, the suggested example demonstrates how NS testing can be automated in live environments. As it will be presented next, virtual code monitoring and testing can be done and introduced in network slicing through charms that are orchestrated by OSM MANO to capture KPIs specific for various service chains, with help of virtual charm factors. (vCF) Is called virtual because it can be configured in/as/or attached to a VNF/NS and is software code through the charms.

5.3.1 Proposed architecture

The old fashioned ways so far in terms of ongoing life of services supervision is to fetch data from the infrastructure, from routers, switches etc and transfer them into a big data plane, but not all the way is reached. A service can be tested and monitored end-to-end from a service chain using the suggested architecture, as shown in Figure 5.9. The goal is to show how NS testing may be organized and automated in dynamic contexts.

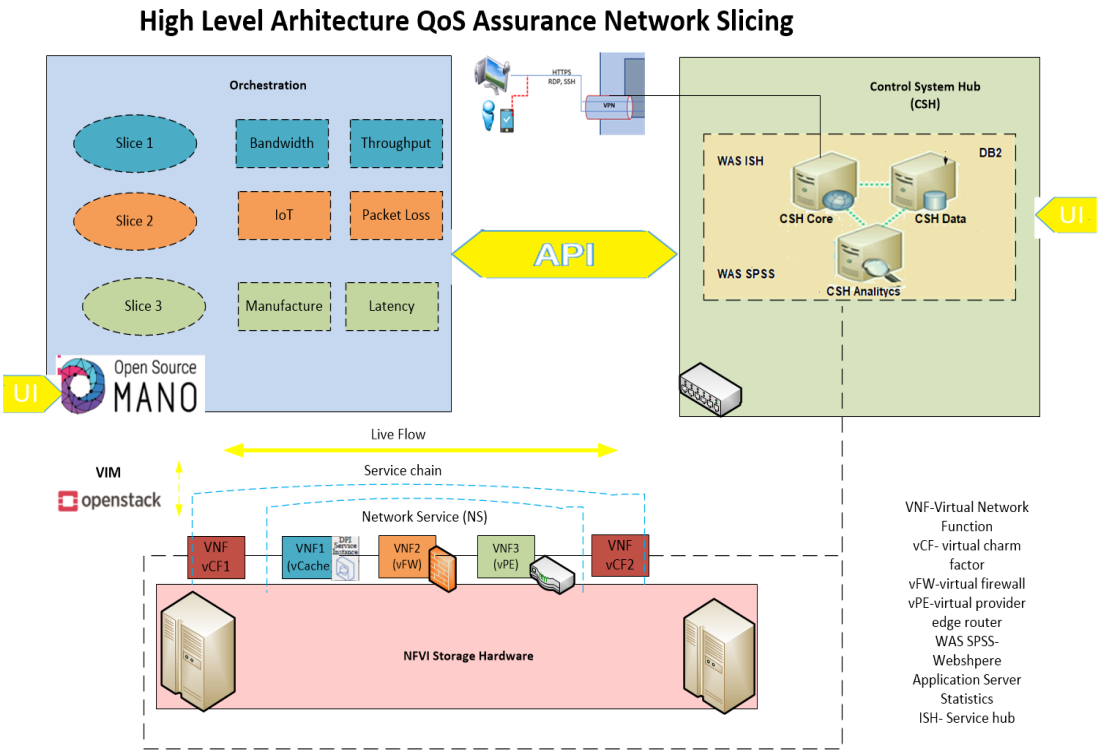


Fig.5.1 *High Level Arhitecture QoS Assurance Network Slicing*

This arhitecture is my proposal

From a high-level perspective, the proposed slicing scenario arhitecture consists of the following parts:

- *OSM* is doing the orchestration , it will deploy the VNFs, NS , service chain and slices, including the test agents.
- *Control System Hub (CSH)* is the platform responsible with the coordination of the vCFs and interacts with the orchestrators through API. It offers also the automation workflows
- *Openstack used as VIM* builds up interoperation between components

In the slicing scenario there are three different slices for different types of services:

- *Bandwidth-dedicated slice* is meant for residential subscribers. Throughput is the KPI for SLA assurance. In a real scenario, a vCache VNF is suitable for it.
- *IoT*- dedicated slice use case demands low packet loss. A virtual firewall (vFW) has been chosen as suitable for VNF
- *Manufacture*-dedicated slice usually wants *low latency.*

