# MANOaaS:
# A Multi-tenant NFV MANO for 5G Network Slices

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*Abstract*—The dramatic densification of connected mobile devices and the expected use cases from the vertical industry demands for a innovative network design that meets upcoming stringent requirements. The adoption and harmonized integration of novel concepts, such as network function virtualization and network programmability, enables the system to master the high expectation—from the 5th generation communication network in support of flexibility—to provide tailored and mutually isolated network slices, high performance, agility and automation. This effectively involves a number of technical challenges for managing and orchestrating physical and virtualized slice resources by means of an advanced management and orchestration (MANO) system.

This paper sheds the light on potential benefits and implementation aspects when the MANO framework is abstracted into customized and distributed MANO instances thereby empowering the MANO-as-a-Service (MANOaaS) paradigm. In particular, such distributed instances are provided to different network tenants for a greater level of control on requested network slice(s). The notion of Management Level Agreements (MLA) in the context of MANOaaS is introduced and differentiated per tenant while being embedded into the proposed architecture. We also position the proposed MANOaaS concept and associated extensions to the MANO reference architecture in the view of standardization bodies and ongoing open-source projects.

## I. INTRODUCTION

THE 5th generation (5G) of network systems and platforms are envisaged to provide an extended set of services provisioned towards a wide variety of heterogeneous service verticals (e.g., automotive, industry, smart-city, e-Health, logistics) generating ultra-high traffic density with differentiated but stringent performance, security and reliability requirements. This involves the challenge of managing diverse and large scale (isolated) services from heterogeneous verticals within the respective quality bounds (namely service level agreements, SLAs) over a shared infrastructure: the ***network-slicing*** paradigm [1].

The core concept of Network-Slicing enables the provisioning of virtualized but mutually isolated customized networks over a shared *virtualized* infrastructure platform. This is illustrated in Fig. 1 where three network-slice instances owned by different service verticals, also referred to as *tenants*, are deployed over a shared virtualized infrastructure. Each slice instance is composed of virtualized network functions (VNF) interconnected by virtualized links (VL) in the order specified by a VNF Forwarding Graph (VNFFG) to deliver a specific network service, such as virtualized evolved packet core (vEPC), virtualized radio access network (vRAN) etc.
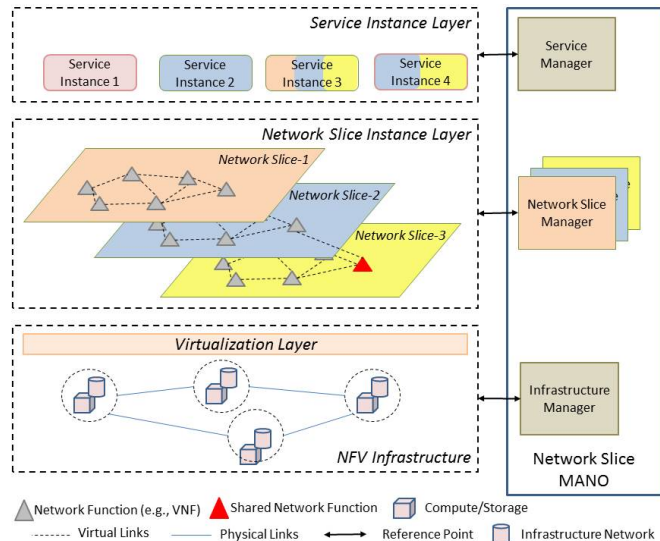


Fig. 1: Overview of the concept of slicing management.

Infrastructure resources (such as compute, network, storage) are automatically abstracted and dynamically allocated to each slice. The network services offered by the slices are consumed by higher level (application) service instances pertaining to specific verticals. Therefore, multiple application services can share the services of a single network slice [3], or multiple slices can be utilized by a single service instance. A credible network-slice Management and Orchestration (MANO) system is required to manage the infrastructure resources, the network-slices and service instance(s) to ensure reliable service delivery within the QoS bounds [2].

In this regard, ETSI NFV has developed an NFV-MANO framework [4] for the life-cycle management (LCM) of NFV Infrastructure (NFVI) resources (compute, network, storage) and the VNFs/VLs forming network-slice or Network Service (NS) instance(s).

