Network Functions Virtualization: An Overview and Open-Source Projects

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***Abstract*—Network Functions Virtualization (NFV) has emerging as a networking technology from telecom industry to provide agility and flexibility in the deployment of network services and to reduce the Capital Expenditures (CAPEX) and the Operating Expenses (OPEX) by leveraging virtualization and cloud technologies. NFV decouples the software implementation of network functions from the underlying hardware, and it provides an abstraction of network functions such as: firewalls, deep packet inspectors, load balancers, among others, via software components that can run on general purpose devices that can be located in a variety of telecom infrastructure, including: data centers, network nodes, and end-user facilities. These Virtual Network Functions (VNFs) can easily be created, moved or migrated from one equipment to another without the need to install new specialized hardware, allowing a faster deployment of the services and providing innovation and a great number of opportunities for the world of networked systems. In this paper an overview of NFV technology is presented, explaining its characteristics, enabling technologies, benefits, use cases and challenges, as well as its relationship with another emerging technology as Software Defined Networking (SDN). The architectural framework and a list with more than 170 SND/NFV open-source projects are also provided, at the end it is described the Proof of Concepts (PoCs) and some research lines in this interesting research area.**

***Index Terms*—NFV, virtual network functions, virtual networks, SDN, network architectures, cloud computing.**

I. Introduction

Currently, networking technology is experiencing a software revolution, the network functions and services are moving from hardware mode to software mode, providing the opportunity to have programmable networks and services [1], [2], [3].

Telecoms networks contain an increasing variety of proprietary hardware appliances, and to launch a new network service is required not only another appliance, but also space, power consumption, technical skills, and a big effort to integrate and deploy the service [1].

Some of the challenges experienced by operators include: shorter life-cycle of devices, software bundled with hardware, vendor specific interfaces, slow protocol standardization, long delay to introduce new features, long and complex upgrade cycle, complex configurations in some cases, services are mostly static and dedicated management systems. Networks operators are addressing with increases in CAPEX (investment needed, e.g. dedicated and expensive proprietary hardware) and OPEX (costs of operation and maintenance, e.g. high maintenance cost, power consumption, training) and they are facing a reduction in the return on investment and constraints on innovation [1], [4].

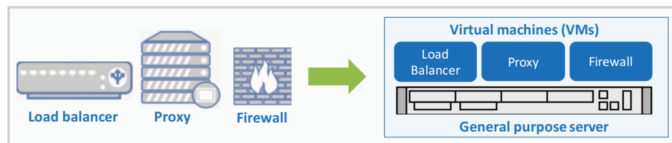

Fig. 1. Vision for NFV

The network operators noticed that the market requirements would not be achieved in the long term due to network capabilities, for these reasons and for those mentioned above, and to deal with current and new services, capacity and functionality requirements NFV technology has been conceived. NFV faces these problems through the implementation of network functions in software, i.e. moving network functions to software, by leveraging standard IT virtualization and cloud technology, consolidating many network equipment (functions) onto industry standard high volume servers [4].

NFV is focused at virtualizing network functions such as: proxies, load balancers, firewalls, gateways, i.e. any network function, running in specialized hardware and migrating them to software-based devices running on virtual machines (VMs). These VMs (VNFs) can run in general purposes servers, and all hardware resources (servers, storage and networking devices) are managed as a common resource pool, and they can be moved, or instantiated in various locations in the network as required, without the need to install new equipment. A pictorial representation of the NFV vision is shown in Fig. 1.

NFV separates functionality from capacity, i.e decouples network services from the hardware that deliver them, as show in Fig. 2, this decoupling increases network elasticity and promotes to heterogeneity.

