Design and Deployment of an Open Management and Orchestration Platform for Multi-site NFV Experimentation

Borja Nogales, Ivan Vidal, and Jaime Garcia-Reinoso, Universidad Carlos III de Madrid

Diego R. Lopez and Juan Rodríguez, Telefónica I+D

Arturo Azcorra, Universidad Carlos III de Madrid and IMDEA Networks Institute

Abstract – Management and orchestration of virtual resources and functions, commonly referred to as MANO, are key functionalities of Network Function Virtualization (NFV) environments. This paper describes the design and deployment of the NFV MANO platform of 5TONIC, the open research and innovation laboratory on 5G technologies founded by Telefonica and IMDEA Networks. This NFV MANO platform provides 5TONIC trials and experiments with access to a functional production-like NFV environment, enabling experimentation with novel NFV products and services. As a relevant feature, the platform is capable of incorporating external sites to complement the portfolio of software and hardware resources that can be made available for experimentation activities. The 5TONIC MANO platform has been designed and built using open-source technologies. The research carried out during its design and deployment has resulted in a contribution already made to its upstream projects, regarding the automated configuration of virtualized network functions. Finally, we explored the scalability properties of the 5TONIC MANO platform, and we experimentally validated its functional capacity to orchestrate multi-site experiments.

Keywords: NFV, MANO, OSM, experimental infrastructure.

I. Introduction

To address the goal of pervasive, configurable, and highly reliable networks, 5G comprises a wide range of technologies, with specific emphasis on the *Software Network* ones. There is common agreement in that these technologies (currently focused on *Software Defined Networking*, SDN, and *Network Function Virtualization*, NFV) are essential to provide the elasticity required to satisfy 5G requirements. One of the key elements in the provision of the Software Network is the orchestration of resources and functions, especially the aspects related to the management of the network functions implemented as cloud applications (*Virtualized Network Functions*, VNFs). The NFV community has coined the acronym MANO (*MANagement and Orchestration*) to refer to these mechanisms.

Regarding 5G experimental facilities in Europe [1], 5TONIC [2] is an open laboratory founded by Telefonica and IMDEA Networks, with the goal of promoting collaboration in the development of 5G technologies. Since its start, several organizations of different nature have joined 5TONIC, running a variety of 5G related experiments and demonstrators, from radio access to advanced applications enabled by new network services. 5TONIC hosts collaborative experiments run by combinations of members and participating organizations, many of them part of collaborative projects within the 5G Infrastructure Public Private Partnership, 5G-PPP. Furthermore, 5TONIC is a key component in the pan-European distributed testbed being deployed by the 5GinFIRE project, a natural continuation of the SOFTFIRE initiative and directly collaborating with related infrastructures worldwide, such as FUTEBOL and ORCA. In the ICT-17-2018 European call for multisite 5G technology demonstrators, 5TONIC has been selected to become part of 5GVINNI and 5G-EVE. Finally, the European Commission has recognized 5TONIC as a digital innovation hub, reinforcing its importance as a key co-creation laboratory in 5G, and its strong scientific and industrial role.

A MANO framework is one of the essential infrastructures such a laboratory must provide, at the same level of radio equipment or cloud-like infrastructure. This framework has to provide a consistent and robust access not only to developers or experimenters dealing with the basic network functionality, but also to users from the different *verticals* (the application areas expected to make a direct and immediate use of 5G features) willing to experiment with 5G advanced services and new applications. The end-to-end nature of 5G services demands the support for multi-site integration, requiring multi-domain collaboration, and therefore implies the incorporation of these MANO capabilities. Finally, in an open laboratory the deployed MANO framework has to be open itself, and facilitate the experimentation with its own components as well.

This paper presents the design, deployment and validation of the 5TONIC MANO platform. The work started with the selection of an open-source MANO implementation able to satisfy the above requirements, continuing with the laboratory deployment, the vertical and network experimenter support, and the integration with other sites. The resulting MANO framework is now supporting experimentation activities within the 5GinFIRE project, and will constitute one of the building blocks for the 5GVINNI and 5G-EVE projects previously mentioned.