The NFVI-owner can support multiple tenants where each tenant is allocated a quota of resources tailored to the tenants' service requirements. The *tenant domain* is characterized by this allotted resource quota. The tenants can instantiate and offer multiple NS instances to external customers within its domain of allotted quota of resources. As part of its service, the NFVI-owner provides the MANO services to the various NSs belonging to different tenants. However, the current design of NFV-MANO framework aims towards providing centralized management of NSs for the multiple tenants. Such

a centralized approach has inherent performance issues and management challenges. The focus of this paper is on a distributed management and orchestration approach, which enables more flexibility and scalability properties.

## II. SLICE MANAGEMENT - CHALLENGES AND GAPS

A centralized approach for the provisioning and runtime management of slices involves a discrete number of challenges on the Life-Cycle Management (LCM) of network slices, the services running on top of them, and the resources orchestration associated to such network slices [5]. One of the core issues is the *Scalability* when the number of tenants and the slices per tenants increases. This in turn increases the load (e.g., monitoring/processing load) on the central-MANO instance leading to delayed responses towards deriving and executing MANO actions to individual tenants' slices [6]. Another fundamental issue is the *Reliability* with a centralized management posing as a single-point-of-failure. Besides scalability and reliability issues, having to rely on a centralized MANO system limits the autonomy of the tenants from implementing own policies and/or rolling out new services or managing existing services. These issues are compounded in cases where the tenant services are running on remote sites or span multiple-sites such as, micro data-centers or edge domains. Such sites providing virtualized infrastructure are also referred to as NFVI-PoP.

Therefore, distributing MANO capabilities is required to address such issues. While the literature provides interesting works in the area of distributed management, in the specific context of NFV-MANO there are few proposals, but not comprehensive enough to tackle the entire problem spectrum. For instance [12] proposes the management of network slices in a multi-domain (i.e., multiple NFVI-PoP) environment, where the slice resources are managed by an overarching MANO system. This approach can distribute the management of NFVI resources and VNFs to individual domains but the end-to-end orchestration is still performed centrally. A more distributed option is highlighted in [9], where NFVI-PoPs have their own (single) dedicated NFV-MANO instances inter-coordinated in a peer-to-peer fashion via the NFVO entity. This approach inherits the delay issues due to the peer-to-peer communication. A similar approach is adopted by [10] that leverages on the container technology to implement a light-weight MANO stack for resource starved individual edge NFVIs. These proposals support partial distribution and lacks the granularity of providing MANO services to individual tenants. In terms of supporting multi-tenancy, [7] proposes an architecture where *fully autonomous* NFV-MANO systems are deployed for each tenant leaving the full coordination of such NFV-MANO instances to an overarching *Inter-slice resource broker* entity that manages multi-domain network slices. Also [8] proposes a distributed approach but solely at the level of the VIM in the view of end-to-end slicing with resources being allocated to the slice in multiple distributed data centers. Instead of relying on a single VIM for the management of infrastructure resource in a data center, an instance of VIM is created on-demand for each slice and exposed the slice's

owner. This enables more flexibility to apply custom strategies and policies while isolation in infrastructure control between multiple tenants is intrinsic with that approach. However, the proposal does not address avoidance or resolution of conflicts when multiple VIMs share physical resources. Also, on-demand MANO aspects are not addressed in [8].

The above cited approaches have some degree of centralization and thus do not address the highlighted challenges in its entirety. They also lack the dynamism and flexibility that are needed to provide *managed autonomy* to tenants towards managing their own slice resources. In light of these issues and gaps, we present our novel solution of MANOaaS that not only provides each tenant the ability to manage its own slices by realizing virtualized abstraction of per-tenant MANO instances, but it also has the *distinguishing feature* of managing the tenants autonomy through negotiation and enforcement of *Management Level Agreements (MLA)*.

## III. MANOaaS - CONCEPTUAL OVERVIEW

The MANOaaS concept is proposed as an extension of the ETSI NFV-MANO model [4]. The core-concept is the provisioning of a virtualized abstraction of a NFV-MANO system to the respective tenants, which we refer to as *tenant-MANO (t-MANO)*. In cloud terms the tenants are said to be provided MANOaaS.