A VNF itself does not provide a service to end customer, to create a service it is used the Service Chain concept, concept created by the European Telecommunications Standards Insti-

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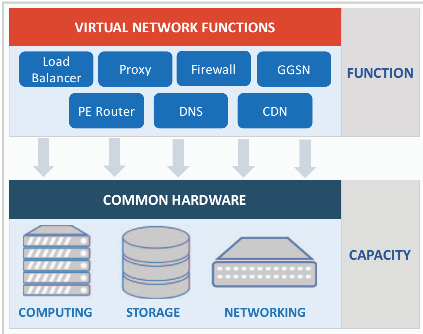

Fig. 2. NFV separtion of functionality from capacity, adapted from [5]

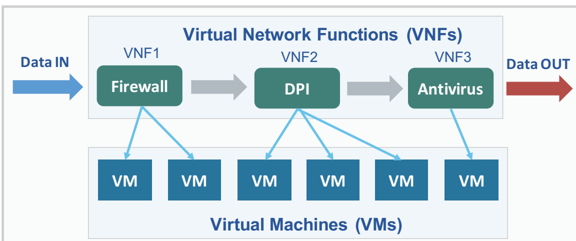

Fig. 3. Example of the deployment of a service through the used of a service chain, adapted from [6]

tute (ETSI) [6]. The Service Chain (SC) also known as Service Chaining or Service Function Chaining (SFC) is a sequence of multiple VNFs that are executed in a given order to deliver a service, a service in the NFV realm is formed by a chain of VNFs. In Fig. 3 is shown a example of a security system composed by three VNFs, which can be deployed in one or more VMs.

In NFV, network services are built by chaining a set of Virtual Network Functions (VNFs) that must be allocated on top of the physical network infrastructure (commodity hardware), this problem is so called resource allocation, placement or embedding problem, and despite that it is a very interesting topic, it goes beyond the scope of the current paper, however good references are [7], [8], [9] and [10].
Despite the fact that this paper tries to cover the most general and important topics about NFV, and because NFV is a very interesting but at the same time an extensive topic, more detailed state of the art works are provided in [11], [12], and [13].

II. NFV Enablers

The main enabling technologies for the development of NFV are: virtualization, cloud technologies and the rising economy of scales related with the production of standard servers [1].
Network Virtualization technology creates an abstracted virtual network on top of a physical network, allowing a large number of multi-tenant networks to run over a physical network. The services associated with the deployment of these virtual networks can be executed in multiple racks in datacenters, in telecommunication nodes also known as Point of Presence (PoP) or even near the user location if necessary. In the first attempts to deploy VNFs it was conceived that each VNF would require a different server, i.e. one server per VNF, but this approach was envisioned as unfruitful because the excess of unneeded resources, and thanks to the use of virtualization technologies, the VNFS can run on VMs and all hardware resources can be managed as a common resource through the use of a hypervisor layer, maximizing the use of hardware resources.
The virtualization technology along with cloud computing principles provide to NFV technology a dynamic operation and on-demand deployment of services. Furthermore, leveraging the economies of scale of the IT industry, specifically with the progress of the industry of standard servers, have helped to change the mentality of the networked systems, moving from expensive proprietary purpose built platforms to low cost generic platforms. While, the technologies described above are very important, it should be remembered that many services could not be implemented without the improved Internet connection speeds provided by ISPs.

III. SDN and NFV

SDN decouples control and forwarding functions separating the control and data plane, and it provides abstraction of network resources, bringing a degree of programability to the network and a simplified network management. The decisions are taken by the controller, which has a entire view of the network, allowing a programmatically control of network resources. Among the main benefits that SDN brings are: a more dynamic network behavior, better utilization of network resources (physical or virtual), control plane becomes directly programmable through the use of APIs and underlaying network can be abstracted from applications and network services. For a more detailed information and for a better understanding of SDN in [14] a survey is provided, although [3] is a more complete survey, information about architecture and terminology is available in [15] and [16], respectively.
NFV separates capacity (hardware) and functionality (software), meanwhile SDN provides programmability to the network, separating the control and data plane. SDN focuses on the virtualization of network devices, and NFV aims to enable the virtualization of network functions and services. Also, SDN is promoted by the Open Networking Foundation (ONF), and NFV is promoted mainly by ETSI and recently by the Internet Engineering Task Force (IETF).
SDN and NFV are totally independent technologies. Network functions can be virtualized and deployed without SDN, and the separation of the control and data plane in SDN can be performed without NFV, but these technologies are inherent complementary, in fact the researches in networked systems have allowed the existence of these technologies, foreseeing that working together they can provide many benefits and developments in the telecommunications realm. The Fig. 4 shows a timeline, from 2006 to the present, with the main proposals and projects in SDN and NFV.