The focus of the arhitecture is not on how or why these slices have been chosen (these can be consider experimental, based on the actual customer requests in context of 5G and network slicing), „*but how to monitor constantly traffic during normal network usage so network quality issues could be tracked and reported dynamic"*. This is achieved with the inovation vCF which is basically an active VNF and acts like a virtual test agent; (see Figure 5.10):

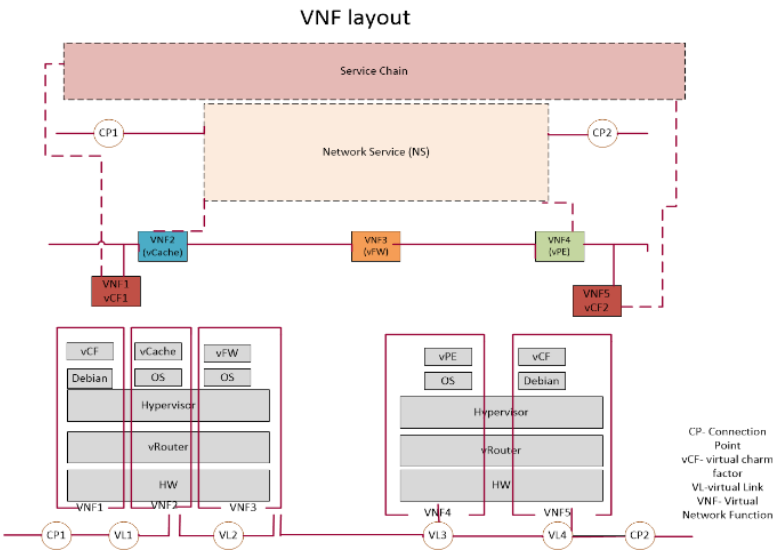


Fig.5.2 *Service Chain and VNFs Layout*

1. **Blueprint/Pattern items- VNFDs** (at OSM)
2. **Blueprint/Pattern items-NSD** (at OSM)
3. **Blueprint activation test templates** (at CSH)
4. **Instantiation of NS and network slices**
5. **Start the VNF and test agents and connect them into service chain**
6. **Call back home to CSH and put them into inventory**
7. **Run trigger from initial accounting primitive for activation of a test service**
8. **KPI fetched to OSM in real time-Figure 5.15**

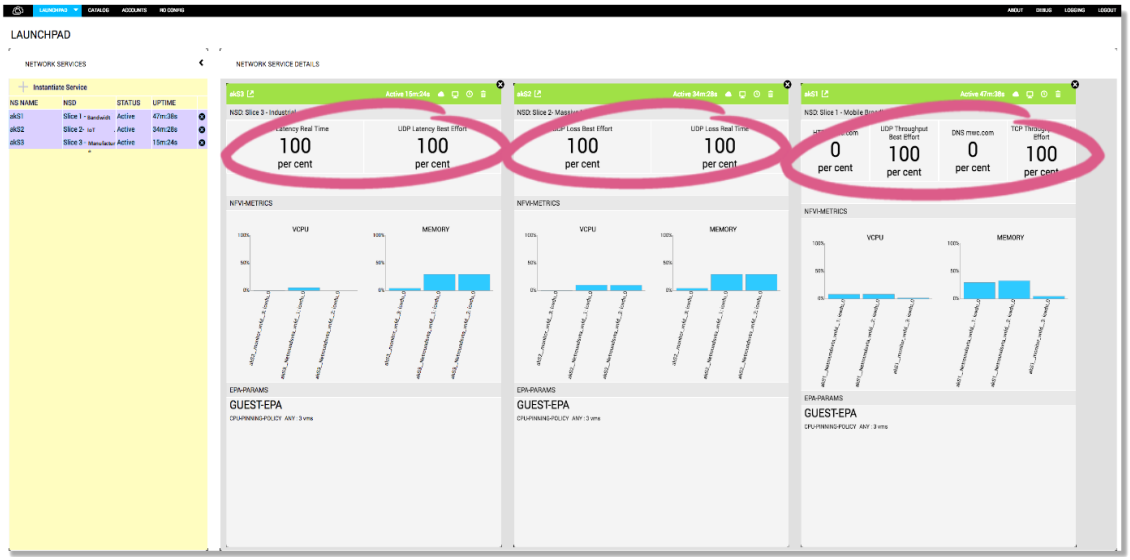


Fig.5.3 *Real-Time SLAs*

Corresponding slices are being monitored 24/7 so what it can be seen here, the green thing is real-time , the slices are monitored continuously and the granularity is of 10 seconds.