A t-MANO instance shall provide the tenants with the required autonomy to manage and orchestrate their own resources, services and policies. The central MANO (c-MANO) system maintains *administrative control* over the deployed t-MANO instances but, depending on agreed MLAs, the *operational control* of the c-MANO is offloaded/delegated to t-MANO instances. The MLA is negotiated between the tenant and the c-MANO provider and determines the scope of the delegated operational capabilities of c-MANO providing either a full or partial set of the features, capabilities and services. This enables the tenant to exercise management and orchestration functions over its respective resource slices (rSlice) and service slices (sSlice) with a minimum reliance on the c-MANO stack. An *sSlice* is essentially the same as a network-slice but within a tenant's domain. An *rSlice* is the dimensioning of the infrastrucure virtual resources allotted to a tenant within its domain.

However, the c-MANO has full administrative rights over the respective t-MANO stack: it monitors the t-MANO for MLA compliance and provides services, features and capabilities to the tenants that are outside the negotiated MLA bounds and, under specific situations, it overrides the t-MANOs decision on actions.

Figure 2 shows the conceptual model of the MANOaaS paradigm. As can be seen, the c-MANO is an *extended* version of the NFV-MANO system [4] having the following essential functional blocks:

- *Virtualized Infrastructure Manager (VIM)* for the management of NFV Infrastructure (NFVI) resources.
- *Virtualized Network Function Manager (VNFM)* for the Life-cycle management (LCM) of VNF(s) that are deployed and instantiated over the NFVI.
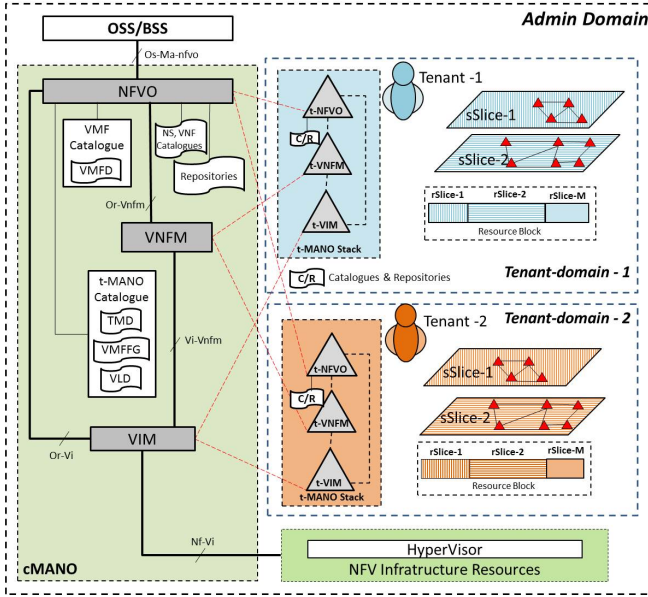
Fig. 2: Conceptual model of MANOaaS paradigm

- *NFV Orchestrator (NFVO)* for the service and resource management of the network services that are formed by chaining various VNFs and characterized by the VNF Forwarding Graph.

The three functional-blocks interact with each other using standard interfaces to provide LCM of virtualized resources belonging to different tenants. LCM actions include instantiation, migration, scale-in/out/up/down, update/upgrade, and delete VNF/NS instances. These functional-blocks are extended to manage the t-MANO instances, as will be explained later.

Moreover, the c-MANO extends the NFV-MANO with Virtualized Management Function (VMF) Catalogue and t-MANO-Catalogue containing t-MANO related descriptor files in addition to the standard catalogues with descriptor files i.e., VNF Descriptor (VNFD) file and NS Descriptor (NSD) file, which are deployment templates specifying the operational, functional, resource, performance, policy requirements of the VNFs and NSs, respectively. These new catalogues and descriptor files will be explained in Section IV.