	ETSI OSM	Cloudify	Open Baton	ONAP
License	Apache 2.0	Free for up to 10 nodes. Premium version is not free	Apache 2.0	Apache 2.0
Data model and descriptor language	YANG YAML	TOSCA YAML	TOSCA YAML	TOSCA YAML
Supported VIMs	OpenVIM, OpenStack, VMware vCloud Director, Amazon Web Services (AWS)	OpenStack, VMware, Azure, etc. (it can be extended using plugins).	OpenStack (VIM driver to extend it)	OpenStack (multicloud project will extend this support)
Supported VNFMs	Juju Charms (see section 3)	Implemented by Cloudify	Implemented by Open Baton	Juju Charms
Maturity	High	High	Medium	Medium

Table 1. MANO solutions

II. Overview of the NFV Reference Architecture

In this section, we briefly review the NFV reference architectural framework defined by the European Telecommunications Standards Institute (ETSI) [3], which is one of the main building blocks of 5G [4]. This framework provides the blueprint for vendors to implement NFV compatible products, being composed of a series of building blocks, including: the NFV Infrastructure (NFVI), providing the virtual computing, storage and networking resources for VNFs, and their abstraction and virtualization layer; the VNFs, which provide the software implementation of network functions; and the Management and Orchestration (MANO) framework, to coordinate the operation of the NFV environment.

In the NFV architecture, VNFs are used to build end-to-end network services (NS) [5]. Accordingly, these can be defined as a composition of interconnected VNFs (in [6], different use cases for NFV are presented, along with research challenges and candidate functions to be provided as VNFs). The MANO framework supports the management and orchestration of the physical and software resources conforming the underlying substrate that enables the execution of VNFs. Moreover, MANO is also in charge of the whole lifecycle management of virtual functions, encompassing the incorporation of VNFs to the system (i.e., a process referred to as on-boarding), their instantiation and their scaling and termination, among other events. These functionalities are provided by the different components of the MANO system: 1) Virtualized Infrastructure Manager(s), VIM, controlling the computing, storage and networking resources; 2) the VNF Manager, VNFM, to handle the lifecycle of VNFs; and 3) the NFV Orchestrator, coordinating the allocation of resources and the deployment of NSes, together with the VIM and VNFM components.

We have analyzed the main MANO implementations aligned with the ETSI architecture. Our analysis considers the type of license, the data models and languages used to describe NSes and VNFs, the supported VIMs and VNFMs, and the maturity of the solution. The results are summarized in Table 1.

III. Design of the 5TONIC NFV MANO Platform

After the initial study phase presented in the previous section, Open Source MANO (OSM) was selected as the baseline technology to build the 5TONIC MANO platform. Being an ETSI-hosted project, OSM delivers a functional implementation of a MANO software stack following the ETSI specifications. According to our analysis, the implementation provides appropriate maturity and stability properties and, being endorsed by relevant stakeholders of the telecommunications market, presents favorable perspectives of evolution, with a commitment to provide regular releases under an open source license. Moreover, the OSM software stack is compatible with diverse cloud computing solutions, and enables the deployment of VNFs at multiple sites, as long as they support a compliant VIM. These features make OSM a suitable candidate to satisfy the requirements imposed to the 5TONIC MANO platform, and have been the main drivers of our selection.

Figure 1 presents an overview of the architectural design of the MANO platform deployed at 5TONIC. The current orchestration service of 5TONIC is based on OSM release THREE [7], which provides a Service Orchestrator (SO), a Resource Orchestrator (RO), and a VNF Configuration and Abstraction (VCA) module.

The SO provides the point of contact for external entities (e.g., the Operations Support System/Business Support System, OSS/BSS) to interact with the OSM system. It supports the lifecycle management of network services, coordinating the creation and deletion of services composed of multiple VNFs, interacting with the RO and the VCA modules. Additionally, it provides other essential enabling functionalities, such as the management of NS/VNF descriptors and packages. OSM Release THREE includes a graphical user interface, offering an intuitive mechanism to ease the on-boarding of NS/VNF packages and the lifecycle management of NS instances.

The VCA module represents the VNF Manager defined by ETSI, supporting the initial configuration of VNFs after deployment (i.e., day-1 configuration). With this purpose, the VCA uses the open-source application-modelling tool Juju [8], which allows configuring VNFs through the execution of software scripts, referred to as Juju charms, that can be specified within VNF packages.