CSH is calculating errors in seconds.- if any of the thresholds specified are violated, those will be detected and reflected back to OSM so OSM will take action for either redeploying or taking action to that specific slice.

5.3.2 Platforms used for the proposed architecture

For the **NFVI Storage Hardware**, servers from IBM have been used.For the **VIM** part, Openstack has been used to be the cloud computing part of the architecture. Another important part from VIM is the network.The **physical network** consists of physical switch configured and also a gateway firewall appliance- Vyatta

Brocade which acts as a router as well as a firewall in order to take control of all physical traffic inside datacenter and between both datacenters (OSM and CSH) as well. For the **virtual network**, Standard switch feature in VMware vCenter has been chosen. This is a network of virtual machines that run on a single physical system and are logically connected so that they can transmit and receive data from one another.

Besides this, Domain Name System (DNS) and Domain Controller virtual servers have been configured as well in VIM inside a Virtual Machine (VM) with Windows Server 2018 ISO. These roles are necessary in order for all the VMs, VNFs and vCFs to be able to communicate with each other.

For **OSM** part, besides the design and configuration of VNFDs, NSDs and network slices (already presented in 5.3.1), another important part which OSM is responsible of, is **the instantiation**.

CSH platform contains tipically three servers: the Data, Core, and Analytics components. At the Core part, the main component consists of IBM® WebSphere® Application Server ISH (Service hub) which serves applications from the front office to the back office. CSH Analitycs is the place where traffic for vCFs is generated. It has IBM SPSS Analytics client software for in-depth data exploration, reporting and modeling.

In CSH Data there are info stored about templates of vCFs and also it stores the reports of monitoring which can be send to customers.

After every slice is instantiated and goes through the activation test, OSM demands CSH to instaurate ongoing live service monitoring (see Figure 5.21).The vCFs triggers traffic to the service chain to certify SLA in genuine term. In order to capture the KPIs , a key characteristic is to insert vCFs but also in various locations in the traffic path.

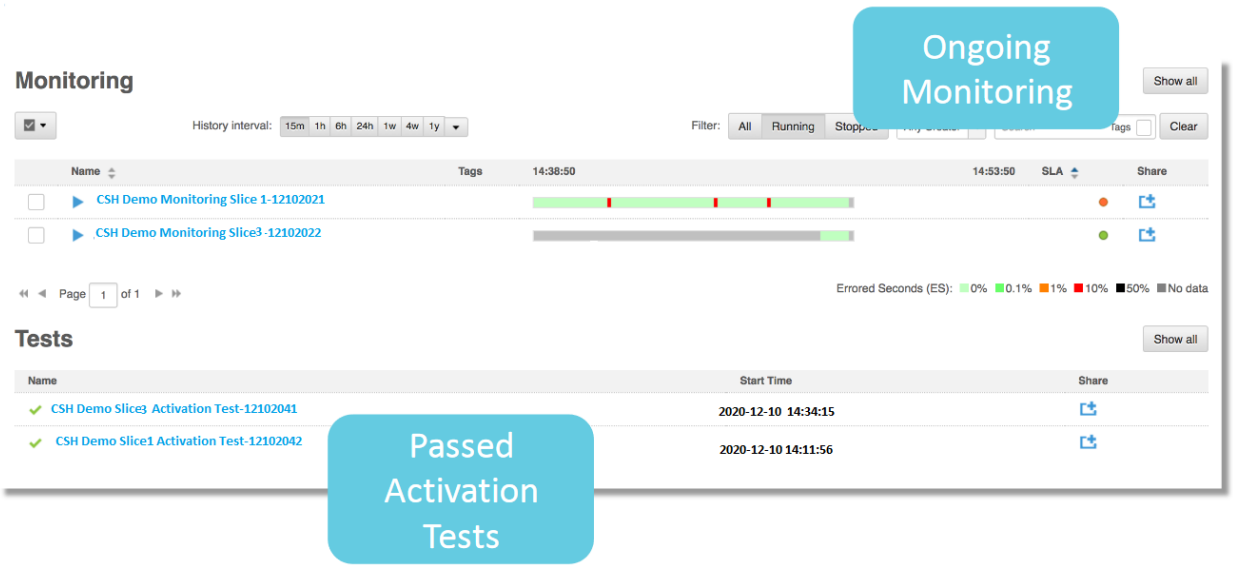


Fig.5.4 *CSH Test and Monitoring*

Chapter 6

Conclusions

NFV approach is generally focused on VNF management and health from resource point of view, this intend thesis exhibit the necesity for a quality test of the NS overall.

