A Pattern for Network Function Virtualization Infrastructure (NFVI)

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In Network Function Virtualization (NFV), different networking components such as firewalls, load balancers, and IDS are provided as a service and rely purely on support from the cloud, which makes expanding and upgrading the network an easy and fast process. Hardware-based Network Functions (NFs) normally require a tightly coupled infrastructure, where changes are hard to make; a Network Function Virtualization Infrastructure (NFVI) makes the process of enhancing and expanding the network much easier. This NFVI emulates the hardware functions using virtual functions to be provided as services. We present here a pattern to describe the NFVI unit.

Categories and Subject Descriptors: D.2.11 [Software Engineering] Software Architectures–Patterns;

General Terms: Design

Additional Key Words and Phrases: Network Virtualization, architecture patterns, network functions, Network function virtualization infrastructure, Virtual infrastructure, cloud computing, telecommunications, NFV Services.

ACM Reference Format:

Alwakeel, A. M., Alnaim, A. K. & Fernandez, E. B. (2019). A Pattern for Network Function Virtualization Infrastructure (NFVI). In *Proceedings of the 26th PLoP'19*, October 7-10, Ottawa, Ontario, Canada. 8 pages.

1.INTRODUCTION

Telecommunication Service Providers (TSPs) have to spend time and effort to deploy physical hardware and equipment for each network function, all this in addition to the need for highly skilled network designers and operators to deal with the complexity of setting up and administering large networks. Furthermore, the network life-cycle is becoming shorter due to the faster evolution of network hardware. As a result, this leads to an increase in the Operational Expense (OPEX) and Capital Expense (CAPEX) for TSPs (Hawilo, Shami, Mirahmadi, & Asal, 2014).

The European Telecommunications Standards Institute (ETSI) introduced NFV as a new concept to provide network functions (NFs) as a service to the consumers in a virtual manner, as an alternative to the traditional legacy way of implementing NFs; this standard has been adopted world-wide by the leaders of networking solutions. The concept of NFV addresses the previously mentioned drawbacks of using the legacy network to provide networking solutions to the users. Moreover, NFV promises the following benefits (Fernandez & Hamid, 2015):

- Independence: software is no longer integrated with hardware. As a result, their evolution can be independent of each other.
- Flexibility: the decoupling of software from hardware helps to reassign and share the same infrastructure resources, which allows performing different functions at different times. As a result, the deployment of network functions and their connections becomes faster and more flexible.

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- Scalability: decoupling software from hardware provides more flexibility to dynamically scale the actual performance of virtualized network functions with finer granularity.
- Reduced energy consumption: with the ability to scale resources up and down, TSPs are able to reduce the OPEX needed to run network devices.
- Cost: Using NFV systems could significantly reduce the cost of using networking solutions.

The Network Function Virtualization Infrastructure (NFVI) of NFV works as a backbone for the system by decoupling the functions from dedicated hardware and moving them into virtual servers. NFV should not be confused with Software Defined Networks (SDN), an architecture for networks that separates the control from the data in switches and routers (Kreutz et al., 2015); SDN controls the topological aspects of networks, not their functionality.

ETSI introduced the basic architecture for NFV systems (ETSI, 2014b), Three different main components together create an NFV system (Fig. 1):

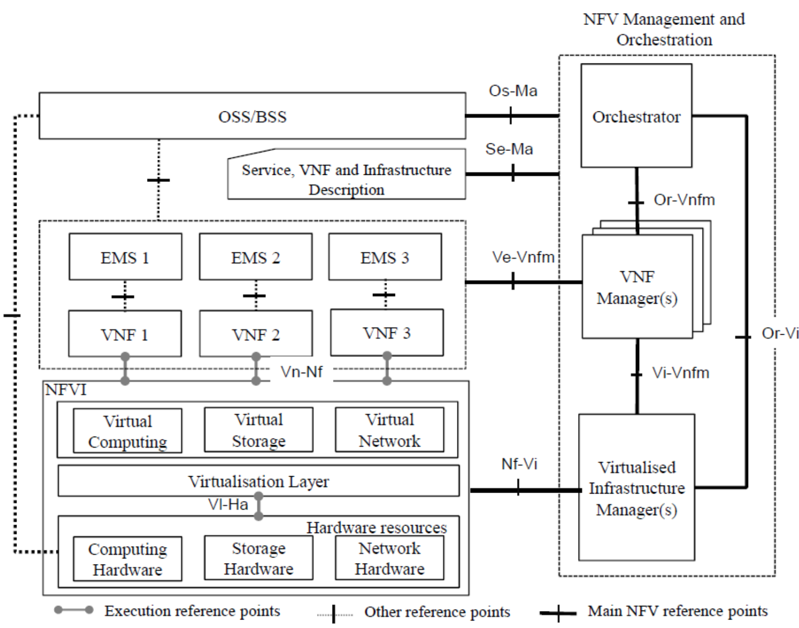

Fig. 1. NFV architectural framework (ETSI, 2014b)

