Management and Orchestration Challenges in Network Functions Virtualization

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NFV continues to draw immense attention from researchers in both industry and academia. By decoupling NFs from the physical equipment on which they run, NFV promises to reduce CAPEX and OPEX, make networks more scalable and flexible, and lead to increased service agility. However, despite the unprecedented interest it has gained, there are still obstacles that must be overcome before NFV can advance to reality in industrial deployments, let alone delivering on the anticipated gains.

ABSTRACT

NFV continues to draw immense attention from researchers in both industry and academia. By decoupling NFs from the physical equipment on which they run, NFV promises to reduce CAPEX and OPEX, make networks more scalable and flexible, and lead to increased service agility. However, despite the unprecedented interest it has gained, there are still obstacles that must be overcome before NFV can advance to reality in industrial deployments, let alone delivering on the anticipated gains. While doing so, important challenges associated with network and function MANO need to be addressed. In this article, we introduce NFV and give an overview of the MANO framework that has been proposed by ETSI. We then present representative projects and vendor products that focus on MANO, and discuss their features and relationship with the framework. Finally, we identify open MANO challenges as well as opportunities for future research.

INTRODUCTION

In recent years, telecommunication service providers (TSPs) have experienced constant dwindling in revenue. This has been attributed, in part, to two main factors. On one hand, the seemingly insatiable traffic demands of subscribers require physical network expansions, which are achieved at increased capital expenditures (CAPEX) and operating expenditures (OPEX) [1]. On the other hand, competition both among themselves and from over-the-top service providers means that TSPs cannot respond to the increased costs with increased subscriber fees.

Network functions virtualization (NFV) [2] has been identified as a potential solution to these problems. The main concept of NFV is the decoupling of network functions (NFs) from capacity (the physical infrastructure on which they run). Breaking the bond between NFs and hardware promises several advantages. First, there is a potential for significant reductions in OPEX through more efficient operations, since most maintenance and updates to NFs can be performed remotely and at scale. In addition, the increased flexibility can lead to more efficient utilization of resources and hence reductions in CAPEX, since TSPs could use the existing network capacity for more user traffic. Finally, NFV may lead to better service agility by allowing TSPs to deploy and/or support new network services faster and less expensively.

These expectations have made NFV a burgeoning research field. The most notable NFV activities are being led by the European Telecommunications Standards Institute (ETSI). The main objective of the ETSI NFV group[1] is to develop standards for NFV as well as share experiences of its development and early implementation. To this end, they have defined the NFV problem, some use cases, a reference architecture, and a management and orchestration (MANO) framework, among other items [3].

However, while a lot of progress has been made, there are still many technical challenges, which must be overcome before the gains anticipated from NFV can come to fruition. Among them, MANO challenges have drawn special attention. The reason behind this interest is that MANO is a critical aspect in ensuring the correct operation of the NFV infrastructure (NFVI) as well as virtual network functions (VNFs). MANO provides the functionality required for the provisioning of VNFs, and related operations such as the configuration of VNFs and the infrastructure on which these functions run. It includes the orchestration and life cycle management of physical and/or virtual resources that support the VNFs [4]. Just like the decoupled NFs, NFV demands a shift from management models that are device-driven to those that are aware of the orchestration needs of NFs running in a virtualized environment. We believe that for NFV to succeed, the main MANO challenges should be addressed at the current specification phase, rather than later when real large-scale deployments commence.

In this article, we survey current efforts that address NFV MANO. In particular, in the next section, we begin by summarizing the MANO framework that has been proposed by ETSI. We then overview representative projects and vendor products that focus on NFV MANO. We classify these projects and products in two ways. First, we map their functionality to the functional blocks of the ETSI MANO framework, and then we study their features based on four criteria:

- Management approach (centralized, distributed, policy-based, self-managed)

[1] http://www.etsi.org/technologies-clusters/technologies/nfv

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- Management functions supported (fault, configuration, accounting, performance, and security: FCAPS)
- Scope (functions, services, network)
- The integration of management with that of software defined networking (SDN) and cloud computing, both of which are complimentary and/or enablers of NFV

Finally, we identify open challenges and discuss opportunities for future research, before concluding the article.

