Symmetric redundancy of network functions and services on virtualized network infrastructures

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Abstract

The traditional way of implementing network functions and network services does not make use of the flexibility, adaptability and interoperability offered by virtualized network infrastructures. Using these infrastructures, it is possible to scale network solutions better, because the resources are being used in the most efficient way possible by virtualizing the required resources. The technologies, tools and products associated with it can now, be a type of service and therefore automated using e.g. a data serialization language like YAML. Considering these developments, the ETSI elaborated an architectural framework, called ETSI MANO, which is used as a reference model for the creation of software that does the orchestration and management of virtualized network functions and network services. This architectural framework has three major components, the NFVO, the VNFM and the VIM that are essential for the management and operation of virtualized network functions and services systems. In this dissertation, an analysis and study of the technologies associated with the three major components of the ETSI MANO architectural framework are performed. Based on the study and analysis done, a symmetric redundant network functions and services system is built on a virtualized network infrastructure. For testing the system, it is deployed a VNF load balancer and two sites, where each site has two web servers.

Keywords: VNFs, NSs, orchestration, management. ETSI NFV framework.

1. Introduction

The network infrastructures were only present in a "bare metal" from not long ago, while nowadays it is shifting to virtualized network infrastructures. The growing of these infrastructures is mainly due to their flexibility, adaptability and interoperability properties. The widespread age of "Cloud" models and virtualization contributes to be a standard when using the Internet. This project aims to study and test the technologies that exist for the orchestration and management of virtual network functions and services in a virtual network infrastructure environment using the solutions that are based on the ETSI MANO architectural framework [1]. This dissertation aims to analyse these solutions, and research simple scenarios where they will be tested in a simple network architecture solution. The design of traditional network infrastructures in the past was benchmarked for the minimal loss of latency, availability, throughput and the capacity to carry data, resulting in hardware and software that were developed and optimized using the criteria's described before. With the increase of complexity and bandwidth usage on technologies such as streaming platforms, Internet of Things or by smartphones, there was a need to scale and expand the existing network infrastructure without increasing the costs too much. Unfortunately, the traditional infrastructure solution posed various bottlenecks in terms of hardware and software bringing companies and developers to find ways of removing those bottlenecks. This led to the concepts of virtualized network infrastructures and virtualized network functions. Having a VNF system fully customizable and define how the VNF system behaves, can be achieved using the ETSI MANO architectural framework. The ETSI MANO architectural framework is the reference framework that companies, developers and users adopted to develop solutions for their needs in this constant changeable world of virtualized network infrastructures. This dissertation describes and analyses the desired skills that are needed to learn more about the optimization of VNF deployment, orchestration and management on virtualized network infrastructures environments. The main goals of this dissertation are to research the technologies, products and tools used on virtualized network infrastructures, and how the VNFs instantiation is done in the present and what is the near future for VNF management and orchestration on virtualized network infrastructures. For this, a virtualized network infrastructure is deployed to test the most documented and developed VNF placement technology that is low on resource utilization, reliable, secure and is part or fully automatable considering the available hardware at the time of implementation of the system solution. Several virtualization and high virtualization models (containers and virtual machine) are analysed, tested and compared.

2. State of the art

The limitations of network infrastructures such as flexibility, scalability, manageability and interoperability limitations makes companies and developers design new software and hardware that defines how the virtualized network infrastructures are deployed and configured to support the use of **virtual network functions and services**. This brings new challenges such as multivendor implementations of VNFs, managing, monitoring and configuring the life cycles and interactions of VNFs, as well the hardware resource allocations of VNFs and the interaction with the billing and operational support systems. Those challenges lead for the creation of an architectural framework also known as the ETSI NFV architectural framework, which defines a reference model for virtual network functions and services that are orchestrated and managed on a virtualized network infrastructure.

2.1. ETSI NFV architectural framework

The European telecommunications standards institute network functions virtualization architectural framework is based on a complete separation of hardware and software criteria, where network functions deployment must be automated and scalable and the control of the network functions operational parameters is done by monitoring and controlling the state of the network [2]. This framework is structured by three high level blocks such as the VNFs, the NFVI and the NFV MANO blocks. The NFVI block is the foundation for this architectural framework where it offers the hardware and software responsible for the virtualization process of the virtual instances. The VNFs block uses the resources of the NFVI block to develop software that implements virtualized network functions and services. The NFV MANO block is on its own a separate architectural framework that is responsible for the orchestration and management of the VNFs and NSs resources. The NFV MANO block is also called the ETSI MANO architectural framework where it is a reference model to developers to create software to manage and orchestrate VNFs and NSs. The next sections and subsections describe in a more detailed manner the ETSI MANO architectural framework and all the relevant technologies that are used nowadays to accomplish what the ETSI MANO architectural framework proposes.

