Overview of 9 Open-Source Resource Orchestrating ETSI MANO Compliant Implementations: A Brief Survey

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***Abstract*—Cloud computing, Network Function Virtualization (NFV), and programmable infrastructures such as Software-Defined Networking (SDN) are transforming ICT business models. These technologies work in an integrated pattern to deliver full management of network service lifecycles at reasonable costs. Coordinating resource control and service creation across these technologies is currently a grand challenge. This is commonly known as network Management and Orchestration (MANO). To date, there has been several research and development efforts dedicated to orchestration platforms, to enable automatic deployment and operation of end-to-end communication services. In this paper, we present a feature-based comparison of popular open-source MANO projects. Each of these projects is mapped to the ETSI NFV MANO reference standard, that specifies the key functional blocks required for network service orchestration in virtualized environments. Our results show that ONAP and OSM orchestration platforms are fully compliant to ETSI NFV MANO and support multi-technological domains (i.e. SDN and NFV). It was established that ONAP, although complex, is much more complete than OSM, and has been adopted by a larger group of global service providers.**

***Index Terms*—Software Defined Networking (SDN), Network Function Virtualization (NFV), Cloud Computing, Management and Orchestration (MANO), ETSI NFV MANO, Lifecycle Management**

I. Introduction

A major topic in the telecom industry today is how to deploy and operate an affordable, efficient, scalable, and automated network infrastructure. One of the biggest hurdles is being able to offer highly reliable services while maintaining business agility and ensuring swift deployment of new services at minimal costs. A potential solution to this predicament is a combination of software defined networking (SDN), network functions virtualization (NFV), and cloud computing.

Cloud computing is a model for on-demand delivery of computing resources including servers, storage, networking, software and databases over the internet to enable economies of scale, flexible resources and lower operating cost. Cloud computing has already been a roaring success. However, network operators are rapidly realizing the value of NFV and SDN as well. While cloud computing supports software applications, NFV virtualises the legacy purpose-built network functions, allowing network operators to run their networks on virtual machines and containers. SDN allows administrators to program the forwarding behavior of virtual networks from a remote centralized console, thereby ensuring better quality of service.

Together cloud computing, NFV and SDN allow network operators to harness the true power of virtual computing as they promise agility, flexibility and responsiveness. All these are features which operators so desperately desire [2]. Importantly, leveraging these networking paradigms is anticipated to significantly reduce the cost of network commissioning as well as the operating costs. In order to realise these paradigms, there is a need for orchestration processes to optimize and automate tasks regarding resource management and service provisioning in the virtualized environment. The European Telecommunications Standards Institute (ETSI) Industry Specification Group (ISG) NFV [3], has developed a reference architectural framework and specifications for NFV network service orchestration and lifecycle management. This specification is commonly known as the ETSI NFV management and orchestration (ETSI NFV MANO). The ETSI NFV MANO specification proposes functional blocks of a MANO solution and does not propose a specific implementation [4].

To date there has been an influx of open-source NFV network service orchestration implementations based on the ETSI NFV MANO architecuture. This study presents some of the most popular open-source MANO practical implementations and compares each platform with the ETSI NFV MANO specification. The aim of this study is to facilitate decision making regarding a suitable orchestration platform to meet different requirements. An ideal MANO platform is one that complies with the ETSI NFV MANO reference framework and support resource orchestration across SDN, NFV and cloud domains [5]. Other factors that largely influence the decision regarding the best orchestrator to adopt include maturity of the orchestrator, community support, and multi-domain support.

This paper is organized as follows: Section II presents an overview of SDN, NFV and cloud computing network paradigms as well as the ETSI NFV MANO reference architectural framework. Section III reviews the state of the art on management and orchestration, Section IV describes some of the most prominent MANO implementations and compares them with the ETSI MANO reference framework. Lastly, Section V concludes the paper.