ETSI MANO Framework

The ETSI MANO framework [4] is shown in Fig. 1. The functional blocks in the framework can be grouped into three main entities:
- NFV architectural layers
- NFV management and orchestration
- Network management systems

These entities, as well their constituent functional blocks, are connected together using a set of defined reference points.[2] The NFV architectural layers include the NFVI and VNFs. NFVI is the combination of both hardware and software resources that makes up the environment in which VNFs are deployed, while VNFs are implementations of NFs that are deployed on those virtual resources.

NFV Management and Orchestration

The NFV MANO consists of three functional blocks: the virtual infractructure manager (VIM), NFV orchestrator (NFVO), and VNF manager (VNFM); and four data repositories: NS catalog, VNF catalog, NFV instances, and NFVI resources.

VIM: A VIM manages and controls NFVI physical and virtual resources in a single domain. This implies that an NFV architecture may contain more than one VIM, with each of them managing or controlling NFVI resources from a given infrastructure provider. In principle, a VIM may be specialized in handling a certain type of NFVI resource (e.g., compute-only or storage-only), or could manage multiple types of NFVI resources (e.g., nodes in the NFVI).

VNFM: Each VNF instance is assumed to have an associated VNFM. The VNFM is responsible for the management of the life cycle of VNFs. A VNFM may be assigned the management of a single or multiple VNF instances of the same or different types, including the possibility of a single VNFM for all active VNF instances for a certain domain.

NFVO: The NFVO aims to combine more than one function to create end-to-end services. To this end, the NFVO functionality can be divided into two broad categories: resource orchestration and service orchestration. The first is used to provide services that support accessing NFVI resources in an abstracted manner independent of any VIMs, as well as governance of VNF instances sharing resources of the NFVI. Service orchestration deals with the creation of end-to-end services by composing different VNFs, and the topology management of the network service instances.

Data Repositories: Data repositories are databases that keep different types of information in the NFV MANO. Four types of repositories can be considered:

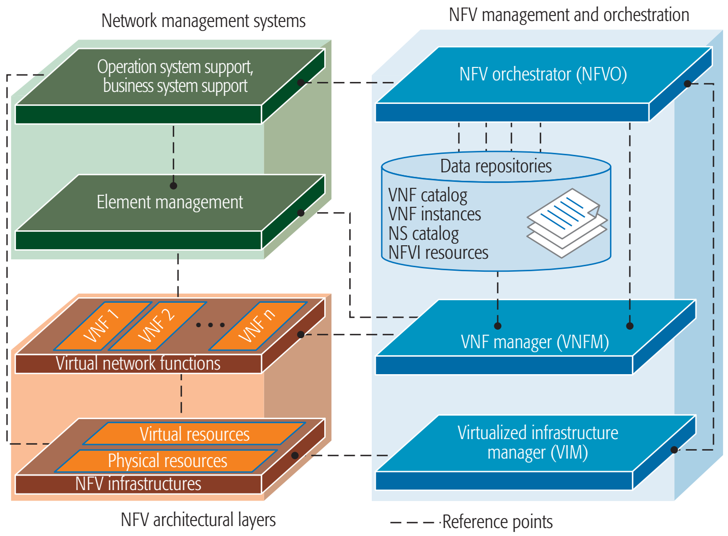

Figure 1. ETSI NFV MANO Framework.

- The NS catalog is a set of predefined templates, which define how services may be created and deployed, as well as the functions needed for the service and their connectivity.
- The VNF catalog is a set of templates that describe the deployment and operational characteristics of available VNFs.
- The NFVI resources repository holds information about available/allocated NFVI resources.
- The NFV instances repository holds information about all function and service instances throughout their lifetimes.

Network Management Systems

NFV is not intended to require a drastic change in the current mechanisms of network service provisioning, and is aimed at a gradual transition from network infrastructures based on physical nodes, easing the integration in a heterogeneous environment. Therefore, network management systems will continue to have a key role in NFV, coordinated with the MANO entities by means of a clear separation of roles. MANO entities will deal with those aspects related to the virtualization mechanisms, while network management functions are expected to take care of the features associated with the semantics of the specific network services being provided by the composition of VNFs and, potentially, physical nodes. These network management systems include element management (EM), operation system support (OSS), and business system support (BSS).

Projects Related to NFV MANO

CloudNFV

CloudNFV[3] is an open platform for implementing NFV based on cloud computing and SDN. The CloudNFV architecture, illustrated in Fig. 2, is made up of three main elements: active virtualization, NFVO, and NFVM. Active virtualization is a data model (based on TM Forum's SID [5]), which represents all aspects of services, functions, and resources. It is made up of

[2] A reference point is a conceptual point at the conjunction of two communicating functional entities. A detailed description of all the reference points in the ETSI NFV MANO framework can be found in [4].