Life and active tests are a proper answer for this, with the integration of vCFs. They can detect earlier cases related on how to get insight of quality assurance from end-users'view and appreciate which parts of network are affected.

Demonstration tests can be performed based on firewall rules, latency, throughput, QoS priority etc. The vCFs have the capability to be versatil, they can be placed at the basic OS levels, hypervisors, VNFD, NSD designs or the entire end-to-end service chain path.

The actual work thesis present three different network slices with different QoS settings and demonstrates how active monitoring and testing contributes at the delivery of a right slice QoS for customers.

6.1 Obtained Results

Chapter 1, Introduction presents thesis, its motivation and structure.The domain of the thesis concentrates very much on MANO, LCM and quality assurance of network slicing stacks for NFV, developing personal experiments and contribution to VNFs, Network Services (NS) and service chains software configurations, concepts and tools. The used frameworks are SONATA 5Gtango and OSM.

In chapter 2, ETSI MANO, SONATA arhitecture and their relational aspects have been debated. Own contributions to NFV experiments using this framework were presented (see 6.2)

Chapter 3 has been completely allocated for OSM: high-level overview, arhitecture and experiments made at OSM hackest.

Chapter 4 results are based on VNF primitives and charms. There is also an example of proxy charm with an own bug fix code contribution. (see 6.2)

Chapter 5 is entirely the work of the author both from theoretical and practical approaches. The main focus is based on network slicing and the challanges which can appear at the customers satisfaction from quality of services level assurance perspective. Due to this, an own QoS network slicing scenarion and arhitecture has been proposed, along with own contribution for testing and monitoring platforms to help both SPs and customers fullfill the service requirments. (see 6.2)

Chapter 6 is allocated for conslusions and future perspective.

6.2 Original contributions

1. Parallel between the architecture of SONATA framework and ETSI NFV model.
   Contributions can be found in: Chapter 2.3 Publications: [1-COMM18]
2. „Virtual Firewall Experiment which has the purpose to block the traffic between two hosts. The purpose is to test the functionality of different VNFs in various topologies using SONATA framework. These topologies are represented as custom emulated networks which use Docker containers as compute instances to run VNFs.”
   Contributions can be found in: Chapter 2.4 Publications: [2-SOFT18]
3. „Virtual Routers Graph Experiment .Main objectives: create a small network of virtual routers which will forward traffic through a network graph between three hosts from three different subnets.”
   Contributions can be found in: Chapter 2.4 Publications: [2-SOFT18]
4. „Another experiment is a network topology whose purpose is to instantiate VNFs with SONATA platform. These VNFs roles are : hosts, routers, firewall, proxy, http server, all virtual. The tests have successfully proved that the access to http server through proxy server worked without a known route and also that firewall filtered the inbound traffic to proxy by blocking a certain network.”
   Contributions can be found in: Chapter 2.4 Publications: [1-COMM18]
5. Comparative view between SONATA framework and ETSI model.
   Contributions can be found in: Chapter 2.4 Publications: [1-COMM18]

6. Related work, short parallel between SONATA and OSM and a study of the actual use cases of OSM. This part was necessary to integrate OSM in the infrastructure and experiments.
   Contributions can be found in: Chapter 3.1 Publications: [3-IARIA ICN20]
7. „NFV experiments whose purpose is to test the functionality of different VNFs in various topologies using OSM framework. These experiments have been realized at 5th OSM Hackfest, Barcelona Feb 4-8/2019 (a report have been offered to university as well). The contribution of the work is personal but the servers,VIMs and workflow steps have been offered by OSM community during the hackfest."
   Contributions can be found in: Chapter 3.3 Tehnical project report: [A.7 OSM Hackfest19]
8. „Selective view on VNF primitives and charms, all of them integrated with OSM . Own contribution: develop a python script in order to ensure that the workload status is set to active only when SSH proxy is properly configured."
   Contributions can be found in: Chapter 4.2 Publications: [4-IARIA AICT20]
9. Debate the challanges of QoS perspective in network slicing thorugh a brief analisation and comparation for QoS and QoE is going to be presented, based on specific projects.
   Contributions can be found in: Chapter 5.2 Publications: [ScientificBuletin]
10. High Level Arhitecture QoS Assurance Network Slicing
    Contributions can be found in: Chapter 5.3.1 Publications: [ScientificBuletin]