Fig. 2 also shows two tenants, i.e. Tenant-1 (T1) and Tenant-2 (T2), define two logical tenant domains within the same administrative-domain, characterized by one or more NFVI-PoPs. Based on their service requirements, T1 and T2 request for NFVI resource blocks of specific flavor (i.e., type and amount of specific resources) from the NFVI-owner who is also the c-MANO provider. After the resource blocks allotment, the tenants then request for the provisioning of a t-MANO system stack. The requested t-MANO instances operate with an agreed level of autonomy and independent from the c-MANO, hence are potentially not bounded to a specific location and can be instantiated in a suitable NFVI-PoP within the provider's domain. Deployment location selection can be based on multiple factors, such as low-delay interactions/coordination with the c-MANO, for instance with states and functions still associated with the c-MANO. It may

also consider the proximity of the VNFs/NSs for low-delay t-MANO operations on local instances with the advantage of *autonomous operations* by the t-MANO as per the MLA description. The c-MANO monitors and enforces the t-MANO operations within the agreed MLA bounds. The MLA negotiation shall mainly involve what services/features/capabilities of the c-MANO system the t-MANO instances will have access rights to and the access levels. The tenants' request for resource blocks, t-MANO stacks and MLA negotiation can be executed via the OSS/BSS or ad-hoc GUI-based portal.

Once the t-MANO system stacks are deployed and instantiated for the respective tenants (please refer to Section IV-B for the process details), they are able to dimension (or slice) their respective allocated resource blocks into *rSlice(s)* and then create, deploy, configure and instantiate their respective *sSlice(s)* without involving the c-MANO. Thus, T1 and T2 will have autonomy in performing fault, configuration, accounting, performance and security (FCAPS) management and LCM operations and orchestration actions over its respective rSlice/sSlice instance(s) as well as for implementing own policies without involving the c-MANO, whereas the degree of autonomy is efficiently bounded by the defined MLA contract.

As mentioned above, the t-MANO stack is an abstract image of the c-MANO system stack where the MANO functional blocks are realized, similar to VNFs, as Virtualized Management Function (VMF) instances and the reference points between the t-MANO VMF instances (i.e., t-VIM, t-VNFM and t-NFVO) are realized over virtual links (VL) within the tenant domain as depicted in Fig. 2. The c-MANO still maintains administrative and management control of the t-MANO service instances and there is a logical peer relationship between the t-MANO VMF instances and the corresponding c-MANO functional blocks. This peer relationship, depicted as red dotted lines in Fig. 2, enables the c-MANO to monitor the t-MANO for MLA compliance and to extend services, features and capabilities to the tenants that are outside their respective MLA bounds.

In case a tenant instantiates a slice which expands through NFVI-PoPs of multiple NFVI-providers, MANO operations are typically handled by each provider's c-MANO system, which coordinates with other providers' c-MANO through well-defined interfaces on orchestration level e.g., the Or-Or interface [9]. An example of a Hierarchical MANO system comprising multi-domain environments can be found in [13]. In support of MANOaaS for such cross-domain deployments, each provider's c-MANO shall instantiate a t-MANO instance for the associated NFVI-PoP in its domain. The inter-coordination between the tenant's multiple t-MANO instances is accomplished by direct interfaces, similar to Or-Or interface, between the t-MANOs' orchestration functions i.e., t-NFVO, without involving the c-MANO as long as the level of control for inter-domain orchestration is within the agreed MLA-bounds. Any other inter-domain operations exceeding the MLA will be performed and inter-coordinated between the different providers' c-MANO systems.

## IV. Implementation aspects of MANOaaS

### A. Architectural Considerations

Our approach focuses on the realization of t-MANO stack by deploying its individual VMF components (i.e., t-NFVO. t-VNFM and t-VIM) in a similar fashion as a VNF, where the t-MANO VMF instances maintain peer relationship with the respective c-MANO functional blocks either over an IP-based network or via some RPC-based method. Fig. 2 gives an overview of the deployment of a t-MANO stack vis-a-vis the c-MANO for T1 and T2. The tenants are allocated a quota of NFVI resource blocks by the c-MANO using the NFV-MANO standard method.

Also, the required VNF packages and relevant catalogues are also on-boarded by the tenant to the c-MANO using standard on-boarding technique. Upon the tenant's request, the c-MANO deploys and instantiates the t-MANO stack by deploying the constituent VMF components (i.e., t-VIM, t-VNFM, t-NFVO) in a similar manner as it would have performed for a VNF/NS. For this purpose, the c-MANO requires t-MANO specific deployment templates provided in the two newly proposed catalogues, namely

- **t-MANO catalogue** consisting of:
  - t-MANO descriptor (TMD) file.
  - VMF Forwarding Graph (VMFFG) file.
  - Virtual Link Descriptor (VLD) file.
- **VMF catalog** consisting of VMF descriptor (VMFD) file.