II. Cloud Computing, NFV and SDN overview

Network service orchestration can be rooted back to three emerging technologies namely, cloud computing, SDN and NFV. The network service orchestrator is responsible for global orchestration of the multi-layer (packet/optical) network resources and distributed cloud infrastructure resources [1]. This orchestrator as illustrated in Figure 1, sits at the top of the network stack. It consists of three types of administrative-domain orchestrators namely a cloud orchestrator (also known as a data center (DC) virtual infrastructure manager (VIM)), a transport SDN orchestrator (WAN infrastructure manager (WIM)), and a virtual network function (VNF) manager.

This section presents an overview of cloud computing, SDN, NFV networking paradigms and their relationships to orchestration.

A. Cloud Computing

Cloud computing is the on-demand delivery of computing services including data storage and networks over the internet. There are three models of cloud services namely, Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS), which offer, respectively, compute resources complemented by cloud storage and network capability, platform for development and deployment of software, and internet-based applications [6]. In a cloud environment, the notion of orchestration has been used to dynamically deploy cloud resources and services across distributed heterogeneous data center infrastructures (micro, small and core) to meet tenants' needs [7]. In particular, cloud orchestration automates tasks such as the creation, runtime lifecycle tasks (such as scaling, fault recovery, redundancy etc.), termination of virtual machines/containers and the management of network interfaces on the required data center for each tenant.

B. SDN

SDN [8] breaks the coupling between data and control planes in network elements, by moving the control intelligence to a centralized entity called the SDN controller. By so doing, routers and switches become simple forwarding devices, whose fowarding behavior is programmed by the centralized SDN controller using protocols such as OpenFlow [9]. In multi-domain scenarios (for example in IP over optical

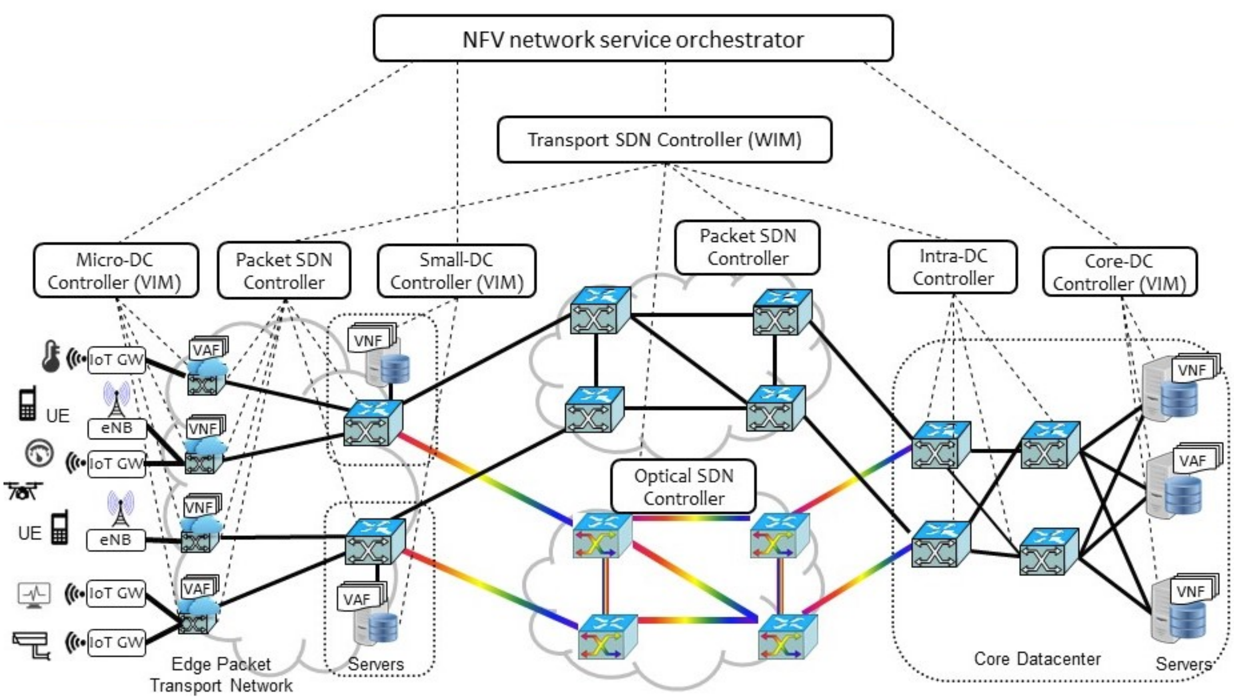

Fig. 1: Next generation carrier-grade network architecture [1]