1. Network Function Virtualization Infrastructure (NFVI)-- NFVI can be considered as a cloud data center that works as a foundation platform for NFV; it contains both hardware resources as well as the virtual resources which together build up the infrastructure on which Virtual Network Functions (VNFs) are executed, deployed and managed. NFVI contains three main components which are virtualized resources, virtualization layer, and hardware resources.

2. Virtualized Network Functions (VNFs) refer to the implementation of network functions in a virtual manner. In NFV systems all network functions are represented as software packages and combined into a network graph which represents the whole network. One single VNF is created from one or more VNF components (VNFC), noting that the entire service could be combined in a single VNF to reduce the complexity of deployment (ETSI, 2014a). However, VNF also could contain separate components which will increase the system reusability and scalability. Moreover, this will help in creating custom networks to support complex systems. Every VNF is connected to an Element Management System (EMS), which is responsible for the functional management of each VNF.

3. The NFV Management and Orchestration (MANO) unit could be considered as the heart of the NFV system. This unit takes care of the management and orchestration aspects of the entire set of VNFs. VNF management functions Include traditional fault management as well as security management. Moreover, the MANO takes care of creating VNFs, scaling VNFs where more components could be added or removed from a single VNF which will lead to increasing or decreasing the capacity of the VNF, update or upgrade VNFs, and terminate VNFs. Also, it takes care of fault and performance management aspects of the system. On the other hand, orchestration differ from management in that its tasks register network services in the catalog, monitor the capacity of network services that the TSP provides to the consumer, and validates and verifies resource requests.

We present here a pattern for NFVI. Because the model of fig. 1 is not sufficiently detailed, we found more details from the descriptions of these functions in several ETSI documents. Our audience includes system designers, system architects, and designers of network systems in TSPs. A glossary in the Appendix describes the acronyms used in this paper.

2. NETWORK FUNCTION VIRTUALIZATION INFRASTRUCTURE (NFVI)

2.1 Intent
The NFVI pattern describes an architectural layer that contains the actual physical components as well as the virtualization layer that performs the implementation of network functions as virtual functions.

2.2 Example
Dave works in a networking company that provides solutions to his customers. He is in charge of improving the efficiency and flexibility of the networks they provide. He is looking for a more cost-effective solution than using hardware functions as they do now, which they consider inflexible and costly.

2.3 Context
Telecommunication providers need to provide a variety of network services such as routers and firewalls to a variable number of customers.

2.4 Problem
Providing a variety of network functions in a flexible and cost-effective way is needed to be able to compete in the market. How can the NFV providers achieve this objective?

The solution to this problem is affected by the following forces:

- Heterogeneity— We need to provide a variety of different types of network functions including some that do not have equivalent physical components.
- Availability— The network service should be available at most times.
- Scalability— The number and type of customers can change up or down along time. The number of functions they require also changes along time.
- Location— different physical components could be distributed in different locations which may introduce connectivity issues if we used hardware devices.
- Upgradability— When used together with physical components an upgrade should not introduce issues for virtual functions.

- Security—Because software functions are less secure than hardware ones, we need to provide a good level of security to our network functions by other means.

- Performance— Virtual functions should provide a good level of performance with no latency or noticeable reduction in performance.

- Cost— Using VNFs should be cheaper than using hardware network systems.

2.5 Solution

Define an architectural unit (NFVI) that contains a virtualization layer which provides network functions using virtualization of hardware resources. The fundamental component of the NFVI is the hypervisor which creates and manages virtual machines that can be used to create networks for NFV consumers. The hypervisor also provides isolation among the virtualized entities.