The RO module coordinates the allocation and configuration of computing, storage and network resources under the control of one or multiple VIMs, in order to support the execution and interconnection of VNFs. VIMs supported by OSM Release THREE, via a plugin model, are indicated in Table 1. Additionally, this plugin model enables the RO to manage a number of SDN controllers, particularly OpenDaylight, Floodlight and ONOS. An analysis of relevant open source solutions regarding NFV and SDN can be found in [9].

In our design, the open experimentation environment of 5TONIC is structured into two independent local NFV infrastructures (NFVIs), providing the hardware and software substrate enabling the appropriate execution of VNFs. Each NFVI is under the control of a VIM, supporting per NFVI isolation among experiments (in our implementation, we have selected OpenStack as the VIM solution). This organization of the MANO platform in two separate datacenters allows the flexible allocation of experiments into independent infrastructures with different capacities. This configuration obeys to the short-term needs identified for the projects and users carrying out experimentation activities at 5TONIC, and may flexibly be updated in the future to accommodate changing requirements. Besides this, the proposed architectural design enables the flexible incorporation of additional sites and datacenters, with heterogeneous infrastructure and equipment as needed, to increase the portfolio of commodity and specific-purpose hardware available for NFV experimentation. Examples of these include internal or external datacenters operated by 5TONIC members, facilities from selected verticals, or external sites owned by partners of relevant research projects. The integration of these sites within the 5TONIC MANO platform is feasible through: 1) the multi-site capacity of OSM, which enables the automated deployment of NSes across multiple NFVIs, as long as they are under the control of compliant VIMs; and 2) the enablement of effective and secure inter-site communications across the Internet and/or other untrusted network domains. The latter is supported in our design with the utilization of virtual private networks. The NFVIs of 5TONIC and the mechanisms for inter-site communications are detailed in the next section.

IV. Deployment of the MANO platform

A. *Description of the experimental infrastructure*

Figure 1 illustrates the main NFV infrastructure that is currently available for experimentation through the 5TONIC MANO platform. As commented, the orchestrator software stack is based on OSM Release THREE. It runs in a virtual machine using a server computer with four GbE ports (server computer 1 in Figure 1). A second virtual machine in this server computer hosts an OpenStack Ocata VIM, which allows the allocation of experiments to a specific NFV infrastructure. This NFVI includes three high-profile servers, each following a Non-Uniform Memory Access (NUMA) architecture, equipped with eight 10Gbps Ethernet optical transceivers supporting Single Root I/O Virtualization (SR-IOV) capabilities. These are interconnected by a 24-port 10Gbps Ethernet switch, used for data-plane communications. Two networks interconnect server computer 1 to the local NFVI: 1) an infrastructure management network, to support the management of local computing, storage and networking resources by the VIM; and 2) a VNF management network, to enable the configuration of local VNFs via Juju.

The NFV experimentation platform at 5TONIC includes a second local datacenter, which may also be used to support the deployment of NSes through the multi-site support of OSM. This datacenter includes an OpenStack Ocata VIM, deployed as a virtual machine in a server computer with four GbE ports (server computer 2 in Figure 1). The datacenter offers an NFVI conformed by three server computers with the same hardware characteristics as the equipment hosting the VIM. Internet-access is provided to all components (i.e., the OSM stack, VIMs and VNFs) through an access gateway and a NAT function that is deployed within the 5TONIC infrastructure.

B. *Inter-site communications*

In the following, we describe the main mechanisms at 5TONIC to support inter-site communications. These are necessary to enable the OSM stack at 5TONIC to coordinate the deployment and operation of network services at sites that are external to 5TONIC, each providing an NFV infrastructure under the control of a compliant VIM.

From the point of view of the MANO platform, inter-site communications encompass the following types of data exchanges:

1) Communications between the OSM stack, deployed at 5TONIC, and the VIMs and SDN controllers operated by external sites. This type of communications allows the OSM stack to coordinate the allocation and configuration of computing, storage and network resources at the diverse datacenters.
2) Communications between the OSM stack and the VNFs deployed at each site, to support day-1 configuration of VNFs via Juju charms.
3) Inter-site communications between VNFs, to enable a VNF at one site to exchange data with VNFs deployed at other sites.