[3] www.cloudnfv.com/WhitePaper.pdf

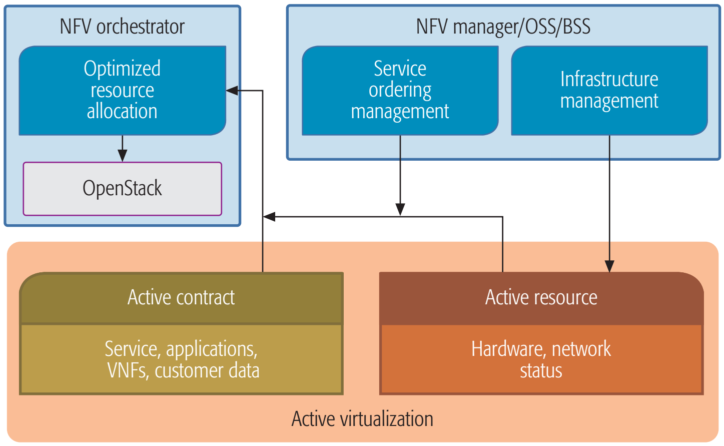

Figure 2. CloudNFV Architecture.

an active contract and active resource. Active resource describes the status of all resources in the infrastructure, while active contract includes all service templates that define the characteristics of all the available NFs. The orchestrator has policy rules, which, combined with service orders and the status of available resources, determine the location of the functions that make up the service as well as connections between them.

After service deployment all resources report their status and traffic to the active resource. The management processes running against active resources allow reflection of this status using management information bases (MIBs). The main difference between the ETSI NFV MANO and CloudNFV is that unlike the former, the latter considers both management and orchestration as applications that can run off a unified data model.

ExperiaSphere

ExperiaSphere[4] is a MANO model for NFV, which is based on a combination of open source tools. ExperiaSphere is founded on the concept of service models. These define how resources expose service features and how the functions decompose to resources. The service models are then used by a broker who selects one or more required service models to create a service instance. Once the service instance is created, its status is tracked throughout its life cycle. To achieve these objectives, ExperiaSphere is based on two principles: structured intelligence and derived operations.

Structured intelligence uses an integration of Universal Service Definition Language (USDL) and topology and orchestration specification for cloud applications (TOSCA) [6] to define the relationship between service elements, service goals, and the infrastructure. Derived operations allow virtualized services and resources to be managed as if they were physical. The management functions operate on virtual elements of the service, using variables defined per element but derived from the state of real resources.

OpenMANO

OpenMANO [7] is an open source project led by Telefonica, which is aimed at implementing the ETSI NFV MANO framework, and addressing the aspects related to performance and portability by applying Enhanced Platform Awareness (EPA)[5] principles. As shown in Fig. 3, the OpenMANO architecture consists of three main components: openmano, openvim, and a graphical user interface (GUI). In addition, there are two command line interfaces (CLIs) used to interact with openmano and openvim.

openvim is a lightweight, NFV-specific VIM implementation directly interfacing with the compute and storage nodes in the NFVI, and with an openflow controller in order to create the infrastructural network topology, and enforce the EPA principles mentioned above. It offers a REST-based northbound interface (openvim application programming interface: API) to openmano, where enhanced cloud services are offered including the life cycle management of images, flavors, instances, and networks. The openvim API extends the OpenStack API to accommodate EPA. OpenMANO has a northbound interface (openmano API) based on REST, where MANO services are offered including the creation and deletion of VNF templates, VNF instances, network service templates, and network service instances.

OPNFV

OPNFV[6] is an open source project founded and hosted by the Linux Foundation, and composed of TSPs and vendors. The objective is to establish a carrier-grade integrated open source reference platform that may be used to validate multi-vendor interoperable NFV solutions. OPNFV plans to validate existing standard specifications, contribute improvements to relevant upstream open source projects, and develop necessary new functionality within both OPNFV and upstream projects. In particular, it is focused on implementing the NFV requirements provided by ETSI. To this end, the first outcome of the project, referred to as OPNFV Arno, was released in June 2015. Arno is an initial build of the NFVI and VIM components of the ETSI architecture.