2.5.1 Structure

Figure 5 shows the class diagram of the NFVI pattern which contains the hardware resources (compute, storage, network) that form the infrastructure resources for NFV services. The VDC is the virtual data center that is dedicated to the NFV service and can be rented from the cloud SP. The VIM is a MANO unit that is responsible for managing and reporting status information between the virtualization layer and MANO unit. The VME is a package that represents the virtual machine environment pattern and it is described in more detail in (Alnaim, Alwakeel, & Fernandez, 2019)[7]; it contains the hypervisor, which is responsible for managing the virtual resources in NFVI. The NFVI class defines the conceptual aggregation of the NFVI functions.

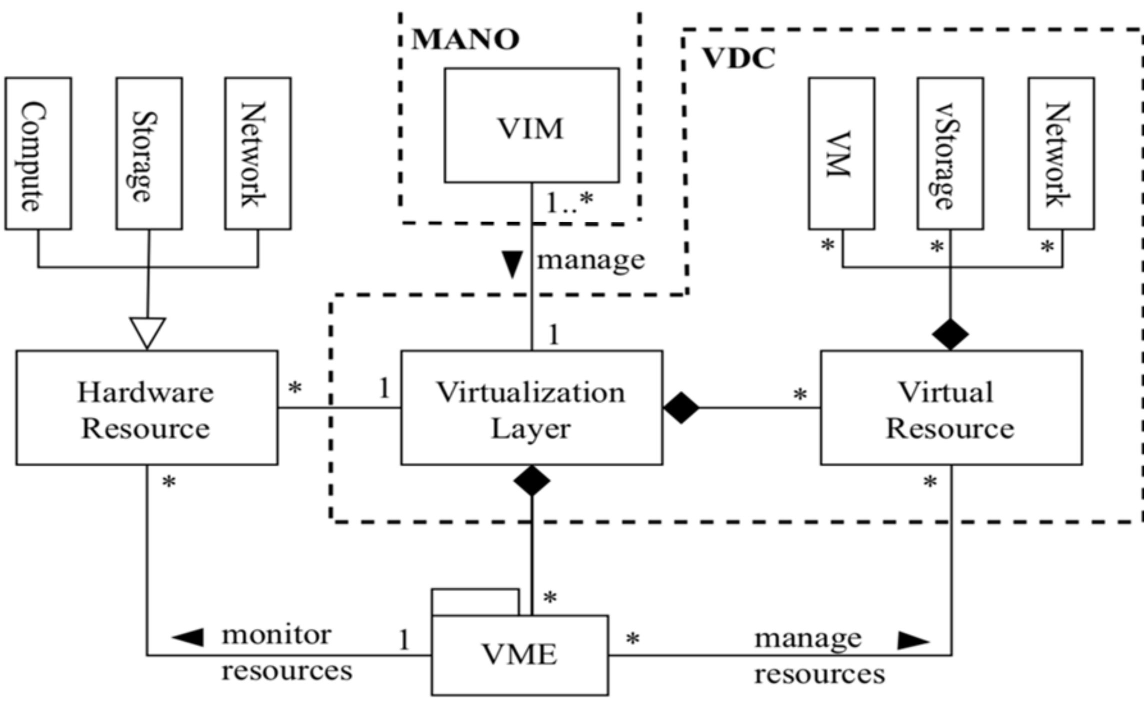

Fig. 2. class diagram of NFVI pattern

2.5.2 Dynamics

NFVI includes several use cases including “Create a set of Virtual Network Functions”, “Assign virtual resources to user accounts”, and “Modify virtual resources”. In this subsection, we discuss two use cases in detail: “Create a set of VFs”, and “Stop VNF”.

UC1: Create a set of Virtual Network Functions for a TSP (Figure 3)
Actor: VIM.
Precondition: The customer has an active account.
Description:

1. VIM receives external request from a TSP to create service composed of a set of VNFs.
2. VIM sends a create service request with details about the needed resources for the service.
3. Hardware unit handles the request and checks for available resources.
4. Hardware resource details get forwarded to the virtualization layer.
5. Virtualization layer creates the virtual function based on the available hardware resources.

Postcondition: A set of VNFs has been created for a TSP.