The first two types involve the exchange of control information, and will be referred to as inter-site control-plane communications; the third type supports the exchange of data among VNFs located at different sites, and will be denominated inter-site data-plane communications. To enable these types of communications with external sites, the approach taken at 5TONIC consists in the utilization of an overlay network architecture based on Virtual Private Networks (VPNs). This approach is schematized in Figure 1, where the three types of communications are represented (type 1 referred to as VIM management; type 2 denominated VNF management; type 3 referred to as inter-site data).

As depicted in the figure, the VPN service that enables inter-site control-plane communications is deployed at 5TONIC. The VPN server offers authorized partners (i.e. external sites

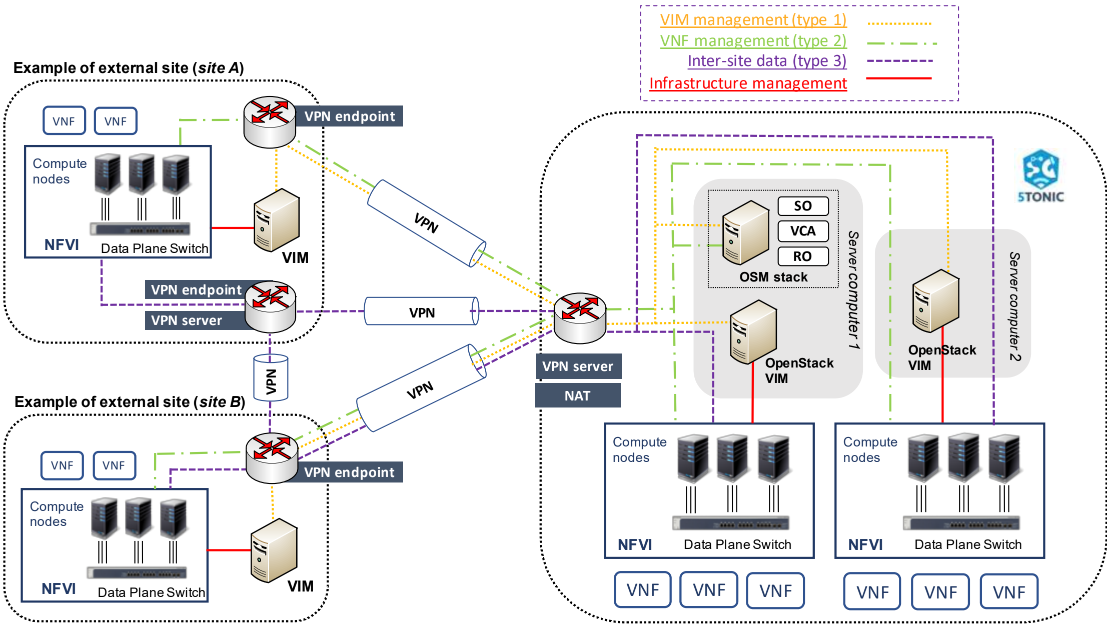

Figure 1. Architectural design of the 5TONIC MANO platform

providing experimentation infrastructures) a secure access with certificate-based authentication to 5TONIC premises, enabling the exchange of control-plane information. This way, inter-site control-plane communications follow a hub-and-spoke distribution model, where information is distributed using a star topology centered at 5TONIC, where the OSM stack is hosted. An infrastructure provider may determine the number of needed VPN endpoints (subject to agreement with the 5TONIC network operations center), and their location inside the provider site. This is shown in Figure 1, where two sites are connected to the VPN service hosted by 5TONIC. In this example, *site B* shares a VPN connection for inter-site control and data-plane communications, while *site A* splits them into two independent VPN endpoints.

With respect to the exchange of data among VNFs deployed at different sites, a feasible approach consists in re-utilizing the aforementioned hub-and-spoke distribution scheme. In this case, the VPN server would act as a traffic relay among external sites. The 5TONIC laboratory is connected through a high-speed network access to the Internet and the GÉANT pan-European network. In addition, the VPN server is a high-profile server computer capable of handling received traffic at line rate. With these considerations, the network infrastructure that supports the inter-site data communications of our MANO platform is appropriate to parallelly run diverse demanding experiments. In our design, direct site-to-site communications are considered as an alternative in those virtual links with delay constraints, to ensure minimal end-to-end latency in specific experiments. This direct communication can be provided at the cost of provisioning additional VPN services at the sites involved in the experiment. Again, this is shown in Figure 1, where *site A* deploys a VPN server, enabling direct communications with *site B* to support the exchange of data among VNFs.