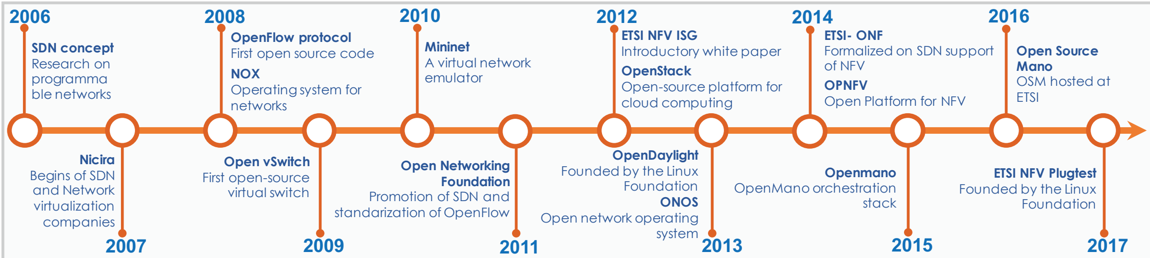

Fig. 4. SDN and NFV timeline, based on [17] and [18]

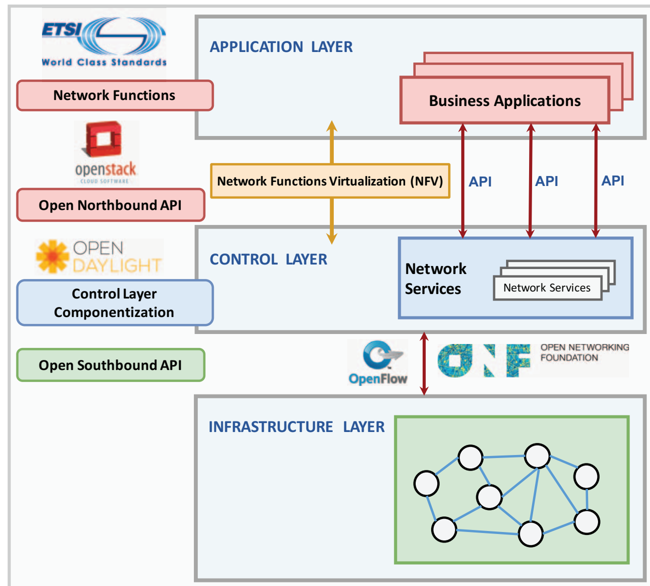

Fig. 5. Integration of NFV/SDN and industry map, adapted from [19]

NFV may improve the efficiency and flexibility of SDN's control plane services, and SDN may ensure the delivery and quality of the network traffic between NFV's virtualized functions. SDN can play a significant role in the orchestration of the NFV infrastructure resources enabling features such as: provisioning and configuration of network connectivity and bandwidth, automation of operations, security and policy control. The SDN controller can be viewed as a component of the NFV infrastructure, and as such, can efficiently work with orchestration systems and control both physical and virtual resources. On the other hand, the SDN controller could be part of a service chain along with other VNFs.
Due to the fact that the goals of SDN and NFV are similar, i.e. to reduce equipment costs and decrease time to market while attaining scalability, elasticity, and a strong ecosystem, since 2014 the ONF has considered has a part of the SDN architecture the NFV technology [19], a pictorial representation of this architecture is shown in the Fig. 5, where it is foreseen that NFV depicts the application layer and that SDN provides the underlying layers that facilitate the deployment of network services. Furthermore, in Fig. 5 are shown the most representative projects in the different layers, projects such as: the OpenFlow protocol [20], the controller OpenDaylight [21] and the cloud computing project OpenStack [22].