2.2. ETSI MANO block

The ETSI MANO block decouples computation, storage and networking from the software that implements NFs by creating new entities such as, the VNFs, NFVI, PNFs, NSs, VNFFGs and VLs. The ETSI MANO architectural framework is responsible for managing the NFVI and orchestrate the resources for the NFs and VNFs. The resources that are considered are mainly CPU, memory, network components (subnets, ports, etc.) and storage. With this, it is important to define VNFs management functions based on operations such as the, instantiation, scaling, updating or upgrading and terminating of VNFs or NSs. These operations are accomplished by the creation of template files that use a template language such as TOSCA which is described in more detail in the following subsection. The ETSI MANO architectural framework architecture is presented in the figure below:

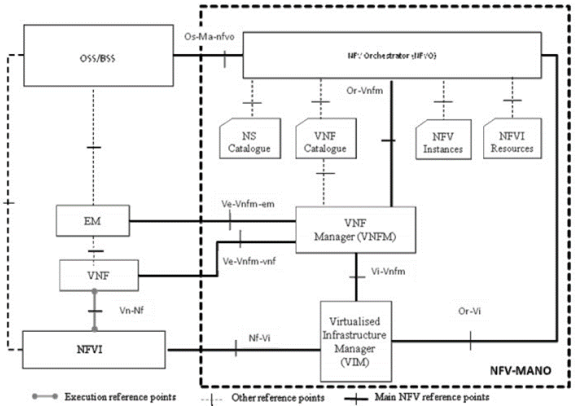

Figure *1*: ETSI MANO framework

Resourced from [1]

The main blocks of the ETSI MANO architecture are the NFVO responsible for the resources allocated to the VIM and the lifecycle management of the NSs, the VNFM responsible for the lifecycle management of the VNF instances, where it can manage only a VNF instance or multiple VNF instances, the VIM responsible for the management and control of the NFVI in terms of the network, storage and compute resources and the Data Repositories responsible for the storage of the templates for the VNFs and NSs. Also holds information about the resources and instances that are being used. The ETSI MANO illustrates also that the NSs as the relation between VNFs and PNFs and defines the elements that a NS relates to. NSs can contain information about the VNFs, PNFs, VLs and VNFFGs and with this information create network forwarding paths to be used on E2E virtualized network services. The ETSI MANO architectural framework instantiation input parameters are used as descriptors which are grouped in a catalogue and therefore translated to records in a runtime context when the virtual instances are deployed. The descriptors are written in the TOSCA language and have information about the network itself, such as the topology, network path, resource requirements for the elements of the network and the physical elements. The records have not only the information given by the descriptors, but also additional runtime information such as CPU, network or disk usage.

2.2.1. TOSCA and YAML

TOSCA [2] or Topology and Orchestration Specification for Cloud Applications is a template

language based on the data serialization and markup language YAML (Ain't Markup Language) that describes the virtualized network functions or services nodes and the relations between them. In fact, TOSCA is a service template language that describes virtualized network infrastructures workloads as a topology template, meaning that is basically a graph of node templates modelling the components and the relations between them. An example of a VNFD written in TOSCA is depicted on Tacker VNF descriptor site [3]. The VNFD example is from a NFVO and VNFM software called Tacker, which describes a VNF topology with three node types, a VDU, a VL and a CP, each with different capabilities and requirements. The capabilities describe the resources that each node will be deployed with and the requirements describe the virtual networks that are associated with each VNF. The YAML language is a data serialization and markup language where integrates and builds concepts from a lot of other languages, e.g. Python, JSON, Ruby, C and XML. YAML language indentation-based scoping is similar to Python language where the indentation facilitates the inspection of the data structures. YAML language literal style leverages this by enabling formatted text to be cleanly mixed within an indented structure without troublesome escaping. YAML also allows the use of traditional indicator-based scoping similar to the JSON language. YAML language core type system is based on the requirements of agile languages such as Perl, Python, and Ruby. YAML directly supports both collections (mappings, sequences) and scalars. Support for these common types enables programmers to use their language's native data structures for YAML manipulation, instead of requiring a special document object model. YAML language foremost design goals are human readability and support for serializing arbitrary native data structures [4].

2.3. VIMs block

The virtualized infrastructure managers block has the responsibility to supervise the virtual infrastructure of a network function virtualization solution. In summary the VIM is a key component of any ETSI MANO architecture, and the following subsections describe some of the most developed solutions that exist nowadays for virtualized infrastructure managers.