C. Provision of access to experimenters

Among the specific objectives that led to the creation of the 5TONIC MANO platform, a strategic aspect that was considered was to provide a multi-user NFV experimentation environment, i.e., open for experimentation activities to authorized parties. OSM THREE incorporates a role-based access control to provide permissions to users to selected projects defined by system administrators: users may have access to different projects and with different roles in each project; projects provide the mechanism to group the access of users to resources. Roles allow the project administrators to grant access to any or all the services of OSM:

- Catalogues, enabling users to view, upload, modify and/or delete NSes and/or VNFs;
- Accounts, used to define the permissions to attach or detach RO, VIM, SDN and VCA accounts;
- Life-cycle management, allowing users to instantiate, scale and delete NSes, among other operations, e.g., through the graphical user interface of OSM;
- Projects, allowing to add/remove users to the given project and modify their assigned roles.

With this, the administrator of the 5TONIC MANO platform can add/delete projects/users and, depending on the existing agreements with verticals and experimenters, configure user accounts, assigning them specific permissions regarding the aforementioned services.

In any case, we want to highlight that the execution of experiments imposes a connectivity requirement: after the deployment of NSes, experimenters must be able to access their resources under experimentation for administration, monitoring, reporting, etc., independently of the site in which their VNFs are actually deployed.

In this respect, at the sight of Figure 1, the VNF management network was selected as a suitable candidate to support the access of experimenters to their VNFs, as this network is mandatory for any new incorporated site and it reaches every deployed VNF. Simplicity is also granted in this solution, if centralized access to this management network is considered. In particular, the same certificate-based VPN mechanism provided by 5TONIC for inter-site communications has been replicated for external experimenters, so no additional complexity has been

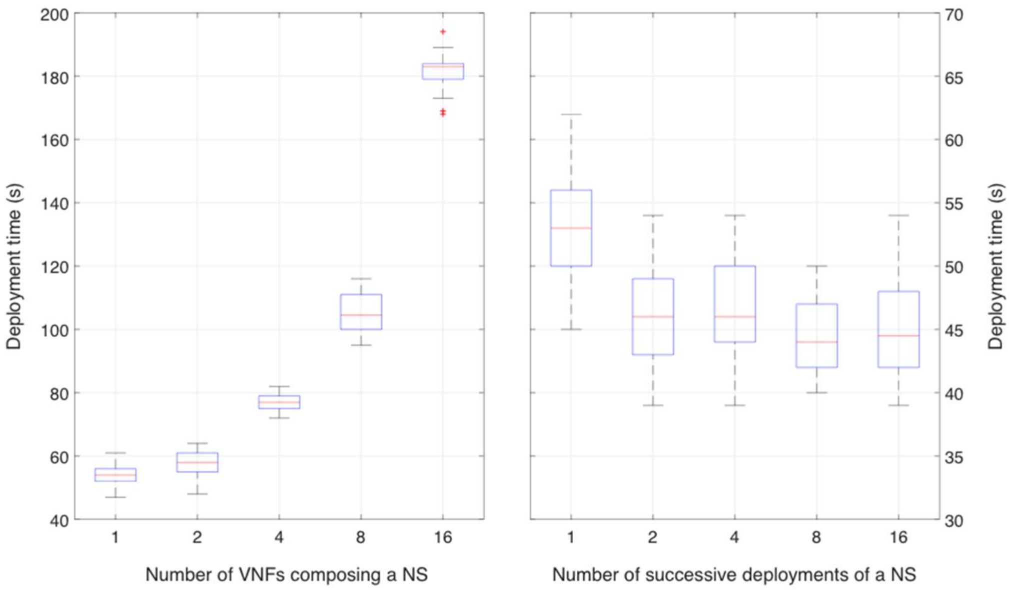

Figure 2. Deployment times provided by the MANO platform

added. On the other hand, from the security viewpoint, a single network shared by all external experimenters imposes the necessity of applying access control mechanisms to account for elements not being physically/logically isolated. In that sense:

- VNFs from different experimenters will not be isolated in the management plane, so experimenters are required not to configure trivial credentials (e.g. admin/admin).
- Certain access rules will be required to isolate control elements (e.g. OSM stack, VIMs), blocking undesired flows and permitting only those strictly required.