The deployment of NFV through their VNFs (such as: firewalls, deep packet inspectors, load balancers, etc.) requires large-scale dynamic network connectivity both in the physical and virtual layers to interconnect VNFs endpoints, which can be provided by an OpenFlow-based SDN solution, because SDN is focused on optimizing the underlying networks. Summarizing, NFV and SDN are are deeply related, together can offer a great opportunity to change how to conceive and build networks, increasing profits and reducing complexity, and changing paradigms of traditional networks.

IV. NFV Benefits, use cases and challenges

A. *Benefits*

The main benefits that NFV technology brings are: reduction in CAPEX and OPEX through reducing equipment costs and related power consumption, reduced time-to-market to deploy new network services and improved return on investment from new services, greater flexibility to scale up, scale down or evolve network services, and opportunities to deploy new innovative services at lower risk [1].
Below a list with the NFV benefits related with the reduction in CAPEX and OPEX is shown.
Reduced CAPEX

- Leveraging Commercial Off the Shelf (COTS) hardware
- Changing from proprietary purpose built platforms

Reduced OPEX

- Less variety and few number of appliances to deploy and maintain
- Faster upgrade cycles, both hardware and software components
- Faster time to market, enabling service innovation
- Adoption of open-source solutions
- Support of multi tenancy, tenants coexisting on the same hardware

B. *Use cases*

NFV could be applied in a variety of scenarios and in fixed and mobile networks, however the most relevant use cases are listed below [1], [6].

- Switching elements: Routers, Broadband Network Gateways (BNG), etc.
- Mobile network nodes: IP Multimedia Subsystem (IMS), HLR (Home Location Register), Radio Network Controller (RNC), Node B, eNode B, etc.
- IP node implementations: Devices capabilities implemented based on the demand evolution
- Tunneling gateway elements: IPSec/SSL Virtual Private Network (VPN) gateways
- Traffic analysis: Deep packet inspectors, Quality of Service (QoS), Quality of Experience (QoE) measurements, traffic monitoring and Service Level Agreement (SLA) monitoring
- NGN signalling: Session Border Controller (SBC), signalling Gateways, etc.
- Converged and network-wide functions: AAA servers, policy control and charging platforms
- Application-level: Content delivery network (CDNs), cache servers, load balancers and application accelerators
- Security functions: Firewalls, virus scanners, intrusion detection systems, etc.
- Virtualization of home devices: Set top boxes, home routers and switches

NFV also allows the proliferation of new cloud oriented service models [23], [24], [25], [26], such as: Network Functions Virtualization Infrastructure as a Service (NFVIaaS), Virtual Network Function as a Service (VNFaaS) and Virtual Network Platform as a Service (VNPaaS).

C. NFV Challenges

Despite the multiple benefits that NFV provides, some challenges have to be taking into account and should be addressed for the deployment of network services[1]. These challenges are listed below.

1) Management: Perfect integration with different hardware vendors, end-to-end automation and orchestration, virtualized network platforms will be simpler to operate than those that exist today.

2) Performance: Comparable performance with physical network functions (PNFs), i.e with traditional network functions.

3) Reliability and stability: Availability of services in carrier grade networked systems. The stability of the network must not be affected when managing and orchestrating a large number of VNFs from different hardware vendors and hypervisors.

4) Security and resilience: Suitable agreements between multiple tenants and network operators to manage and control the physical and the virtual infrastructure, as well as, the automation and orchestration processes, a VNF should be as secure as a VNF. Also, VNFs must be recreated on demand after a failure.

5) Portability/Interoperability: Ability to load and execute VNFs in different but standardized datacenter environments, provided by different vendors and for different operators.

6) Migration and co-existence with legacy & platforms: NFV must work in a hybrid network composed of classical PNFs and VNFs.

7) Management, Orchestration and automation: A consistent management and orchestration architecture is required to leverage the flexibility of VNFs in a virtualization environment.

8) Minimizing energy consumption: Minimization of energy consumption through the use of consolidation, shifting or migration techniques.

9) Standardization: Analyze requirements for technical specifications and standards.

A more detailed discussion about challenges in NFV is provided in [11].