2.3.1. The OpenStack platform

The OpenStack platform is an open source project that aims to be a cloud operating system that manages and deploys the network, storage and computing resources of a complete virtualized infrastructure over a set of hardware resources. The following figure details the conceptual architecture of the OpenStack elements (services) [5]:

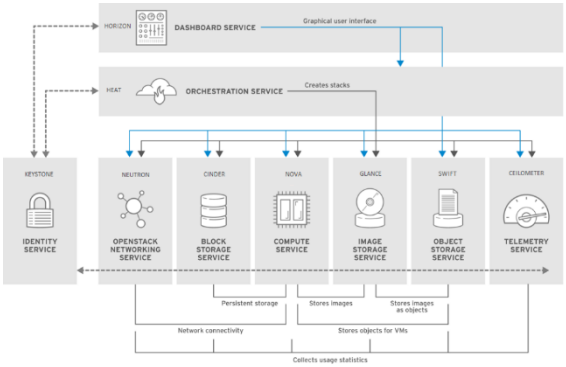

Figure 2: High-level overview of the OpenStack essential projects

Resourced from [5]

These elements or projects can be classified has essential projects and additional projects and are explained in more detail on the subsections below. The growth of the Internet and hardware infrastructures network solutions implies new challenges for operators to manage, configure and launch on demand new services using the resources for them as efficient as possible. OpenStack is an excellent solution for that matter because it offers virtualization of compute, storage, networking and many other resources. Each component in OpenStack manages a different resource that can be virtualised for the end user. Separating each of the resources that can be virtualized into separate components makes the OpenStack architecture very modular. OpenStack can be divided into four groups: Control, Networking, Compute and Storage. The Control tier runs the Application Programming Interfaces (API) services, web interface, database, and message bus. The Networking tier runs network service agents for networking. The Compute tier is the virtualization hypervisor, with services and agents to handle virtual machines. The Storage tier manages block (Volumes; partitions) and object (containers; files) storage for the Compute instances. All the components use a database and/or a message bus.

2.3.1.1. Essential OpenStack projects

The essential projects are the projects that an OpenStack platform cannot operate without. The essential projects to deploy an OpenStack installation are [8] the Nova project that manages and provisions virtual machines running on hypervisor nodes, the Neutron project that provides network connectivity between the interfaces of OpenStack services, the Glance project that is a registry service that is used to store resources such as virtual machine images and volume snapshots, the Keystone project that is a centralized service for authentication and authorization of OpenStack services and for managing users, projects, and roles and some advisable but not mandatory projects to add to an OpenStack installation as they facilitate the usage of the OpenStack platform such as the Horizon project that is

a web browser-based dashboard that is used to manage OpenStack services, the Swift project that allows users to store and retrieve files and arbitrary data, the Ceilometer project that provides measurements of cloud resources, the Heat project that is a template-based orchestration engine that supports automatic creation of resource stacks and the Cinder project that manages persistent block storage volumes for virtual machines. All the services communicate with each other by APIs and the AMQP.

2.3.1.2. Relevant OpenStack additional projects

The additional OpenStack projects are software tools that are developed as a side project to add some new features / services to the OpenStack platform. The most important ones for the scope of this dissertation are the Octavia and Octavia dashboard projects that aim to be a load balancer as service project and a GUI of Octavia project that can manage a fleet of virtual machines, containers, or bare metal servers on demand, the DevStack project that is a compilation of scripts to quickly bring up a complete and updated version of the OpenStack platform hosted on a bare metal or virtual machine, the Diskimage-builder project that is a tool for automatically building customized operating-system images to be used in clouds and other environments, producing cloud-images in all common formats (qcow2, vhd, raw, etc), bare metal file-system images and ram-disk images, the Kolla project that is a provider of production-ready containers and deployment tools for operating OpenStack clouds that are scalable, fast, reliable, and upgradable using community best practices, the Magnum project that makes container orchestration engines such as Docker Swarm, Kubernetes, and Apache Mesos available as first class resources in OpenStack. Magnum uses Heat OpenStack project to orchestrate an operating system image which contains Docker and Kubernetes and runs that image in either virtual or bare metal machines in a cluster configuration, the Kuryr-kubernetes and Kuryr are OpenStack containers networking projects that enables native Neutron-based networking in Kubernetes. With Kuryr-kubernetes it is now possible to choose to run both OpenStack VMs and Kubernetes Pods on the same Neutron network and the Kata containers project that aims to "deliver standard implementation of lightweight virtual machines that feel and perform like containers but provide the workload isolation and security advantages of virtual machines". The architecture of the Kuryr project is described in more detail by the figure below:

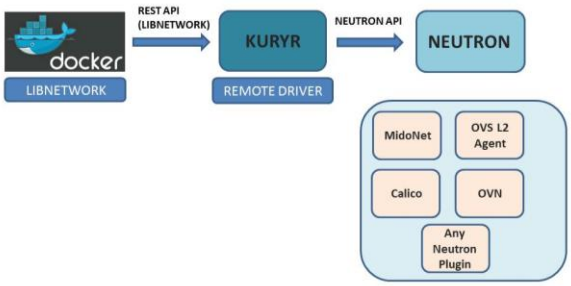

Figure 3: Kuryr architecture

Resourced from [6]

Kuryr uses the libnetwork API to map and create Neutron objects. By doing this, the solutions that Neutron provides (security groups, NAT services and floating IP´s) for networking can be used by containers networking.