11. Platforms used for the porposed arhitecture and network configuration.
    Contributions can be found in: Chapter 5.3.2 Publications: [BlackSeeConf]
12. Software code detailed
    Contributions can be found in: Chapter 5.3.3 and Anexa 6

6.3 List of original publications

1. „***A. Țapu***, C. Conțu, E. Borcoci**,** ***Multiple Chained Virtual Network Functions Experiments with SONATA Emulator***, The Twelfth International Conference on Communications COMM 2018”

   Published in: 2018 International Conference on Communications (COMM)

   Date of Conference: 14-16 June 2018

   Date Added to IEEE Xplore: 08 October 2018

   ISBN Information:

   Electronic ISBN:978-1-5386-2350-3

   USB ISBN:978-1-5386-2349-7

   Print on Demand(PoD) ISBN:978-1-5386-2351-0

   DOI: 10.1109/ICComm.2018.8484762

   Publisher and Indexed in : IEEE BDI Conference

   Conference Location: Bucharest, Romania

   ISI Web of Science Number: WOS:000449526000053 ISBN:978-1-5386-2350-3, I SSN: 1550-3607

2. „***A. Țapu***, C. Conțu, E. Borcoci, ***Network Function Virtualization Experiments using SONATA Framework***, The International Symposium on Advances in Software Defined Networking and Network Functions Virtualization SOFTNETWORKING 2018”

   Published in: ICN 2018, The Seventeenth International Conference on Networks

   April 22, 2018 to April 26, 2018 - Athens, Greece ISBN: 978-1-61208-625-5

   https://www.iaria.org/conferences2018/ProgramICN18.html

   awarded paper

   https://www.iaria.org/conferences2018/awardsICN18/icn2018_a5.pdf

   Also published in Journal

   https://www.iariajournals.org/networks_and_services/tocv11n34.html

3. C.Conțu, ***A.Ciobanu*** E.Borcoci, „***Virtual Network Function Use Cases Implemented on SONATA Framework***”, - extension of paper4 no.2,

International Journal on Advances in Networks and Servicesis published by IARIA.ISSN:1942-2644 journals site: http://www.iariajournals.org vol. 11, 2018, No. 3&4, pages: 103-112,

https://www.iariajournals.org/networks_and_services/netser_v11_n34_2018_paged.pdf

4. „***Andra Ciobanu***, Cosmin Contu, Eugen Borcoci "***Study on Use-Cases of Open Source Management and Orchestration Framework in 5G Projects***"- 2020 - The Nineteenth

   International Conference on Networks"

   Published in: **ICN 2020, The Nineteenth International Conference on Networks**

   February 23, 2020 to February 27, 2020 - Lisbon, Portugal

   ISBN: 978-1-61208-770-2

   - awarded paper: http://www.iaria.org/conferences2020/AwardsICN20.html

   http://www.thinkmind.org › *icn_2020_2_30_38009*

5. „***Andra Ciobanu***, Cosmin Contu, Eugen Borcoci "***Charms and Virtual Network Functions primitives Experiments using Open Source MANO framework***" - the Sixteenth Advanced International Conference on Telecommunication"

   Published in: AICT 2020, The Sixteenth Advanced International Conference on Telecommunications

   https://www.semanticscholar.org/paper/Charms-and-Virtual-Network-Functions-Primitives-Ciobanu-Borcoci/3580ef2158b5dbcfe054f4b1ea9b0515a23a3c0a

   http://www.thinkmind.org/index.php?view=article&articleid=aict_2020_1_20_10029

   awarded paper https://www.iaria.org/conferences2020/AwardsAICT20.html

6. Eugen Borcoci, ***Andra Ciobanu***, Cosmin Contu , ***"Layered Network Domain Resource Management in Multi-domain 5G Slicing Environment"***, ADVANCED INFORMATION AND COMMUNICATION TECHNOLOGIES-2019