carrier-grade networks as illustrated in Figure 1), there are SDN controllers assigned to manage specific segments of the network (such as fronthaul, backhaul and core). In order to coordinate control plane actions with multiple heterogeneous SDN controllers, a transport SDN orchestrator (also know as the controller of controllers) is deployed [10]. The transport SDN orchestrator uses a common transport API to hide the lower-level functionalities of each controller, and presents an abstracted view of each SDN controller thereby simplifying inter-controller state information exchange and failovers.

C. NFV

NFV was proposed by the ETSI ISG NFV standards developing organization [3]. NFV decouples network functions such as firewall, network address translation and caching from dedicated hardware appliances and implement them as a software running on high volume commercial off-the-shelf servers (COTS). The entire classes of virtualized network functions can be interconnected to offer full-scale communication services. This interconnection is commonly referred to as service function chaining (SFC) [11]. Within the scope of the ETSI ISG NFV [12], a service function chain is a forwarding graph connecting virtual network functions. This is equivalent to the SFC defined by the IETF SFC working group [11]. By migrating to virtual network functions, the overall cost invested on equipment is reduced, whilst the time-to-market new services and innovation are likely to be significantly improved. NFV opens unprecedented opportunities such as virtualization of the Evolved Packet Core (EPC), virtualization of the IP Multi-media Subsystem (IMS) and most importantly, network slicing [13]. With NFV, a single virtualized network function can be part of one or more network services. This emphasizes the multi-tenant aspect of NFV which enables network slicing. Network slicing allows multiple logical networks to be instantiated on top of a common shared physical infrastructure. Therefore, multiple tenants (such as MVNOs, over the top (OTT) service providers and vertical markets (such as education, automotive, healthcare and manufacturing)), each having different requirements and constrains can coexist on the same physical infrastructure.

D. ETSI NFV MANO

The ETSI ISG has proposed a reference architectural framework (depicted in Figure 2) and specifications for NFV management and orchestration (ETSI NFV MANO). The ETSI NFV MANO framework does not explicitly capture SDN in its reference architecture, under the assumption that a fully-fledged transport infrastructure is already deployed and ready to be used. However, there has been a lot of effort by ETSI towards SDN integration options to the ETSI NFV MANO framework [14]. The ETSI NFV MANO identifies the following functional blocks [15]:

- **Operations/ Business Support System (OSS/BSS)**: in order to ensure compatibiltiy with legacy systems, the ETSI MANO architecture needs to be integrated with open APIs into OSS/BSS systems. The OSS/BSS functional block is responsible for operation and business functions such as network inventory, service provisioning, network configuration, fault management, order capturing and billing. However, for interoperabiltiy with the virtualized environment, the OSS/BSS will need to be upgraded [16];
- **Element Management System (EMS)**: this functional block is responsible for management functions such as fault, configuration, accounting, performance, security for a virtual network function (VNF);
- **Virtual Network Function (VNF)**: represents virtual network functions (such as virtualized routers, switches and firewalls) deployed on commodity hardware;
- **NFV Infrastructure (NFVI)**: represents the physical infrastructure (compute, storage and networking) and software where VNFs are deployed, managed and executed;
- **Virtual Infrastructure Manager (VIM)**: responsible for controlling and managing of NFVI resources (such as compute, storage and networking). Available VIM solutions include OpenStack [17] and Amazon Web Services (AWS) [18] as cloud operating systems and OpenDayLight [19] and ONOS [?] as SDN controllers;
- **VNF Manager (VNFM)**: oversees configuration and lifecycle management (instantiation, update, scaling and termination) of VNF instances running on top of virtual machines or containers;
- **NFV Orchestrator (NFVO)**: also known as a NFV network service orchestrator (see Figure 1) is responsible for orchestration of NFVI resources across multiple VIMs and lifecycle management (on-boarding, instantiation, scaling, updating and termination) of network services to deliver end-to-end connectivity (service function chains) and network slices.