2.3.2. Kubernetes

Kubernetes is an open source solution for managing and orchestrating containers. The architecture type is client-server, where it has one or more master servers that controls and defines how the worker nodes should act and react to the master node. Kubernetes infrastructure is based in five different principles such as pods, services, volume, namespaces and deployment. Pods and Volume are the storage units of Kubernetes, where it stores all information related to the containers and the data of each Pod respectively, Services are a logical set of pods and acts as a gateway to the exterior, allowing (client) pods to send requests to the service without needing to keep track of which physical pods make up the service, Namespaces are based in the Linux namespaces, where here it is a virtual cluster (a single physical cluster can run multiple virtual ones) intended for environments with many users, and finally the Deployment is normally done via a deployment file in the YAML language which describes the configuration and state of pods. An example of the workflow (with a single master server and two worker servers) of Kubernetes is depicted in the following figure:

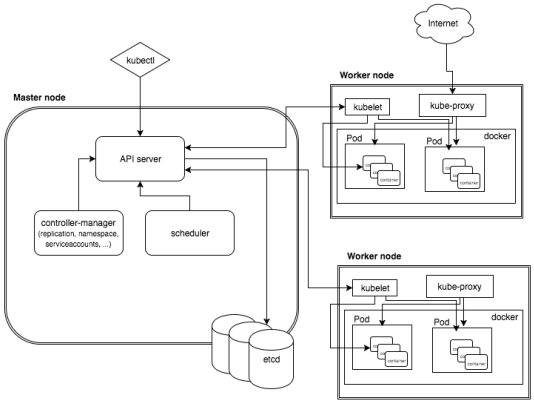

Figure 6: Kubernetes cluster example architecture

Resourced from [7]

The master node provides Kubernetes with cluster control, making global choices for the cluster and deciding what to do when a cluster event is detected, it has a central management entity (kube-apiserver), a distributed key value storage (etcd), a scheduler that helps optimizing resource utilization (kube-scheduler) and a controller that regulates the state of the Kubernetes or manages the cloud provider (kube-controller-manager or cloud-controller-manager). The worker node has a service daemon (kubelet) responsible for taking pod specifications and health checks, a proxy service daemon (kube-proxy) responsible for the networking in the worker node and a container runtime (Docker) that is the software that will run the containers on the Pod. Kubernetes has also some useful features (addons) like a DNS Server, a Web UI, a Container Resource Monitoring and a Cluster-level Logging that can make the life easier on the administrator of the Kubernetes platform. Kubernetes has become in the last few years the standard container orchestration platform, mainly because of the performance gain by using containers over virtual machines and the high availability of the applications running on the containers is provided by the use of container replicas quotas and the health container checks.

2.3.3. Docker

Docker is a client-server application (like Kubernetes), that leverages the technologies of namespaces, control groups, union file formats and container formats. The Docker engine is defined as follows:

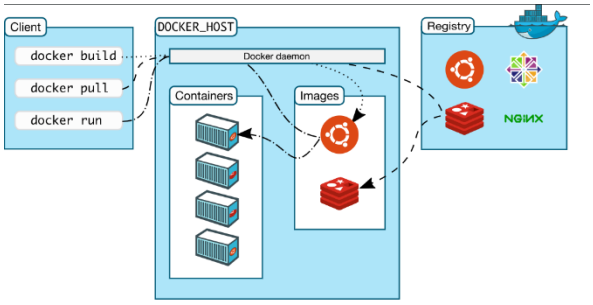

Figure 7: Docker architecture

Resourced from [8]

Docker is composed by a docker daemon (dockerd) that manages the Docker objects (images, containers, networks and volumes) and the communication with other Docker daemons to manage Docker images, a Docker Client that consists of a REST API and CLI (Docker command or a Docker client) being used to interact with the Docker daemon, a Docker registry for the storage of Docker images (default one being Docker Hub) and a Docker object or objects that can be images, containers or services. Docker is a fast and consistent delivery system of applications because of the use of containers and being a light program to run offers great scaling, a fast deployment system and the amount of work uses less resources in opposition of using virtual machines.

2.4. NFVOs and VNFMs blocks

The network functions virtualization orchestrator and the virtualized network functions manager blocks are normally bundled together in a software suite but have different responsibilities that need to be attended to. The NFVO is responsible for overlooking the instantiation, scaling, updating and terminating network services. The VNFM is responsible for overlooking the instantiation, scaling, updating and terminating of virtual network functions. The next subsection describes the software used for the implementation of the NFVOs and VNFMs blocks.