Published in: www.aict.info/2019 AICT 2019 : The Fifteenth Advanced International Conference on Telecommunications

https://www.thinkmind.org › articles › aict_2019_...
https://www.semanticscholar.org/paper/Layered-Network-Domain-Resource-Management-in-5G-Borcoci-Ciobanu/0da977fb068d96c5bdc0b689b6b34e454abf6083

7. *E.Borcoci, C.Contu,* ***A.Ciobanu*** *„**5G Slicing Management and Orchestration Architectures - Any Convergence?**”*, The Eleventh International Conference on Advances in Future Internet AFIN 2019, October 27, 2019 to October 31, 2019 - Nice, France, https://www.iaria.org/conferences2019/AFIN19.html

8. Eugen Borcoci, Cosmin Contu, ***Andra Ciobanu*** " ***On Heterogeneity of Management and Orchestration Functional Architectures in 5G Slicing***, IARIA 2019"

   Published in: International Journal on Advances in Internet Technology, vol 13 no 1 & 2, year 2020, **http://www.iariajournals.org/internet_technology/**

   Paper Invited for IARIA Journals

   https://www.iaria.org/conferences2019/AwardsAICT19.html

9. E.Borcoci, C.Contu, **A.Ciobanu**, *extension of the Paper no.8*, "On Heterogeneity of Management and Orchestration Functional Architectures in 5G Slicing", International Journal On Advances in Internet Technology, **vol 13, no 1&2, year 2020,** http://www.iariajournals.org/internet_technology/tocv13n12.html

10. **Andra Ciobanu**, Eugen Borcoci, Marius Vochin ***„SCENARIO FOR OPTIMUM SERVICES POSITION WITH CONTROL SYSTEM HUB AND OPEN SOURCE MANO IN EDGE COMPUTING***”, Scientific Buletin 2021

Accepted and In course of Publishing:

http://www.scientificbulletin.upb.ro/openconf/data/fromreviewer/14505.pdf

Submission Number 11125

Indexed in ISI and SCOPUS

11. **Andra Ciobanu**, Eugen Borcoci, Marius Vochin, **„A Quality-of-Service Scenario Awareness for Use-Cases of Open-Source Management and Control System Hub in Edge Computing**”, BlackSee Conference 2021

Published in: https://www.academia.edu/49040476/A_Quality_of_Service_Scenario_Awareness_for_Use_Cases_of_Open_Source_Management_and_Control_System_Hub_in_Edge_Computing

Indexed in: IEEE BDI Conference

12. Pantelimon-Teodor Tivig, Eugen Borcoci, Alexandru Brumaru, **Andra-Isabela-Elena Ciobanu**, „***Layer 3 Forwarder Application - Implementation Experiments Based on Ryu SDN Controller***", IEEE ISNCC Dubai Conference 2021

Accepted, waiting for publishing: https://www.isncc-conf.org/ International Symposium on Networks, Computers and Communications Dubai 2021

Indexed in: IEEE BDI

13. ***Andra-Isabela-Elena Ciobanu***, Cosmin Contu, Eugen Borcoci, Marius-Constantin Vochin, Frank Y.Li, ***„Optimal Service Placement with QoS Monitoring in NFV and Slicing Enabled 5G IoT Networks"***, Globecom GC 2021 Workshop IoST5G&B

Submitted July 2021 – waiting for acceptance : Indexed in: IEEE BDI

14. Eugen Borcoci, ***Andra Tapu***, Cosmin Contu, ***"D1.2 Virtual Evolved Packet Core"***, ORANGE- Romania – UPB cooperation project "5G Technologies", 2018

PhD Scientific Research Reports

A.Ciobanu, „Virtualization methods for network,systems and servers in cloud", Ph.D Scientific Research Report 1 (unpublished), University Politehnica of Bucharest, Romania, April 2017

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List of Projects

Colaboration from UPB with Orange Romania in project called „SLICENET:End-to-End Cognitive Network Slicing and Slice Management Framework in Virtualised Multi-Domain, Multi-Tenant 5G Networks” , February-May 2018

„A Massive MIMO Enabled IoT Platform with Networking Slicing for Beyond 5G IoV/V2X and Maritime Services”, November 2020-ongoing

6.4 Future objectives

The last project mentioned above is the ongoing and future work on the same area of network slicing. The intention is to bring out contributions until the end of this project and participate also to other opportunities. The area of interest will be kept on NFV, SDN, cloud computing but also on tangential modern and new technologies.

From academic perspective, the possibility to enter the teaching staff hierarchy is taken into account as well.

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