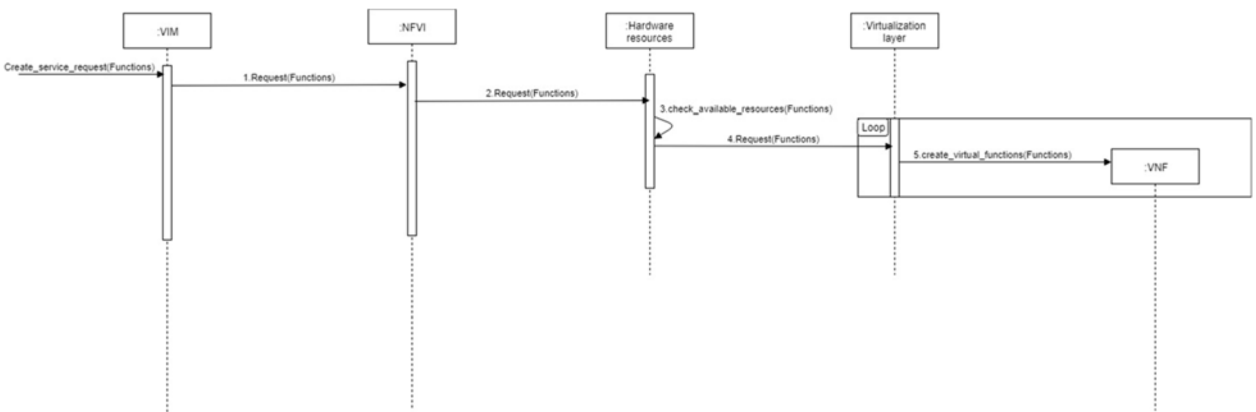

Fig. 3. Sequence diagram for Use Case “Create a set of Virtual Functions”.

UC2: Stop VNF (figure 4)

Summary: A Consumer sends a request to stop a VNF. The request is indirectly forwarded to the VIM which is a MANO unit. The result of this scenario is stopping the virtual resources that leads to stopping the VNF.

Actor: VIM on a request from the Consumer.

Precondition: a VNF is running.

Description:

1. The VIM, a MANO unit, receives a request to stop a VNF
2. The VIM forwards the request to the VME through the virtualization layer. The VME contains the hypervisor, which handles the request.
3. The VME stops the virtual machine that runs the VNF or a set of VNFs.
4. The VM is paused.
5. The VM is stopped.

Postcondition: a VNF or a set of VNFs will be stopped.

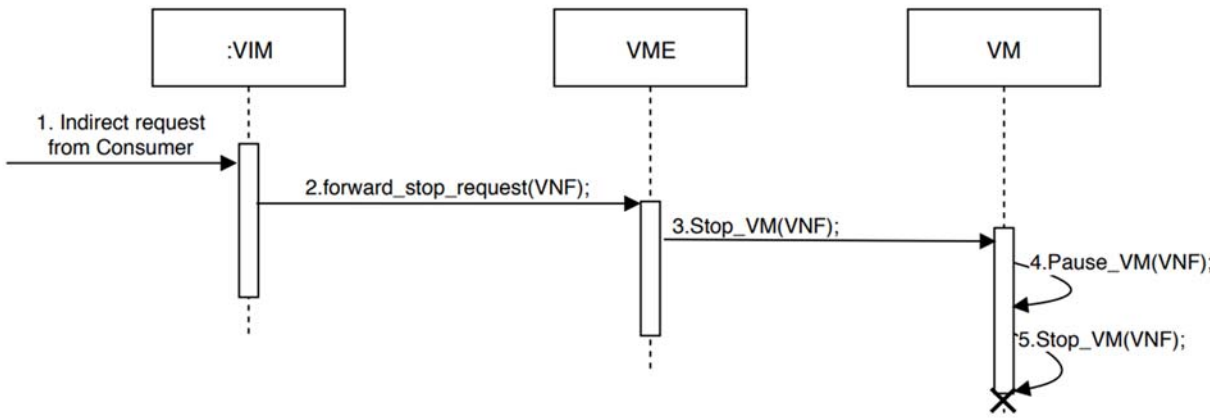

Fig. 4. Sequence diagram for Use Case 2: "Stop VNF"

2.6 Implementation

NFV providers must have different hardware equipment ready based on the services they plan to provide to their users base. They need a virtual machine environment as a base for this software in the form of virtual machines created by a hypervisor. Each created service must be registered in a services repository where the Management and Orchestration unit (MANO) can assign it to specific users; this process is explained in detail in the MANO pattern (Alwakeel, Alnaim, & Fernandez, 2019). The VMs in the VDC are used only to deploy NFV services; the VM should have only one VMI installed on it

2.7 Known uses

- Ericsson NFVI solution enables operators to deploy virtual function, OSS, BSS, IT (Ericsson, 2017). Ericsson uses the standard provided by ETSI to implement NFVI. Moreover, their solution includes an automated MANO to have better overall performance.
- Cisco Network Function Virtualization Infrastructure (NFVI) provides the virtual layer and hardware environment in which virtual network functions (VNFs) can operate (Cisco, 2016).
- Cloudband by Nokia uses an OpenStack Platform to implement an NFVI (Alcatel-Lucent, 2014).
- Huawei has released its 100 Gigabit Ethernet-capable NFVI solution that provides high bandwidth and low latency performance (Huawei, 2017).