2.4.1. Tacker

Tacker is an OpenStack additional project for NSs an VNFs orchestration and management adhering to the ETSI MANO architectural framework. It has a generic NFVO and VNFM to deploy network services and virtual network functions providing E2E solutions. The next figure shows how Tacker workflow and architecture are:

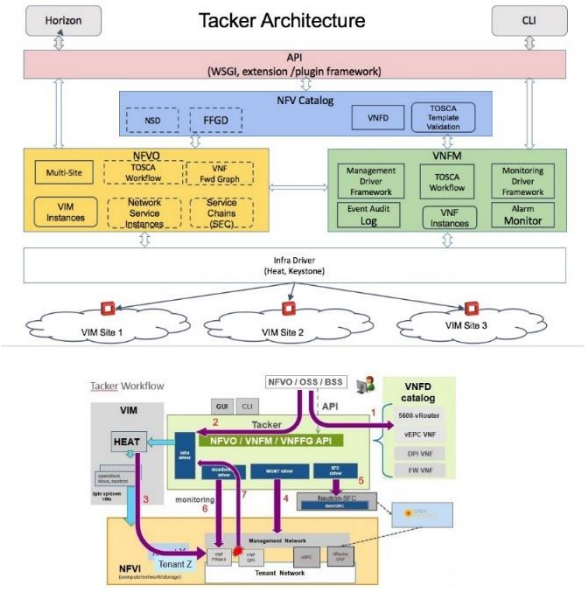

Figure 9: Tacker architecture and Workflow

Resourced from [9]

Tacker has three fundamental elements. The Network Functions Virtualization Catalog that contains the VNF, NS and VNF Forwarding Graph descriptors. The Virtualized Network Functions Manager (VNFM) that creates, updates, deletes and monitors VNFs. The Network Functions Virtualization Orchestrator (NFVO) that optimizes resource checks and allocation of VNFs. The NFVO can orchestrate VNFs, throughout multiple VIMs or Sites and can create a service function chain between VNFs by using a VNF Forwarding Graph Descriptor. Tacker can be deployed and configured manually or using the additional OpenStack projects DevStack or Kolla. Tacker only supports currently as VIMs the OpenStack and Kubernetes platforms.

3. Architecture

The architecture is to deploy and test a system that encompasses one of each of the three main blocks of the ETSI MANO architectural framework presented on chapter two of this dissertation report. The proposed architecture solution will have a frontend network with one VNF acting as a Load Balancer and a backend network with two web servers. The backend network will have replicated sites (one and two) with two virtualized infrastructure managers installed on the different sites. A client can connect and test the system functionalities. The architecture is depicted below:

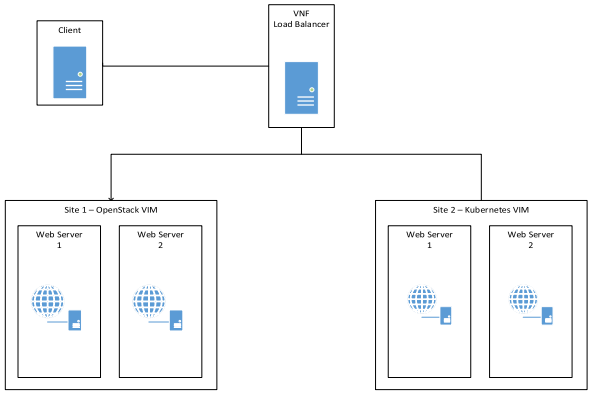

Figure 10: Project architecture

The system workflow starts by the users connecting to the system via a VNF acting as a load balancer that will redirect traffic depending on the load balancing algorithm that was selected, connecting the users to the sites on the backend network. Each site will have two web servers that will be used for testing the load balancer and the sites functionalities, e.g. handling HTTP requests. The orchestration and management of the global system will be done via a management server. The management server is configured using the necessary software researched in chapter two of this dissertation report and some extra tools that will be described in the next subsection. The ideal scenario will be that, the servers on site one and the VNF acting as load balancer will be hosted on virtual machines, as for the servers on site two will be hosted on containers. The process of being hosted by virtual machines and containers is also important to test, analyze and compare how different these host virtualization techniques are in terms e.g. resource utilization. The proposed architecture is a heavy system to deploy and the available hardware is limited, so the implementation takes all that in consideration by building the system with the minimal resources necessary not compromising the proposed architecture.

3.1. Implementation

The implementation starts with phase number one where a management server is deployed and configured to host the DevStack and Tacker projects used on phase number two. Phase number two main objective is to deploy and configure the DevStack and Tacker projects. Phase number three deploys and configures the backend and frontend VNFs hosted on virtual instances (containers or virtual machines). The next subsections describe in more detail how all the phases were processed.