The information inside the TMD file is used by the NFVO and the VNFM of the c-MANO system to instantiate a t-MANO instance for the tenant, which consists of the mainly three VMFs interconnected by VLs, whereby the characteristics of the VLs are described by the VLD. The VMFFG, similar to VNFFG, contains meta-data about the VMF Forwarding Graph itself, references to VLs, VMFs, connection points etc. The TMD, VMFFG and VLD are quite similar to NSD, VNFFG and VLD but contain necessary extensions that are relevant to the t-MANO requirements. An overview on NSD, VNFFG and VLD are provided in [4].

We assume that VLs between the t-MANO VMFs support the standard NFV-MANO reference points and the interfaces and operations defined over them whereas the tenant requests for the complete t-MANO stack. However, there might be some interfaces or operations that the t-MANO instance may not be allowed to access or execute due to MLA restrictions. The restricted interfaces and operations are executed by the c-MANO for the respective tenants' slices. The tenants may also maintain own VNF/NS catalogues and repositories as part of their t-MANO service instance. Nonetheless, these catalogues and repositories must be first validated by the c-MANO before they are assigned to the t-MANO system.

The VMFD file is a deployment template that describes the respective VMF components of the t-MANO stack in terms of deployment, operational and functional requirements. It also contains interface, connectivity and KPI requirements, and also specifies the services, features and capabilities of the respective VMF components. Additionally, it shall also specify the parameters agreed during MLA negotiation specifying services, features and capabilities of the respective VMF

TABLE I: Example of negotiation parameters as part of Management Level Agreement (MLA).

| Primary Key | Secondary Key | Parameter | Description |
|---|---|---|---|
| t_mano_id | ns_id | tenant_id | The tenant id to which the t-MANO belongs |
| | | tnfvo-id | The id of the t-NFVO component of the t-MANO stack. |
| | | tvnfm-id | The id of the t-VNFM component of the t-MANO stack. |
| | | tvim-id | The id of the t-VIM component of the t-MANO stack. |
| | | time_to_live | The duration of the t-MANO instance |
| | | resource_flavor | The resources (type & amount) for t-MANO instance |
| | | resource_id_list | The list of resources and amount assigned for t-MANO |
| | | domain_id | The domain where t-MANO instance is deployed |
| | | do_auto_scaling | Permission to perform scaling operations |
| | | do_auto_healing | Permission to perform healing operations |
| | | do_migration | Permission to perform migration operations |
| | | do_update | Permission to perform update operations on VNFs/VNFCs |
| | | vmffg | Pointer to VMFFG |
| | | scale_policy | Scaling policy |
| | | migration_policy | Migration policy |
| | | healing_policy | Healing policy |
| | | mano_event_list | List of events executed by t-MANO |
| | | allow_recursion | Permission for a t-MANO stack to instantiate further t-MANO stacks i.e.,recursively. |
| | | tmano_instance_list | The list of t-MANO instances recursively instantiated |
| | | decision_profile | Indicating c-MANOs control profile for overriding t-MANOs decisions. Can be Proactive, Reactive or Autonomous, the latter indicating complete autonomy to t-MANO. |
| | | tmano_state_info | Carries state information of the t-MANO system |

components that a tenant is allowed to access/execute. Thus the VMFD files are more dynamic, unlike VNFD files, which are static deployment templates, and are updated during the MLA negotiation process. The VMFD can be updated each time the c-MANO updates any of its MLA parameter for e.g. whenever the tenant creates a new sSlice. Thus a t-MANO instance can be configured to recognize different MLAs for different sSlices belonging to the same tenant. Table I provides an example of a non-exhaustive list of the MLA parameters negotiated for a t-MANO instance. The TMD and VMFD files also contain information for identifying the various t-MANO stack instances and their location in a multi-site environment. This is evident from Table I where the parameters are indexed by the id of the t-MANO instance (t_mano_id) and the network slice(s) (ns_id) managed by the respective t-MANO stack.