ZOOM

ZOOM[7] is a TM Forum project aimed at enabling the deployment of services by automating the provisioning process through improved OSS/BSS models. To achieve this, the project regularly conducts a range of hands-on technology demos each of which is developed from what they call a *catalyst project*. Each catalyst project is sponsored by one or more network operators and equipment and software vendors in a real-world demo. The project currently runs about nine catalysts with a focus on NFV aspects including end-to-end automated management of hybrid networks, and demonstrating the impact and value of dynamic security orchestration in an NFV environment.

Pre-Standardization NFV MANO Products

CloudBand

Alcatel-Lucent's CloudBand[8] is an NFV platform comprising software and hardware stacks with two elements: a node and a management system. The CloudBand node provides the com-

[4] http://www.experiasphere.com/

[5] https://01.org/sites/default/files/page/openstack-epawpfin.pdf

[6] https://www.opnfv.org/

[7] https://www.tmforum.org/collaboration/catalyst-program/current-catalysts/

puting, storage, and networking hardware to host cloud services, while the management system is the MANO element of CloudBand. The management system aggregates distributed cloud resources — the nodes — to provide a view of the entire NFVI as a single pool. It orchestrates, automates, and optimizes VNFs across the service provider's network and data centers.

Ensemble Service Orchestrator

Overture's Ensemble Service Orchestrator (ESO)[9] is an NFV service and VNF life cycle management and orchestration system. The system coordinates and connects virtual resources to physical network elements to create virtualized services across multiple networking layers. ESO supports the placement of VNFs in centralized as well as distributed data centers. It uses the OpenStack cloud controller to manage the virtual computing environment, including virtual machines, virtual switches, and data center switches. ESO is the key component of Overture's Ensemble Open Service Architecture (OSA), which is a framework for service MANO.

OpenNFV

HP's OpenNFV[10] is an NFV platform that leverages open source technology to provide an open end-to-end NFV and SDN infrastructure. OpenNFV is aligned toward providing solutions to each of the functional blocks defined in the ETSI NFV reference architecture. With regard to MANO, OpenNFV includes three solutions; NFV director, NFV manager, and Helion OpenStack.

The NFV director is an NFVO that can be used to automate the deployment and monitoring of a VNF ecosystem. Its aim is to ensure that each VNF can efficiently run on heterogeneous hardware platforms and virtualization environments. VNF managers are responsible for the VNFs life cycle actions (e.g., by deciding to scale up or down). The Helion OpenStack provides an open source cloud platform for running VNFs.

Open Network Strategy

Cisco's Open Network Strategy (OPN)[11] includes a services orchestrator, a VNFM, and an SDN controller, all of which are aimed at providing implementations for some of the functional blocks of the ETSI MANO framework. The services orchestrator is responsible for providing the overall life cycle management at the network service level. It uses model-based workflows that enable the design of services based on predefined service elements. The VNFM provides VNF life cycle management, including the creation, provisioning, and monitoring of both Cisco and third-party VNFs. Finally, the SDN controller is responsible for connecting the virtualized services to the service provider VPNs, the Internet, or both.

Planet Orchestrate

Planet Orchestrate is part of Cyan's Blue Planet Suite,[12] which is an SDN and NFV platform aimed at service orchestration, automation, SDN control, and multi-vendor management capabilities. Its functionality is based on the requirements of ETSI's NFV MANO framework. It uses TOSCA templates and information models to define service components and their relationships.

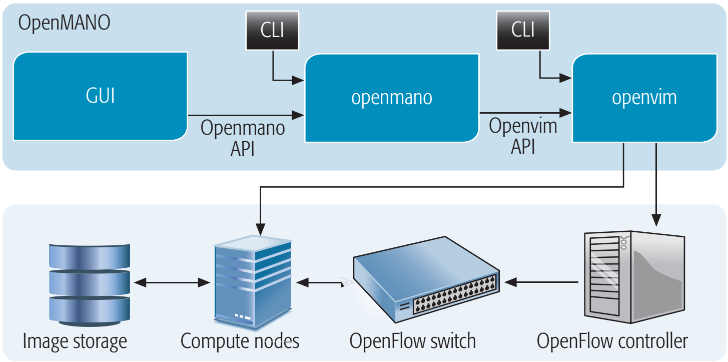

Figure 3. Telefonica's OpenMANO Architecture.