3.1.1. Management server deployment and configuration

The main goal is to deploy a bare metal or virtual solution of a management server that consists on installing and configuring the software of the virtual network infrastructure that is going to be used to deploy the architecture solution described before. The first step is the most important one as encompasses the research of the software and hardware requirements for the system architecture and choosing the right tools to deploy the management server. The tools chosen were for a virtual solution of the management server, just because it is easier to test the hardware requirements for the architecture solution as is a better modular solution than the bare metal solution, e.g. if a virtual machine does not meet the right requirements it is faster to install and configure the hardware and operating system on the virtual machine. The tools chosen to deploy the virtual solution to the management server where, Packer [10] and Vagrant [11] that are tools respectively, to manage updated virtual images to be used on virtual machines and to deploy those virtual images onto virtualization platforms such as VirtualBox or QEMU. The problems that were encountered here were the time necessary to choose the right operating system and the minimal hardware and software requirements to deploy the management server as it depends on phase two of the implementation of the architecture solution. The operating system chosen was Ubuntu Server 16.04 with Ansible [43] and openstack-sdk packages installed with sixteen GB of RAM, five CPU cores and sixty GB of disk. Vagrant uses a Vagrantfile that is written in the Ruby language where it defines the virtual machine configuration to be used for the management server.

3.1.2. DevStack and Tacker projects deployment and configuration

After the management server is up and running, it is time to the next phase where the DevStack and Tacker OpenStack additional projects are deployed and configured. These projects were chosen based on the hardware requirements of all the software researched for the ETSI MANO architectural framework blocks. For the VIM block the project used for this was DevStack where it deploys a virtualized network infrastructure platform and installs the OpenStack and Kubernetes VIMs. For the NFVO and VNFM blocks, the project used was Tacker. The first step of using the DevStack project is meeting the following requirements such as DevStack should be run as a

non-root user with root enabled privileges and having GitHub [12] and PIP [13] (package installer for Python) programs installed on the management server used to deploy DevStack. The next step involves using the GitHub program called git to download the repository of DevStack to a folder and access the folder. When in the DevStack folder, the most important files to look for are the stack.sh, openrc and local.conf files. The stack.sh is a bash script file that uses the information of the configuration local.conf file to install and configure the OpenStack and Kubernetes VIMs. The openrc is also a bash script file used to load the OpenStack environment variables to the management server so that OpenStack can be accessed and managed. The configuration local.conf file that needs to be created by the user of the management server is based from the local.conf.kubernetes [46] file, that can be accessed on the DevsStack GitHub site with slight modifications. The relevant configurations options for the local.conf file are the IPs and passwords for the services that will utilize that information such as, the OpenStack database and network services, the IP range and network interface that is going to be used to give Internet connectivity to virtual instances, e.g. virtual machines or containers, enabling a log file, it is very important because if anything goes wrong, it is possible to search for errors during installation, enabling the use of the Kubernetes VIM and selecting the hyperkube [14] version to be installed. The hyperkube version can be selected from google public hyperkube image repository [15] and enabling the necessary OpenStack services by using the enable plugin command tag. The OpenStack services are then downloaded from a GitHub repository and automatically configured with the default options. The customization of the services is done via proper tags and the tag availability depends if the service has DevStack installation support. After all the configuration is done, the file must be saved under the DevStack folder and then run the stack.sh script. One problem that originated running the script, was when the management server has one network interface and the login method to the management server is via SSH, it is necessary to run the script on a separate virtual terminal by using the command screen. The script is going to run a series of installations and configurations on the system, so it is not recommended to run this script on a daily use operating system installation. This is one of the reasons why the management server is a virtual machine described in the phase before. The script run time depends in the amount of services it must install and configure, but the script at a fresh install of the operating system on the management server takes about forty five minutes and the time decreases after the first run, to thirty minutes. At the end of the script the output gives useful information such as the time it took to install and configure the script, the default IP address used by the user of the management server to access, e.g. via browser the OpenStack UI, the users (admin and demo) that have relevant privileges to access the OpenStack platform and the version of OpenStack that was installed. In this phase the most relevant problems that were faced were, the script stops working as of a bug on the DevStack project as the association of the bridge br-ex (responsible for the routing of the external network to the internal networks of the OpenStack platform) to the network interface of the management server removes the DNS name resolution of the management server and when using a hyperkube version above version 15.0 the installation of Kubernetes fails. These problems were solved by, using a GitHub repository commit version of the DevStack project older than the one that was being used and using an older version of hyperkube. This phase was the most time consuming because of all the configuration options that need to be learned and tweaked to fulfil the needs of the architecture solution and the limitations of hardware resources that where presented at the time of this phase implementation, e.g. the IST resources were so limited and overbooked, that the private hardware resources must be upgraded so the architecture solution implementation could continue. After this, it is necessary to configure the management server to create and have access to the virtual instances that needed for the architecture solution implementation by loading the environment variables of the OpenStack platform onto the management server and creating a SSH key to be able to access to the virtual instances. A series of configurations need to be done the OpenStack platform each time the it is deployed such as changing the DNS nameserver IPs on all default OpenStack networks, creating a router to access the virtual machines, creating ports in the router to all default OpenStack networks, adding SSH keys to the OpenStack platform to be able to access the virtual instances, adding or changing the rules on the default OpenStack security groups and adding new operating system images to the OpenStack platform. A problem of time consumption happens when these configurations of the OpenStack platform occur and the solution was using an automation tool such as Ansible [43], which is a Red Hat project that focuses on IT automation, using YAML has a standard to create template files, that can deploy and modify virtualized network infrastructures and their elements. The template file (also called ansible playbook) was created for configuration steps described above. Now that the system is fully configured, it is time to use the Tacker project. The first thing that needs to be done is to register the OpenStack and Kubernetes VIMs onto tacker and for that it is necessary to create two YAML files that have the information needed to register both VIMS. After the formulation and creation of the files it’s time to register the VIMs onto Tacker via the OpenStack CLI or GUI, and depending on the commit version of Tacker, the registration of the Kubernetes VIMs cannot work due to a bug on the code, so the