2.8 Consequences

. The NFVI pattern presents the following advantages:

- Heterogeneity—Since the networking functions are all virtual they can all easily be made compatible.
- Availability— NFV services can be running at most times if the TSP includes some redundant implementation of VNFs..
- Scalability— Since the service will be provided in virtualized manner the TSP just needs to allocate more cloud resources when the number of customers increases.
- Location— The NFVI is part of a TSP and it can use any of the locations of their cloud service.
- Upgrades— New functions can be added to the existing VNFs without affecting existing functions.
- Security— the NVF can build secure networks by including appropriate controls in them; for example, authorization to use specifics VNFs.
- Performance— The TSP can allocate more VMs to a network to increase its performance.

- Cost— The NFVI provides a cost-effective network to its customers because creating new functions does not require actual hardware costs.

Liabilities

- Problems may occur when trying to combine old hardware functions with VNFs due to integration and compatibility issues.
- Security is a concern in NFV systems. Every network function is now provided as software which increases its attack surface but they can be made more secure as indicated above.

2.9 Example Resolved

Dave decided to use an NFV system rented from a public cloud, where physical components are emulated by virtual functions with the help of an NFVI. This allows Dave's company to deliver network functions to the user without the complexity of deploying and installing new equipment.

2.10 Related patterns

- A pattern for Network Function Virtualization (Fernandez & Hamid, 2015) presented the NFV architecture that shows how to create network services using Software-as-a-Service (SaaS) of the cloud. This is a general pattern than contains the NFVI as a class. This pattern refines the details of that pattern.
- Cloud ecosystem (Fernandez, Yoshioka, Washizaki, & Syed, 2016) shows how the NFV pattern interacts with the different parts of the cloud ecosystem as well as with other external systems.
- A pattern for an NFV Virtual Machine Environment (Alnaim et al., 2019) shows this environment and how it is related to NFV, as well as describing how the NFV architecture interacts with the virtual environment.
- A pattern for NFV Management and Orchestration (MANO) is given in (Alwakeel et al., 2019). This pattern shows how the NFVI is managed and controlled by the MANO unit.
- A Reference Architecture model for NFV is provided in (Alnaim, Alwakeel, & Fernandez, 2018), which shows all the components of the architecture.

3.CONCLUSIONS

NFV is a new technology still under development that can be considered as the future of networks. The NFVI is a critical component of an NFV system because it is the unit responsible for converting functions provided by hardware into virtual functions provided as software.

We presented here a pattern for NFVI which complements our previous work on describing precisely the units of an NFV system. As indicated, the ETSI model is too high level and imprecise to be useful to users and developers of NFV systems.

ACKNOWLEDGEMENT

We thank our shepherd, Prof. Michael Weiss, for his valuable comments that significantly contributed to improve our paper. The participants in the PLoP 2019 Writers' Workshop (Alla Zakurdaeva, Lina Garces, Neil Harrison, Rafael Papa, and Hind Milhem) made valuable comments.

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GLOSSARY

Acronym	Definition
TSP	A telecommunications service provider is a type of communication service provider that provides networking solutions
NFV	Network Function Virtualization is the service to be provided to the user in the form of virtual functions.
NFVI	Network Function Virtualization Infrastructure is the unit with physical resources that are used to build virtual services.
NF	Network Function: each function includes a set of network-related operations
MANO	The Management and Orchestration unit takes care of controlling and managing the NFV system.
VM	Virtual Machine is an emulation of a computer system and its functionality.
VIM	Virtual Infrastructure Manager manages and controls the infrastructure in NVF systems.
VNF	Virtual Network Functions are virtual implementations of network functions.
VDC	Virtual Data Center is a pool of cloud infrastructure resources specifically designed for enterprise business needs
VME	Virtual Machine Environment is the environment where VMs are created.
VNFC	Virtual Network Function Component: a set of these components together create a VNF. Every VNF in any NFV system contains one or more VNFCs.