V. NFV ETSI

ETSI NFV is an initiative started in October 2012 when a group of vendors and operators created a new Industry Specification Group (NFV ISG) and published a white paper describing the objectives, the motivations and the use cases [1]. Nowadays, there exist a substantial literature about NFV on the Internet, like the one available at: http://www.etsi.org/technologies-clusters/technologies/nfv.

The most important ETSI NFV ISG Specifications are:

- NFV-INF 001 NFV Infrastructure Overview
- NFV 002 NFV Architectural Framework
- NFV-INF 003 v1.1.1 Infrastructure Compute Domain
- NFV-INF 004 v1.1.1 Infrastructure Hypervisor Domain
- NFV-INF 005 v1.1.1 Infrastructure Network Domain
- NFV-INF 007 v1.1.1 Interfaces and Abstractions
- NFV-INF 010 v1.1.1 NFV Service Quality Metrics
- NFV-MAN 001 v1.1.1 Management and Orchestration
- NFV-REL 001 v1.1.1 Resiliency Requirements
- NFV-SEC 001 v1.1.1 Security Problem Statement
- NFV-SEC 003 v1.1.1 Security and Trust Guidance
- NFV-SWA 001 v1.1.1 Virtual Network Function Architecture

For details about ETSI's current NFV activities, the following link is available: http:www.etsi.org/nfv.

A. NFV Architecture

NFV architecture is composed by three main components: VNFs , VNFI (VNF Infrastructure), and Management and Orchestration (MANO) [4], the architectural framework is shown in Fig. 6. These components are described below.

1) Virtualized Network Functions (VNFs): A VNF is a software implementation of a network function which is capable of running over the NFVI. A VNF can run on one or more VMs, an it is managed by an Element Management System (EMS), which responsible for its creation, configuration, monitoring, performance and security. The EMS provides fundamental information required by Operations Support System (OSS) in a service provider's environment, the EMS performs management functionalities for one or several VNFs.

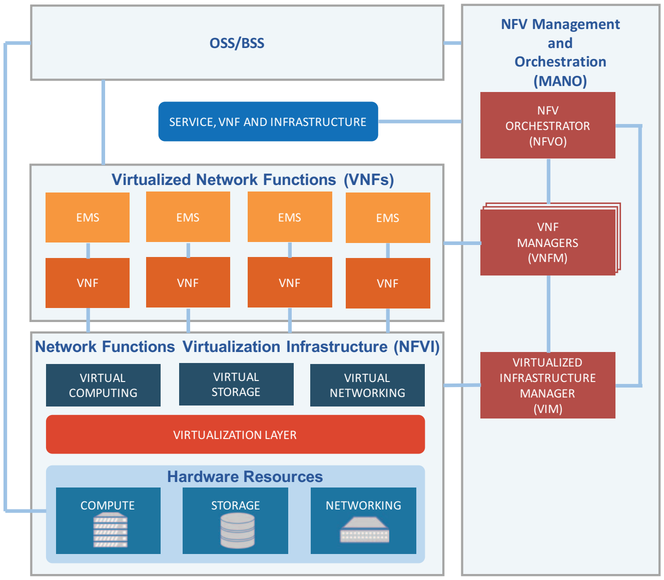

Fig. 6. NFV architecture, adapted from [4]

2) Network Functions Virtualization Infrastructure (NFVI): Physical and software resources, and virtualization layer, on top of which VNFs are executed. The NFVI-PoPs include processing, storage and networking resources. The NFVI is implemented as a distributed set of NFVI nodes deployed in various NFVI PoPs as required, to support the locality and latency objectives of the different use cases and fields of application. The virtualization is an important element in the NFVI domain, because it abstracts the hardware resources and decouples the VNF software from the underlying hardware, thus ensuring a hardware independent lifecycle for the VNFs.

3) Management and Orchestration (MANO): MANO includes all the management and orchestration functions (management of physical and/or software resources) required for managing the lifecycle of VNFs on top of the NFVI. The NFV MANO also interacts with the (NFV external) OSS/BSS landscape, which allows NFV to be integrated into an already existing network-wide management landscape.
The NFV MANO is composed by three key functional blocks: NFV Orchestrator (NFVO), VNF Manager (VNFM), and Virtualized Infrastructure Manager (VIM).