Planet Orchestrate can perform VNF management and orchestration functionality. The NFV orchestration engine performs placement of VNFs and supports distributed NFVI to optimize use of NFV resources. On the management side, it supports the performance, availability, and security demands of service provider applications. Performance monitoring and alarm/event reporting is provided for the NFVI and virtual functions. Intrinsic knowledge of the topology and the mapping between application and virtual resources enables fault isolation and recovery as well as high availability and resiliency.

Summary: In Tables 1 and 2, we summarize current activities toward NFV MANO. In Table 1, we map the functionalities of each project or product to the functional blocks of the ETSI NFV reference architecture. We can observe that most projects or products choose to rely on existing infrastructures and cloud systems such as OpenStack for achieving the NFVI and some form of data modeling and storage to model and store VNFs. On the MANO side, it can be noted that almost all propose a solution for each of the three functional blocks, VIM, VNFM, and NFVO. The difference, however, is in the functionality. This can be observed in Table 2, which summarizes the management and orchestration functionality of each project/product based on their description. For this purpose, we define four functionality categories. The management approach classifies them based on whether they are centralized, distributed, policy-based, or automated (self-managed). The management function classifies them according to their support for five of the basic management functions — FCAPS. We define the management scope to include functions, services, and networks. An approach is classified as a network management one if it proposes functionality to manage network nodes and links, while service management applies to an approach that manages both functions and their connectivity or chaining to form a service. Finally, since SDN and cloud computing are very important technologies with regard to NFV, we also categorize a project/product based on its ability to manage the interactions between SDN and/or cloud and NFV.

[8] http://resources.alcatel-lucent.com/asset/180265

[9] http://www.overturenetworks.com/products/network-virtualization/

[10] http://www8.hp.com/us/en/cloud/nfv-architecture.html

[11] http://www.cisco.com/c/en/us/solutions/collateral/service-provider/network-functions-virtualization-nfv/white-paper-c11-732123.html

[12] http://www.cyaninc.com/products/blue-planet-sdn-platform

	NFV architectural layers		NFV MANO framework				Traditional management systems	
	NFVI	VNFs	VIM	VNFM	NFVO	Data repositories	OSS/BSS	EM
CloudBand	Nuage, RedHat, CloudBand	VNF Modelling (TOSCA)	CloudBand node	CloudBand Management System	CloudBand Management System	✓		
CloudNFV	Active eesource	Active Contract	Infrastructure manager	OSS/BSS	✓	Active Contract	✓	OSS/BSS
ESO		✓	Ensemble network controller (ENC)	ESO	ESO	Database		
Experia-Sphere	Resource somain	TOSCA, USDL	Infrastructure manager	State-action service life cycle management	State-action service life cycle management	Derived operations	State-action service life cycle management	Derived operations
OpenMANO	✓	✓	Openvim		OpenMANO			
OPN			SDN Overly Controller	✓	Services orchestrator			
OpenNFV	✓		HP Helion Open-Stack Carrier Grade	✓	HP NFV director	HP NFV director	✓	
OPNFV	✓		✓					
Planet Orchestrate				✓	✓			
ZOOM			✓	✓	✓	Shared catalog	Order, SLA, and billing management systems	

Table 1. Mapping of state-of-the-art projects and products to the ETSI MANO.

Challenges and Research Opportunities

Resource Management

The servers used to host VNFs have a finite amount of memory, compute, and storage capacity. And since in practice these servers may be distributed across multiple domains, inter-domain link capacity will also be finite. Therefore, to achieve the economies of scale expected from NFV, physical resources should be efficiently managed. Dynamism, scalability, and automation are important features of such resource management. In this context, we identify three main challenges as listed below.

NFV PoP Locations: The first item is determining the locations of NFV points of presence (PoPs) [3]. In cases where the VNFs will be hosted in operator network nodes, it is necessary to decide which subset of the nodes can be used as NFV PoPs. As this does not have to be done often, it could be formulated as an optimization problem with the objective of considering the (latency to the) location of subscribers, and the setup and maintenance costs of both servers as well as fronthaul links in the case of virtualized radio access networks.

Function Placement: In order to compose a service, its constituent functions must be deployed. Decisions must be made on where functions should be placed among the available PoPs. This problem is related to the virtual network embedding (VNE) [8], and similar approaches may be applied. To this end, it may be formulated as a mathematical problem with such objectives as load balancing and energy conservation. However, any such formulation should be able to take the function chaining and/or precedence requirements into consideration to avoid network congestion.