### B. Process overview of t-MANO deployment and instantiation

The c-MANO, with the help of the t-MANO Catalog and VMF Catalog, deploys a t-MANO stack for a tenant that can dimension the allocated resource block of NFVI resources into required rSlice(s) depending on the requirements of the tenant's sSlice(s). This is illustrated in Fig. 2, where the NFVI resource block allocated to a tenant is dimensioned into three resource slices namely *rSlice-1*, *rSlice-2* and *rSlice-M*. *rSlice-M* is dedicated to fulfil the resource requirements specific to the t-MANO stack. Once the rSlices are created and the t-MANO deployed, the t-MANO performs regular LCM operations on the resource/service slices within the MLA bounds.

An overview of the general process for the deployment and instantiation of t-MANO stack is illustrated in Fig. 3(a), while Fig. 3(b) expands on the configuration/instantiation process of the VMF entities, which is part of the process depicted in Fig. 3(a) but presented as a separate figure for convenience. The c-MANO instantiates the t-MANO stack.

After the request has been validated (message-4) and the resource block assigned (message-5), the tenant requests for

(a) Instantiation process of t-MANO stack

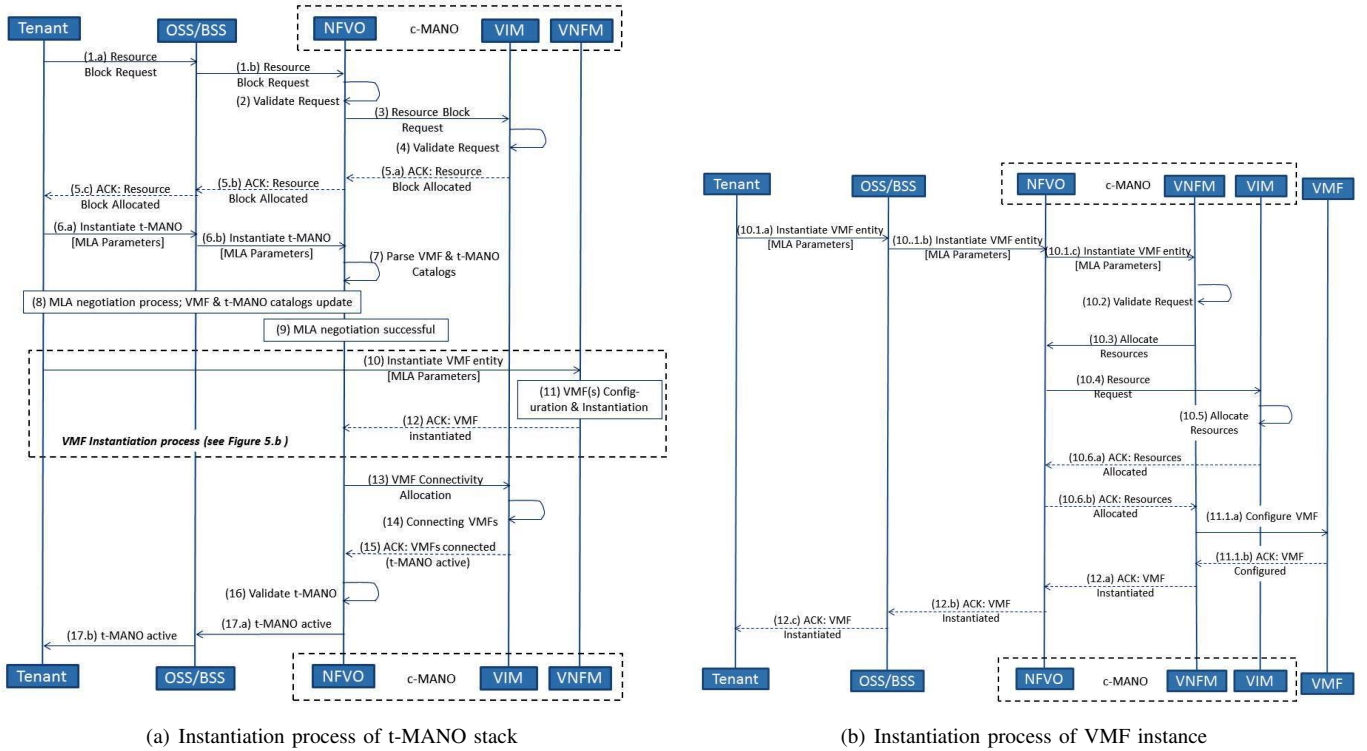(b) Instantiation process of VMF instance

Fig. 3: Process flow for instantiation and deployment of t-MANO.

the instantiation of the t-MANO stack in its tenant-domain (message-6). The request message also carries the MLA parameters (see Table I) specifying the access privileges that the tenant requires for accessing the service/feature/capabilities of the t-MANO stack. Then the NFVO parses the VMF and t-MANO catalogs (message-7) to verify that all relevant VMF packages and descriptor files are available and up-to-date.