- *NFV Orchestrator (NFVO):* Performs orchestration functions of NFVI resources across multiple VIMs, instantiates VNF Managers, and performs the lifecycle management of network services. The NFVO interacts with the OSS/BSS for provisioning, configuration, capacity management, and policy-based management, NFVO also manages the network service deployment templates and VNF packages. There is usually only one orchestrator that oversees the creation of a network service.

- *VNF Manager (VNFM):* Performs orchestration and management functions of VNFs. The VNFM interacts with the EMS and the VNF for provisioning, configuration, and fault and alarm management. The VNFM is in charge of managing the lifecycle of VNF instances, it is responsible for: initialize, update, query, scale and terminate VNF instances. Each VNF instance must be associated exclusively with a VNFM.
- *Virtualized Infrastructure Manager (VIM):* Performs orchestration and management functions of NFVI resources. The VIM is responsible for controlling and managing the NFVI resources including compute, storage and network resources. VIM provides functionalities for allocating, upgrading and releasing NFVI resources, and it manages the association of the virtualized resources. It is in charge of managing VNF Forwarding Graphs (service chains) in order to create and maintain virtual links, virtual networks, subnet and ports. Multiple VIMs instances may be deployed.

4) Operations Support System (OSS) and Business Support Systems (BSS): OSS are the general management systems that together with BSS, help providers to deploy and manage various end-to-end telecommunications services (such as orders, billing, troubleshooting, etc.). OSS deals with: network, fault, configuration, service and element management, meanwhile BSS deals with: customer, operations, order, billing and revenue management.

B. NFV projects

There are a large numbers of open-source solutions, not only for NFV but also for SDN, among the most well know are: Openflow [20], Mininet [27], OpenDaylight [21], OpenStack [22], OpenMano [28], Open Source Mano (OSM) [29] and Open Platform for NFV (OPNFV)[30]. In the current paper as an appendix, an updated and detailed list with the information of more than 170 open-source SDN/NFV projects is provided, this list is also available at: https://goo.gl/4phqXW.

C. NFV Research

In order to encourage research around NFV in [23] a number of research topics have been listed, some examples include:

- Service chaining algorithms
- NFV orchestration algorithms
- Abstractions for carrier-grade networks and services
- Performance studies: scheduling, optimization, portability and reliability
- Security of NFV Infrastructure
- Impacts of data plane workloads on computer systems architectures
- Performance monitoring and reliability of network services
- Energy-efficient NFV architectures
- New network topologies and architectures
- Tools and simulation platforms

D. NFV Proof of concepts

NFV ISG has defined a framework for coordinating and promoting public demonstrations of Proof of Concept (PoC) platforms. The objective is to encourage the development of an open ecosystem by integrating components from different players and to delineate goals for NFV adoption, as well as to achieve industrial awareness and confidence in NFV's ability to become a workable and trusted technology. NFV PoCs also help guide ETSI NFV ISG by offering insightful feedback on interoperability and other technical barriers. The numbers of proofs are growing up and the results are being openly available, in [31] the NFV ISG provide a list and relevant information about NFV PoCs, at the moment of the writing of this paper have been performed more than 40 PoCs.

VI. Conclusions

In this paper is presented an overview of NFV technology, describing its technical characteristics, benefits and the enabling technologies, as well as summarizing several use cases, challenges and the relationship and the evolution with SDN technology. It is illustrated its architectural framework as defined by ETSI, a classification of SDN and NFV open-source projects is provided, and some interesting future research and PoCs are described. NFV abstracts the network functions from hardware where they run making network equipment more open, these virtual functions can be executed in virtual machines and in a certain order allowing to offer more agile and flexible current and new network services, giving a large number of options and promoting innovations to both operators and users. NFV separates the functionality from capacity and along with SDN are envisioned to become critical technologies to change the conception of the current networked systems, providing the creation of a network softwarization ecosystem for future telecommunication service provision.

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Appendix A
SDN/NFV Open-Source Projects

In this section is shown a list of SDN and NFV open-source projects, which is available at:
https://goo.gl/4phqXW.