In addition, while most current NFV proofs of concept have been based on each VNF being hosted by a dedicated VM, such an approach would not scale, especially for light functions such as those that are part of customer premises equipment. In this case, it would be more efficient to host multiple functions in a single VM by use of docker containers. In this case, there would be a need for scheduling approaches (e.g., [9]) for allocating the VM resources.

Dynamic Resource Management: One of the selling points of NFV is the ability to scale resources dynamically. There must be capabilities to increase or reduce the amount of resources allocated to specific functions or VMs. While current virtualization or cloud platforms allow for this, many of them require a manual trigger by the user or resource owner. Therefore, automation and self-allocation mechanisms that allow the network to dynamically manage resources are critical to the success of NFV.

Distributed Management

Current MANO approaches mainly focus on centralized solutions, which pose scalability limitations, especially in scenarios where services span multiple administrative domains. This is mainly attributed to the communication overhead and the delay incurred by the collection and analysis

		Cloud-Band	Cloud-NFV	ESO	Experia-Sphere	OpenMA-NO	OPN	Open-NFV	OPNFV	Planet Orchestrate	ZOOM
Management approach	Centralized	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Distributed										
	Policy-based	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Self-managed	✓		✓	✓		✓	✓		✓	✓
Management function (FCAPS)	Fault			✓			✓		✓	✓	✓
	Accounting					✓			✓		
	Performance	✓	✓	✓		✓	✓	✓		✓	✓
	Security	✓								✓	✓
Management scope	Functions			✓		✓	✓		✓		✓
	Services	✓	✓	✓	✓	✓	✓			✓	✓
	Network			✓						✓	✓
Managing related areas	SDN	✓				✓	✓		✓		
	Cloud	✓	✓		✓			✓	✓	✓	✓

Table 2. Characteristics of state-of-the-art projects and products.

of data associated with a large number of heterogeneous sources, which prevents these processes from being executed frequently. As a result, the lag in learning the state of services and resources does not allow for online reconfiguration operations. To better react to demand dynamics but also to changing service requirements, efficient monitoring mechanisms need to be implemented, which feed distributed management entities the necessary information to perform dynamic configuration changes. A communication protocol to support lightweight coordination among distributed decision makers, aiming to optimize the usage of resources and the performance of services, is another key research issue.

Management of SDN

While NFV and SDN are not dependent on each other, they are closely related and complementary. Individually, NFV and SDN introduce high levels of dynamism and variability, which curtails the visibility and control of human operators. Therefore, traditional management approaches must be improved to accommodate each of them. While some claim to be based on SDN, all the surveyed projects and solutions focus on managing virtualized compute infrastructure/resources and functions. In the same way, from the SDN perspective, the focus is on managing networks in a programmatic way. We are not aware of management solutions that combine both, which is a key research area. In addition, the management of SDN itself still has open questions [10] such as the number of controllers, their location, and avoiding conflicts in cases where more than one controller manages a given forwarding element. In this case, ideas from policy-based management that have been proposed in most of the surveyed MANO solutions may be extended to SDN.

Security in the Cloud

As SDN and NFV focus on the remote programmability of network resources and their functions, it opens up an important set of new potential threats and attacks that, if successful, could have a far greater impact than in a non-NFV environment. The ETSI NFV security group recently drafted a document that defines the possible security threats that NFV brings to the table.[13] The document is a statement regarding possible security problems but does not yet provide a recommendation to tackle them. Partly because of this, security is currently underdeveloped. Of the surveyed projects and solutions, only CloudBand proposes a comprehensive security solution including anomaly prediction, detection, and isolation, as well as providing security as a service. In the case of ZOOM and Planet Orchestrate, security support is claimed based on a set of best practices and integration with another product, respectively.

Therefore, real security support is lacking in all NFV products, despite the relevant new threats. Important security challenges in this area are detecting and blocking possible intrusion. Specifically, in multi-vendor environments, there are new security concerns of one TSP competitor having access to another TSP's data/configuration. In such a case, isolation between them is important.

Management across the Board

Most solutions provide a way to perform configuration. A limited number add performance management as well, and, as discussed above, only a few provide — albeit limited — security management too. In most solutions, accounting management is completely overlooked. As such, there are currently no ways to track network utilization to ensure that individual parties can be appro-

[13] NFV Security; Problem Statement. Bob Briscoe (Rapporteur). Draft Group Specification published, Oct 2014.