Once the verification is completed, the NFVO and the tenant undergo the MLA negotiation process (step-8). Assuming a successful negotiation (step 9), the relevant VMF descriptor files are dynamically updated. Since the MLA has been successfully negotiated, the NFVO starts the process of instantiating and configuring the VMF instances (i.e., t-NFVO, t-VNFM, t-VIM) for the t-MANO stack requested by the user (process flow 10 -12), as shown in Fig. 3(b). Specifically, the tenant make a request for the instantiation of a VMF entity to the c-MANO's VNFM entity via OSS/BSS (messages 10.1.a-b). The NFVO, based on the VMFD forwards this request to the VNFM (message- 10.1.c), which after validating the request (message 10.2) sends a message to NFVO to allocate requisite resources for the requested VMF entity (message-10.3). The NFVO forwards to the VIM (message-10.4) that reserves and allocates necessary resources from the resource block within the tenant domain for the requested VMF instance (message-10.5).

Once the VMF has been deployed, the VNFM configures the newly deployed VMF in the tenant domain with necessary configuration parameters specified in the VMFD and bounded by the agreed MLA parameters (message-11.1.a). Now the VMF configuration is confirmed (message-11.1.b) so that the VNFM informs the tenant that the requested VMF has been instantiated (messages 12.a-c). Note that such a process is

repeated for each different type of VMF block belonging to the t-MANO stack i.e., t-NFVO, t-VNFM and t-VIM.

While VMFs are being configured and instantiated, the NFVO instructs the VIM to establish connectivity between the t-MANO VMF instances to realize the respective reference points (messages 13-14 in Fig. 3(a)). The NFVO validates the operational integrity of the newly instantiated t-MANO by performing some validation tests (message-16). A successful validation notifies the tenant that the requested t-MANO is active and ready for being used (messages 17.a-b). The tenant can use it for creating, managing and orchestrating its own resource/service slices and policies within the bounds of agreed MLA.

To validate our proposal, we carry out a simulation campaign developing a simple network simulator in a well-known mathematical tool, namely MATLAB, where a different number of tenants may directly request resources to the c-MANO entity as depicted in Fig. 2. The size of the resource blocks amongst the tenants are distributed randomly following the normal distribution. Requests within the tenants-domain for rSlice arrive following a normal distribution, with $30\%$ requiring up to $80\%$ of the total available capacity of the system.Some random requests may also ask for resources more than the total available capacity, that will be rejected. Such values are chosen to meet the expected 5G requirements on the complete isolation of few slices. We omit the analysis of the overhead required by each single approach due to the space limitation leaving it to future work.

Preliminary results provide an empirical evaluation in Fig. 4. In particular, we show the impact of the degree of autonomy in terms of the success rate of t-MANO requesting resource reservation for e.g., slice instantiation/scaling/migration at
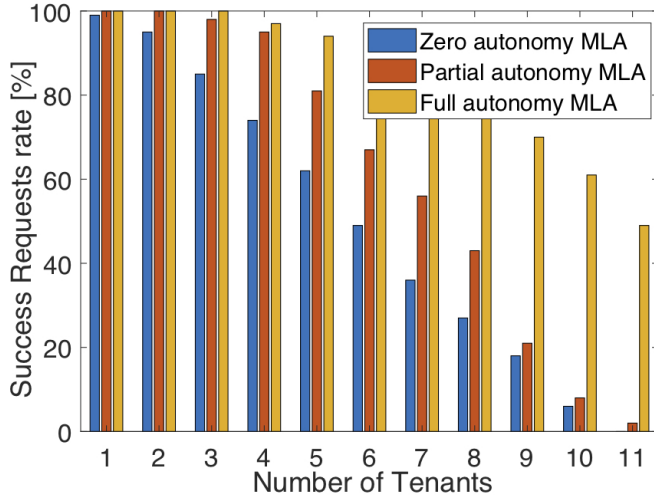
Fig. 4: Success resource requests rate with multiple tenants and different negotiated MLAs.