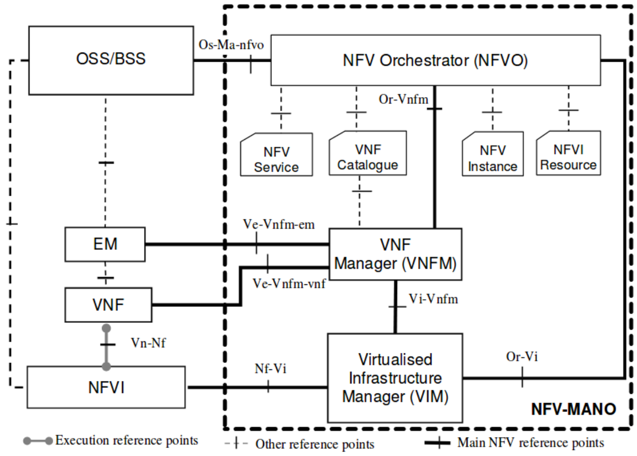

Fig. 2: ETSI NFV MAN0 architectural framework with reference points [15]

In addition to the aforementioned functional blocks, ETSI NFV MANO consitutes four repositories used to store management and orchestration information [15]:

- **NFV Service:** this is a set of predefined templates that specify the procedure(s) followed for service on-boarding, creation and termination;
- **VNF Catalogue:** set of templates that describes the attributes of VNFs;
- **NFV Instance:** used to store all information regarding virtual network functions and services;
- **NFVI Resource:** used to store information related to NFVI.

III. Related Work and Contribution

To date there has been several research efforts to address the topic of orchestration in different domains including cloud computing [20], NFV [21]-[22] and SDN [8], [23]. Weerasiri et al. [20] propose a taxonomy and survey of cloud orchestration approaches. However the scope of their work was limited to cloud platforms and did not feature SDN and/or NFV. Similar to Weerasiri et al., [8] and [21]-[23] do not consider resource orchestration across multi-technological (SDN, NFV, and Cloud) domains. Saadon et al. [24] provides a state of the art review of orchestration standardization efforts and implementation in SDN/NFV architectures. The main objective of Saadon et al. was to investigate how orchestration, SDN and NFV influence the OSS/BSS systems. Similar to Saadon et al., Rotsos et al. [25] present an analysis of orchestration standardization activities from the network operator viewpoint. Vaquero et al. [26] identify some of the challenges introduced by heterogeneous orchestration techniques. The authors go on to propose some of the technologies that can help address some of these challenges. De Sousa et al. [5] presents a taxonomy of orchestration techniques and a comprehensive survey on ongoing orchestration standardization efforts, open research challenges and opportunities. To the best of our knowledge, there is currently no study that explores compliance of different open-source network service orchestration platforms to the ETSI NFV MANO reference framework. Our study presents an up-to-date architectural comparison between some of the most prominent orchestrators. We compare these orchestrators by analyzing features such as compliance with ETSI NFV MANO reference framework, leading developers, multi-domain support and compatibiltiy with legacy systems. Importantly, we also investigate resource orchestration in the SDN, cloud and NFV technological domains.

IV. MANO Solutions

This section describes open source projects related to MANO as well as pre-standardization NFV MANO implementations. Table I summarizes the features supported by open source projects. Multi-domain support (see Table I) refers to the ability to orchestrate across multiple administrative domains belonging to different infrastructure providers.