These security policies are implemented at an access control gateway, controlled by the 5TONIC network operations center. Experimenters will be enabled to connect to the VPN server of 5TONIC, being only granted access to this gateway. Access control lists are then configured at this node, controlling incoming connections to the VNF management network, and ensuring security for the orchestration modules.

D. Mechanisms to support the configuration of VNFs

As already commented, the VCA module is the OSM component in charge of the configuration of VNFs, generally aligned with the VNF manager entity of the ETSI NFV framework. It presents an interface to Juju, allowing the configuration of VNFs through the execution of a limited form of Juju charms, called VNF Configuration charms or proxy charms [10].

Aiming at increasing the range of configuration options available to VNF developers in OSM, as well as facilitating the portability of existing VNF developments, we have explored the utilization of other well-known and wide-used mechanisms for VNF configuration, identifying Ansible [11] as a technology of particular interest.

Under the aforementioned considerations, we have developed a base charm layer that allows configuring a VNF using an Ansible playbook. This base charm layer is based on other existing Juju layers [8], and provides a template ready for customization that allows creating a proxy charm capable of executing an Ansible playbook through the Juju framework of OSM. The base charm layer has been contributed to the OSM community [12] being available as open source software.

E. Mechanisms for evolution and continuous integration

One of the most salient characteristics of current software development is the support for continuous integration techniques, allowing a seamless evolution of operational environments as their software bases evolve. We will maintain this characteristic for the 5TONIC MANO platform and, given the extremely active nature of the foreseen OSM software evolution, proactively integrate any breakthrough features that are incorporated in the platform software base and that require a platform update beyond continuous integration mechanisms. To support continuous integration and upgrades, 5TONIC currently hosts a version control system with the source code of the 5TONIC MANO platform, and an independent small-scale production-like NFV experimentation environment. This environment will support tests with new releases of OSM and OpenStack, i.e., the main open-source solutions that provide the basis for the 5TONIC MANO framework. It will also support experimentation with other OSM components and plugins (e.g., to evaluate the integration of new types of VIMs, SDN controllers and public cloud support), and the validation and debugging of extensions to the NFV MANO platform. Independently of any specific tests that might be executed in each case, the validation of the management and orchestration functionalities prior to a platform upgrade is enabled by a number of scripts (supported from release THREE of OSM), which carry out the automated deployment of a set of reference NSes and verify their operational availability. After appropriate validation, changes can be committed into the mainline code and scheduled to the production MANO platform in 5TONIC. The small-scale NFV environment has initially been configured with a functional OSM stack and an OpenStack VIM, each running on a mini-ITX computer. The platform currently includes five additional mini-ITX computers, which may be used to flexibly build one or several NFVIs, or to deploy additional functionalities as needed.

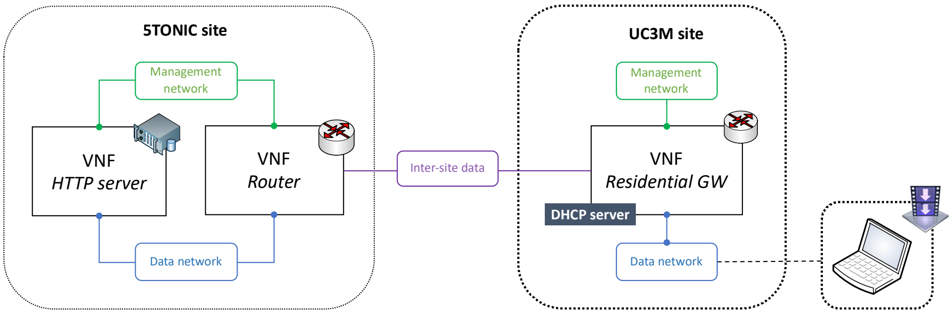

Figure 3. Multi-site NS used for functional validation

V. Practical validation

We carried out a number of experiments to explore the performance of the 5TONIC MANO platform and its scalability properties. In a first experiment, we studied how the deployment time of an NS is affected by the number of its constituent VNFs. With this purpose, we deployed an NS at 5TONIC with a number of interconnected VNFs (1, 2, 4, 8 and 16). For each case under consideration, we repeated the deployment 30 times and calculated the average deployment time. The results of this experiment are shown in the left side of Figure 2. According to these results, the average time required to deploy an NS with a single VNF is approximately 54 s. This time increases by less of 10s for each additional VNF that composes the NS.