While remarkable progress has been made by ETSI in defining the NFV MANO framework and the constituent (intra-operator) interfaces, there is still much to be done in terms of defining interfaces aimed at supporting interoperability between different vendors with different functions.

priately billed for their use. This is very contradictory given the openness that NFV promises, especially in introducing a more multi-vendor world where different parties can coexist on the same device through virtualization.

More generally, the management of the entire service life cycle is still missing. One of the unique selling points of NFV is that it promises to automate the entire process of setting up and removing a service (chain), including configuration, performance optimization, response to faults, and billing. With support for accounting missing in all products, this promise has not yet been delivered. One of the reasons is that accounting is often heavily intertwined with legacy solutions. Providing support for all FCAPS functionality is therefore highly challenging, but at the same time very important for NFV to really bring a change to the telco world.

Programmability and Intelligence

Given that NFV envisions the deployment and maintenance of complex services across heterogeneous physical resources, a rich set of programmable interfaces should be developed, which will extend the current SDN functionality beyond the scope of controlling simple connectivity resources. Based on the abstraction of the flow, SDN solutions control the distribution of traffic in the network according to forwarding rules. Additional abstractions that apply to computation and storage resources are required so that network functions can be instantiated across multiple vendor technologies, but also interfaces that will allow dynamic (re-)programming of the configuration of those functions and control (e.g., their placement).

A related research challenge concerns the level of intelligence that can be achieved. This is defined by the way in which services are programmed (e.g., declaratively) and the degree to which parameters can be configured. A MANO system should be intelligent enough so that (re-) configuration operations can be automated to a large extent, especially those that react to runtime events. In this respect, intelligent mechanisms that automatically transform high-level policy to operational parameters and perform configuration integrity checks are of paramount importance.

Interfacing and Interoperability

One of the main goals of NFV is to break the bond between equipment vendors and TSPs, and the services they provide. One key requirement for this is support for interoperability. While remarkable progress has been made by ETSI in defining the NFV MANO framework and the constituent (intra-operator) interfaces, there is still much to be done in terms of defining interfaces aimed at supporting interoperability between different vendors with different functions. Interoperability problems can already be observed in all the surveyed projects and solutions. For example, while they all are "based on the ETSI MANO framework," each of the projects and solutions surveyed uses a custom model and/or representation for functions and services. This would mean that unless clear interfaces are defined, it is impossible to chain functions from different operators into a single service. This is because while ETSI proposes VNF and network service descriptors as templates for definition of functions and services, it does not define a data model to realize descriptors.

In this direction, the Alliance for Telecommunications Industry Solutions (ATIS)[14] has been focused on inter-carrier interoperability, new service descriptions, and automated processes. While ATIS has recently proposed seven inter-provider use cases aimed at the same, these are generally generic descriptions. In particular, they do not define any technical requirements or solutions that could be used to enable the use cases.

Conclusion

In this article, we present an overview of the NFV MANO framework recently proposed by ETSI as well as representative projects attempting to realize the framework. Other research projects as well as industry products focused on NFV MANO have been surveyed, identifying their functionality as well as their mapping to the ETSI NFV MANO. Based on these, we identify and discuss open challenges as well as opportunities for research with regard to MANO in NFV.

We have observed that while ETSI completed the first phase of work, the proposed MANO framework still lacks details and standards on the implementation for both the managers as well as the interfaces. As a result, most of the pre-standardization solutions are in fact customized and based on proprietary solutions, which will likely lead to interoperability issues. In addition, while some of the identified challenges such as security are being considered in some of the projects and/or industrial products, others such as resource management — in particular automated resource management — have not received significant attention yet. It is our opinion that the success of NFV will depend, in part, on the availability of mechanisms that are able to autonomously manage network and function resources.

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Diego Lopez received an M.S. from the University of Granada in 1985 and a Ph.D. degree from the University of Seville in 2001. He joined Telefonica I+D in 2011 as a senior technology expert and is currently in charge of the Technology Exploration activities within the GCTO Unit. He is focused on network virtualization, infrastructural services, network management, new network architectures, and network security. He actively participates in the ETSI ISG on NFV (chairing its Technical Steering Committee), the ONF, and the IETF WGs connected to these activities.

While ETSI completed the first phase of work, the proposed MANO framework still lacks details and standards on the implementation for both the managers as well as the interfaces. As a result, most of the pre-standardization solutions are in fact customized and based on proprietary solutions.