A. CORD/XOS

CORD (Central Office Re-architected as a Datacenter) [27] is an open source project aimed towards unifying SDN, NFV and cloud computing services to provide everything-as-a-Services (XaaS). This project integrates a number of open source platforms including ONOS SDN controller (used to configure, monitor and maintain the network infrastructure), XOS (plays the role of a VNFM when mapped to the ETSI NFV MANO reference framework) and OpenStack (for cloud management). The XOS includes the following layers: (i) a data model (implemented in Django web framework) which records system status information, (ii) a set of customizable views running on top of the data model enable access to orchestration services and (iii) a controller for management of state information distribution across different domains. CORD can be used for residential, mobile and enterprise networks.

B. Cloudify

Cloudify [30] is an open source cloud and NFV platform originally created by GigaSpace to optimize NFV orchestration and management. It consists of an NFVO for lifecycle service management and a generic VNF manager when mapped to the ETSI NFV MANO reference architecture. It is compatible with both virtualized devices (containers and virtual machines) and non-virtualized devices. Although Cloudify provides an implementation of most of the ETSI NFV MANO functional blocks, its is not fully compliant as it is not compatible with legacy systems. To provide full lifecycle service management, Cloudify uses a TOSCA (Topology and Orchestration Specification for Cloud Applications [36])-based blueprint. Advanced orchestration operations are achieved through a Agile Reference Implementation of Automation (ARIA) library [37].

C. ONAP

ONAP [28] is a project developed by the Linux Foundation that enables design, creation of VNFs and end-to-end orchestration of services composed using VNFs. ONAP resulted from the union of Linux Foundation's OPEN-O [38] and AT&T's ECOMP [39]. Both OPEN-O and ECOMP were both developed for the orchestration of SDN and NFV. ONAP includes big data and artificial intelligence (AI) modules for optimization of policies and to automate network service deployment and management [40]. It has been adopted by a larger group of global service providers, such as AT&T and China Mobile and renowned vendors such as Ericsson, Nokia, Cisco, and Huawei.

D. OSM

OSM [29] is an open source NFV management and orchestration platform hosted by ETSI. This platform was developed to align with the ETSI NFV information models and to meet production requirements. The OSM consists of two decoupled orchestrators namely, resource orchestrator and service orchestrator. The resource orchestrator provides orchestration in the SDN and cloud technology domains. The service orchestrator handles lifecycle management of network services and VNFs and consumes data models such as YANG.

TABLE I: Management and Orchestration Implementations

Orchestration Solution	Leader	Resource Orchestration			NFV MANO Framework				Multi-site
		Cloud	**NFV**	**SDN**	**VNFM**	**VIM**	**NFVO**	**OSS/ BSS**	
CORD/XOS [27]	ON.lab	✓	✓	✓	✓		✓		✓
ONAP [28]	Linux Foundation	✓	✓	✓	✓	✓	✓	✓	✓
OSM [29]	ETSI	✓	✓	✓	✓	✓	✓		
Cloudify [30]	GigaSpace	✓	✓		✓		✓		
OpenBaton [31]	Fraunhofer	✓	✓		✓	✓	✓		✓
X-MANO [32]	H2020 Vital		✓				✓		✓
Gohan [33]	NTT Data	✓	✓	✓	✓		✓	✓	
Tacker [34]	OpenStack Foundation	✓	✓		✓		✓		
TeNor [35]	FP7 T-NOVA	✓	✓	✓			✓		

OSM implements open source platforms such as Riftware [41] as network service orchestrator, OpenMANO [42] as resource orchestrator (NFVO), and Juju 17 server [43] as the generic VNFM. However, OSM does not cover multiple adminstrative domains. OSM has been adopted by major European network operators like British Telecom and Telefonica and is supported by vendors such as ZTE.