In a second experiment, we evaluated how the deployment of an NS is affected by existing deployments. With this purpose, we performed 16 successive deployments of an NS with a single VNF, measuring the time required for each deployment. We repeated each cycle of 16 deployments 30 times. The right side of Figure 2 shows the average deployment time for the first, second, fourth, eighth and sixteenth deployment of the NS. According to the obtained results, we observe that the deployment time of an NS is not affected by previous deployments.

The results of these experiments indicate that the 5TONIC MANO platform has the potential to instantiate large NSes with appropriate deployment times, considering the key performance indicators established by the 5G Infrastructure Public Private Partnership [13] (i.e., average service creation time not higher than 90 minutes).

Next, we describe an experiment carried out to validate the multi-site functionalities of the 5TONIC MANO platform. In this experiment, we built an external site at University Carlos III of Madrid (UC3M), consisting of an access gateway, an OpenStack Ocata VIM, and an NFVI with two compute nodes interconnected by a GbE switch.

To enable inter-site communications with 5TONIC, we obtained a specific IP address space from the 5TONIC network operations center, along with the appropriate VPN credentials to gain authorized access to the laboratory. We configured the external site to use IP addresses within the allocated range, and we used the provided credentials to set up the access gateway as a VPN endpoint of the overlay network architecture of the 5TONIC MANO platform. In addition, we created a virtual network at the external site, with layer-2 connectivity to the access gateway. Analogously, a virtual network was created at one of the 5TONIC datacenters, with network connectivity to the access gateway of the datacenter. Both virtual networks were interconnected via VXLAN [14], configuring the access gateways as VXLAN tunnel end points.

With this, we used the graphical user interface of OSM to onboard the NS shown in Figure 3, as well as its constituent VNFs. The NS includes an HTTP server function, which maintains a number of video files that can be requested on-demand by interested users using the HTTP protocol (i.e., a common approach used by existing video-on-demand services such as YouTube). A router function supports the exchange of HTTP traffic between the server and remote network locations where video requests are originated. One of such locations is represented by a residential gateway function, allowing a user terminal to: 1) obtain IP access connectivity; and 2) request a video file from the HTTP server, which is then streamed to the user terminal. Additionally, the residential gateway hosts a DHCP server that supports the automatic network configuration of the user equipment. The NS and the VNFs have been made available under an open source license [15].

We instantiated the NS using the graphical user interface of OSM, allowing us to carry out the deployment of the VNFs at different sites. In particular, the HTTP server and the router function were deployed at 5TONIC, while the residential gateway function was deployed at UC3M. Both the router and the residential gateway were automatically interconnected through the VXLAN, which enabled inter-site data communications. Day-1 configuration of VNFs (configuration of static IP addresses, activation of IP forwarding in the router and the residential gateway, and start of HTTP and DHCP services) was executed with Ansible playbooks, using our base charm layer *ansible-charm*. After the deployment and configuration of the VNFs, a user device (a commodity laptop) was connected to the NFV infrastructure of the external site, obtaining access to the virtual data network of the residential gateway. After the laptop's interaction with the DHCP server, and completion of its network configuration, we used *GStreamer* to request and play a specific video file from the HTTP server.