GitHub branch used in Tacker must be the master branch to fully pass these kind of problems, just because the branch is more often updated than the other ones.

3.1.3. Backend and frontend VNFs deployment and configuration

With the VIMs registered, it is necessary to register the backend and frontend VNFs by making one or two descriptor template files for each VIM. There are two ways to approach the configuration and deployment of the frontend VNF, one can be done manually where it is used a descriptor template file and all the configuration for the load balancer is done manually in terms of networking, failsafe protection and the software used for the load balancer or two where it is used a OpenStack additional project described on chapter two called Octavia. The Octavia project is a LBaaS where it shares the concept of XaaS [16], where anything can be called a service in a virtualization system. The configuration selected was the second one because the way that Kubernetes works with the OpenStack platform is by using the OpenStack networks via the kuryr-kubernetes project while the access to the Kubernetes Pods is done via an ingress Octavia LBaaS project controller. The backend template files for each VIM are different. Each template file has its own configuration options just because they use a different type of hardware and software virtualization (containers or virtual machines) that have different options for configurations, e.g. on a Kubernetes template file it is necessary to define a service type tag that can grant access from the external network to the application running on the containers. The configuration of the VNFs can be done by a bash script, where for that is necessary to use a specific image built with the OpenStack additional project diskimage-builder, using a user_data tag on the template descriptor file, where configuration and installation commands can simulate like it was a bash script file or using the management server by running directly the bash script file with the SSH command. These configuration options are well documented but the safer to use would be the third option, just because the other two have problems with them. The first configuration option the diskimage-builder project has software bugs where it only builds successfully images of the latest versions of the operating systems and when using these images with Tacker the bash script does not run properly making the VNF unconfigurable. The second configuration option is a good option, but the template file organization and length can become quite unorganized and big due to inserting the bash script data onto the template descriptor file. In the third option the template descriptor file and bash script file are separated, and the script file is loaded via SSH using the management server for that matter. The software tools used for the backend and frontend VNFs are a HAProxy software is used on the frontend VNFs, being the most documented, tested and versatile load balancing software, and NGINX and PHP software are used on the backend VNFs. The HAProxy software used on the frontend VNF is preinstalled with the Octavia OpenStack additional project and it is configured as a HTTP load balancer with a load balancing round-robin algorithm. The load balancer is also configured with a “health monitor” that checks the state of the backend servers. Layer seven policies that do redirection based on the path that is entered on the browser can be configured also, giving extra security to the backend servers. The backend VNFs will act as web servers that verify if the configurations on the load balancer are working as intended. After loading the configuration files onto the VNFs, it is time to test the architecture solution implementation. In this phase the installation, deployment, connectivity and functionality are tested of the architecture solution. This phase will be described in more detail on the next section of the report. A problem occurred in this phase were that if a test fails and it is necessary to reboot the management server the virtual network interfaces created by the DevStack OpenStack project does not persist over a system shutdown or reboot, so the solution is to remove the configurations and installations done on the management server. Gladly the DevStack developers thought of that and created two scripts called unstack.sh e clean.sh. The unstack.sh script stops all services associated with OpenStack and the clean.sh script cleans all configurations and installations done by DevStack on the management server. After that it is necessary to run the stack.sh file and to do all VNFs configuration and deployment.