E. OpenBaton

Pioneered by Fraunhofer Fokus Institute, OpenBaton [31] is an open source implementation of the NFVO based on the ETSI NFV MANO reference standard and the OASIS TOSCA [36] specification. The latest release (Release 4) of OpenBaton offers many features for compliance with the ETSI NFV MANO specification. Some of the most important features include, an NFVO for end-to-end service orchestration, a generic VNFM for multi-vendor infrastructure management, FCAPs, autoscaling and event management engines. OpenBaton can orchestrate across multiple administrative domains. It can be run on top of different NFVI which include AWS, Openstack, Docker containers and LXC containers. However, the OpenBaton community is quite small which threatens the maintainability and life time of the project.

F. X-MANO

X-MANO [32] is a cross-domain NFV orchestration platform. This platform includes several interfaces and modules to guarantee confidentiality of information (such as traffic matrices and internal topology) and cross-domain service lifecycle programability. The former is achieved by abstracting implementation details of VNFs combined with a consistent information model .

G. Gohan

Gohan [33] is an open source SDN and NFV orchestration engine led by NTT. It is based on micro-services to simplify the deployment model. It supports the definition of services using JSON Schema and policies. With this schema, Gohan provides what is known as schema-driven service deployment. Gohan consists of a REST API server, database backend, command line interface, and web user-interface. It can be used as network service orchestration layer on top of cloud services or as a NFV MANO to manage both VIMs and legacy network elements.

H. Tacker

Tacker [34] is an open source project led by OpenStack focusing on building an ETSI NFV MANO compliant network service orchestrator (NFVO), and a generic VNFM for VNF deployment and operation. The VIM platform used by Tacker is OpenStack. The NFVO provides full service orchestration across multiple VIMs, optimization of VNF placement (using VNFs and service descriptors) and resource allocation. While the VNFM manages the lifecycle of the NFV infrastructure, including creating/terminating, monitoring, migration, configuration and auto healing of VNFs.

I. TeNor

TeNor [35] is a multi-tenant/multi NFVI-PoP orchestrator (NFVO) developed by the FP7 T-NOVA project. Similar to Gohan, the TeNor architecture is based on micro-services for a more modular operation of the system. One of the key modules of TeNor is the service mapping micro-service, used to map the VNFs composing a requested network service to the the best available location in the infrastructure. The service mapping module is implemented using network service and VNF descriptors. TeNor embraces both the concept of generic VNFM and VNF-specific VNFMs proposed by the ETSI NFV MANO specification [3].

V. Summary of Comparison

This paper carried out a feature-based comparison of popular MANO solutions by mapping their functional blocks to the ETSI NFV MANO specification. Support for resource orchestration across multiple technological (SDN, cloud and NFV) and administrative domains was also investigated. Finally, production readiness was studied by looking at the adoption coverage of the MANO solutions by service providers and network vendors.

From this review, it is clear that most of the orchestrators are driven by the ETSI NFV MANO specification. This is likely because an orchestrator that follows the ETSI reference framework is generally prefered, as it specifies all modules needed to achieve flexible on-boarding of network services. However, other factors such as scalability, deployment complexity, maturity, production readiness and the reputation of the community developing the orchestration platform also play a major role regarding the choice of platform to adopt. With this in mind, there are two orchestrators that are currently top contenders in the telcom arena: ONAP and OSM. Both platforms are ETSI compliant with the scope to cover NFVO, VNFM, VIM, SDN controllers, reference points and security. However in terms of adoption coverage, ONAP is in much better position in that it has been adopted by a larger group of global service providers than OSM. Moreover, it has been shown that ONAP is more ready for deployment in production environments [44]. One downside of ONAP is deployment complexity since it is a product of a combination of two huge projects (ECOMP and OPEN-O) requiring the composition of numerous lines of a code.

In future, we intend to carry out plug tests featuring ONAP and OSM orchestrators to study their performance differences. Our ultimate goal is to set up a full-fledged virtual carrier grade network incorporating either ONAP or OSM (depending on which one performs better) for swift deployment of network slices.

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