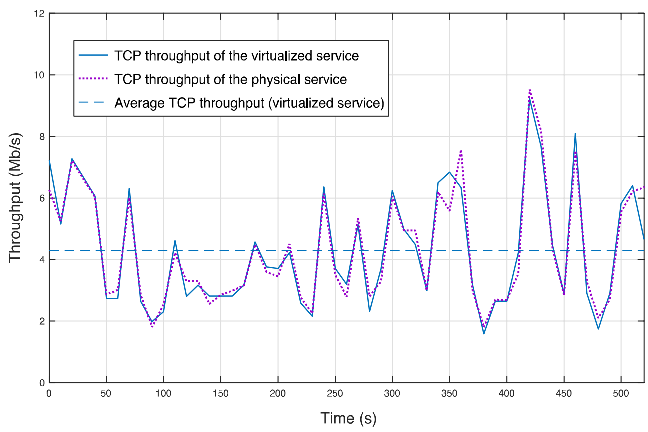

Figure 4. TCP throughput during the experiment

Figure 4 represents the TCP throughput of the video delivery corresponding to the experiment, measured at the user equipment. The video file was received with an average rate of 4.44 Mbits/s, being uninterruptedly played out as it was received from the HTTP server. An analogous execution of the service, using a physical machine to deploy the HTTP server, and connected to the user equipment through a switch, provided similar throughput (also shown in Figure 4).

VI. Conclusion

The design and deployment of the 5TONIC MANO platform has resulted in diverse technical challenges, derived from its multi-user and multi-site requirements. We have addressed these challenges, designing and deploying such an open MANO platform, with specific mechanisms to enable the secure exchange of inter-site control and data-plane information, as well as the secure access of the platform users to their VNFs. Additionally, this work has resulted in a contribution to the OSM upstream project, concerning the configuration of VNFs. We have also explored the performance of the platform, and we have experimentally validated its functional capacity to manage the lifecycle of multi-site network services. Our future work encompasses the evolution to OSM release FOUR, as well as the integration of the NFV experimentation environment with external international sites coming from the 5GVINNI and 5G-EVE projects.

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Borja Nogales (bdorado@pa.uc3m.es) is currently a Ph.D. candidate at University Carlos III of Madrid. He is involved in the European research project 5GinFIRE and in the national project 5GCity. His research interests include Network Functions Virtualization (NFV), 5G networking, and Unmanned aerial vehicles (UAVs).

Ivan Vidal (ividal@it.uc3m.es) received the Ph.D. in Telematics Engineering in 2008 from the University Carlos III of Madrid, where he is currently working as visiting professor. His research interests include Unmanned aerial vehicles (UAVs), 5G networks, and Multimedia Networking. He has been involved in several international and national research projects, including the H2020 5GinFIRE and 5GCity, and has published more than 50 scientific papers in several conferences and international journals.

Diego R. Lopez (diego.r.lopez@telefonica.com) joined Telefonica I+D in 2011 as a Senior Technology Expert and is currently in charge of the Technology Exploration activities within the GCTIO Unit. Diego is focused on network virtualization, infrastructural services, network management, new network architectures, and network security. Diego chairs the ETSI ISG on Network Function Virtualization and the NFVRG within the IRTF. More information: https://www.linkedin.com/in/dr2lopez

Juan Rodríguez (juan.rodriguezmartinez@telefonica.com) received his Telecommunications Engineering degree from the Polytechnic University of Madrid (UPM), Spain. In 2004, he joined Telefónica I+D, working on Network Evolution and then leading R&D activities on MPLS. He moved in 2013 to the Network Innovation and Virtualization Group in the global CTO Unit of Telefónica, where he is currently participating as a Network Innovation Manager. He has deep experience in European Collaborative Programs like CELTIC, FP6/FP7 and H2020.

Jaime Garcia-Reinoso (jgr@it.uc3m.es) received the Telecommunications Engineering degree in 2000 from the University of Vigo, Spain and the Ph.D. in Telecommunications in 2003 from the University Carlos III of Madrid, Spain, where he works as an associate professor. He has published over 50 papers in the field of computer networks in magazines and conferences. He has been involved in several international and national projects like the H2020 5G-TRANSFORMER, the H2020 5G-Crosshaul and the H2020 5G-EVE.

Arturo Azcorra (azcorra@it.uc3m.es) received his M.Sc. degree in Telecommunications from UPM in 1986 and his PhD 1989. In 1993, he obtained an MBA with honors. He is IEEE Senior Member and ACM SIGCOMM Member. He has been visiting researcher at MIT and UC Berkeley. He has participated in 49 research projects since the first Framework Programme of the EU. Azcorra has been the project coordinator of 5GTRANSFORMER, 5G-Crosshaul, CARMEN, CONTENT and E-NEXT. More information: http://en.wikipedia.org/wiki/Arturo_Azcorra