run-time within low to high resource contention scenarios. Considering that the underlying infrastructure resources are shared, a t-MANO has to reserve a rSlice for carrying out sSlice instantiation/scaling/migration operation. In case of a t-MANO instance with an MLA granting full autonomy, i.e., the c-MANO operational control is fully delegated and resources are guaranteed to the t-MANO instance, it can be seen that the success rate is much higher than those of t-MANO stacks with partial or zero-autonomy. This is because with zero or partial autonomy the t-MANO has greater dependence on c-MANO for resource reservation. Their requests will be referred to c-MANO where it will be contended against other similar requests from other tenants. Thus their requests may get rejected in situations of high resource contention. This behavior gets more pronounced when there are more tenants (higher resource contention) asking for finite resources, in which the t-MANO will exhibit a much lower success rate with respect to t-MANOs with full autonomy. In other words, the t-MANO getting full granted autonomy has a much higher success rate due to stringent resource guarantees.

## V. MANOaaS in the context of SDOs and Open Source Projects

The NFV MANO is the standard MANO framework proposed by the ESTI ISG NFV. There are several open-source projects that are developing MANO platform like the ETSIs OSM [1] and LFNs ONAP [2]. However, the open-source projects do not align 100% with the standard NFV-MANO reference architecture. They cover the basic management functions of the ETSIs NFV-MANO, like NFVO and VNFM functionalities, but they provide additional value-added features. For VIM, these platforms rely on other open-source projects such as OpenStack as being the more prominent option.

In consideration of enabling MANOaaS support, the control and semantics being exposed from a c-MANO provider to a tenant should be carefully considered, while keeping the

[1] https://osm.etsi.org/
[2] https://www.onap.org/

concrete platform of c-MANO transparent. Considering that t-MANOs are semi-autonomous with still some level of dependency on c-MANO, e.g. to enforce rules for virtualized infrastructure management, states distribution between t-MANO and c-MANO components, needs to be thoroughly investigated and planned towards the design of suitable redundancy management and fail-over procedures. Consideration should be given whether the value added features, such as for data analytics, can be instantiated on a t-MANO and exposed to a tenant. The relevance to keep in mind of closer association of VNF context with components of the c-MANO and the t-MANO respectively is, as example, further substantiated by a recently proposed study in 3rd Generation Partnership Project (3GPP) about the analysis and harmonization of semantics used on the one hand by a slice specific network data analytics VNF, and on the other hand by the ONAP data analytics components.

Without being specific to any particular implementation of a MANO stack, some projects specify their own proprietary framework to wrap around complex functions for the handling of orchestration and lifecycle management tasks, but still offer a tenant sufficient level of control and customization. In case a tenant is not interested in obtaining control on a customized MANO stack, [14] specifies a high-level API named One-stop API, which abstracts low-level NFV-MANO functions but enables a tenant to instantiate and manage a tailored slice, whereas a feature denoted as Plug&Play exposes a combination of customized control functions and tools to a tenant in support of plugging proprietary control logic into a slice (vertical-in-the-loop). [15] introduces the Slice-as-a-Service concept based on virtualized compute and networking resources, which serve as a base to onboard services per tenants request. A request is processed by the Lightweight Software Defined Cloud (LSDC) platform, which on the one hand offers different levels of granularity and formats to request a slice, but then takes over the lifecycle management of the instantiated service.

## VI. Conclusions

Service verticals require an advanced management and orchestration of network resources in the 5G networks deployment. In this paper, we have broken down the monolithic concept of the MANO stack to bring into play the network slicing paradigm by introducing the novel concept of MANO-as-a-service (MANOaaS). In particular, the centralized MANO (c-MANO) has been abstracted into multiple distributed instances (t-MANO) pursuing differentiated management level agreements (MLAs) between infrastructure provider and tenants. We have $i$) presented a novel MANOaaS architecture showing the inter-connections between distributed instances and centralized MANO stack, $ii$) detailed autonomy negotiation process of the management level agreements (MLAs) between infrastructure provider and tenants, $iii$) unveiled the similarity and open issues with the main standardization bodies and ongoing research projects. We believe that this solution represents an important and required step towards fully network slicing isolation with additional performance and management gains in 5G networks.

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