4. Evaluation

The evaluation phase is the most important phase of all systems implementation, just because it validates all the work that was done. It also detects if something is not running how it should be, by testing all the elements in the system and giving out precious information to the administrator. With that information the administrator can monitor and fix all the elements that are not corresponding to the normal behaviour. The next subsections describe the tests performed on the architecture solution implementation.

4.1. Tests

The tests are divided on functional and performance tests. The tests validate if the functionality, failover and scalability of the implemented solution are working as intended. The table below describes in a short manner what tests were done on the implemented solution:

Test number	Test short description
1 – Functional test	Verify VIMs and VNFs deployment and configuration

2 – Functional test	Verify frontend and backend VNFs connectivity
3 – Functional test	Verify frontend and backend VNFs functionality
4 – Functional test	Verify frontend and backend VNFs failover
5 – Performance test	Verify VNFs scalability

Table 1: Summary table of the evaluation tests

4.1.1. Tests 1 to 3

The tests one to three are done via a Python script where issues one hundred GET requests to the VNF acting as load balancer and outputs the graph below:

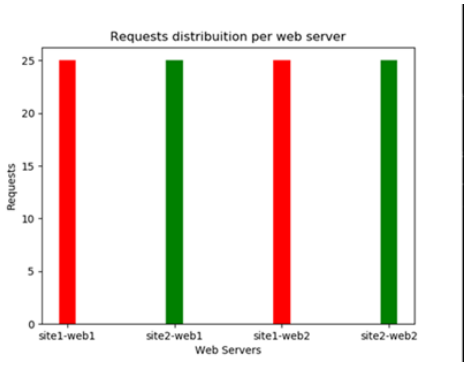

Figure 1: Distribution of GET requests with four web servers

The algorithm chosen for these tests is the round robin algorithm and as it is seen on the graph above, all the one hundred requests are evenly distributed proving the web servers and load balancer functionality. The success of the web servers and load balancer functionality also validates the frontend and backend VNFs connectivity (test two) and the VIMs and VNFs deployment and configuration (test one).

4.1.2. Test 4

Test four is where the frontend failover testing is done via a terminal command (**openstack loadbalancer failover name_of_lb**) where it simulates with an interval of time a failover scenario that is performed on the load balancer. The command initiates the failover by destroying the virtual machine that hosts the load balancer, verifies that the load balancer no longer is available and performs the recoverability process of creating a new virtual machine using the load balancer configuration metadata. The backend failover is tested by creating a health monitor checker and shutting down a backend VNF virtual machine or container via the OpenStack CLI or GUI and verifying that the load balancer becomes aware and do not forward HTTP traffic to that specific virtual machine or container.

4.1.3. Test 5

Test 5 uses a scalability property on the VNFDs, where it defines how many replicas of a VM or container a system can make. To test this the script used on the test 1 to 3 section was slightly modified where it calculates the GET response average time plus the computational time for each web server. The number of replicas was increased to three on site 2 and the script outputs the following graph and times:

Figure 2: Distribution of GET requests with five web servers

site1-web1	**site1-web2**	**site2-web1**	**site2-web2**
885 ms	886ms	887ms	884ms

Table 2: Requests time with four web servers

site1-web1	**site1-web2**	**site2-web1**	**site2-web2**	**site2-web3**
847ms	847ms	847ms	846ms	846ms

Table 3: Requests time with five web servers

As it is seen on the graph above and tables, the time is reduced by forty milliseconds proving that the scalability performance is relevant and is working as intended

5. Conclusion

All the technologies described on chapter two are still being heavily developed and complementing their core environment to using containers. Containers in comparison with virtual machines use less resources, meaning better overall performance for the workflow of a VNF solution. Nevertheless, the use of virtual machines means a better isolation for the adopted VNF solution that containers cannot deliver yet. That is why kata containers enables the merge of virtual machines and containers by adding the good features described from both virtual machines and containers. The problems encountered while doing this dissertation were mainly, the documentation of the researched technologies that needs improvement on explaining how some of the projects work and what certain aspects of the projects do, e.g. to lost a lot of time searching for a solution when the installation script used by the DevStack project stops working. Unfortunately, due to limitations on the hardware resources it was not possible to test all the technologies described on chapter two and to scale the proposed architecture solution as it was intended. The projects used on the implementation of the proposed architecture are still being heavily developed, and still need optimization regarding merging the features of containers and virtual machines. Nevertheless, the

implementation of the architecture was successful and describes well what is the expectation for the future of virtualized network functions and services.

6. Future work

For future work, if the resources permit, it is very important to implement and research other possible architecture scenarios. For example, creating a multi VNF network service where it deploys different VNFs with different virtual networks graphs. With these virtual network graphs, it is possible to create virtual network paths and selecting witch VNFs are associated with each virtual network path.

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