Management and Orchestration of Mobile Network Services over Federated Mobile Infrastructures

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***Abstract*—This article proposes a novel method and system to solve the issue of the Management and Orchestration (MANO) of end-to-end network services when the MANO system is deployed in a mobile infrastructure which is within the user domain. Such a MANO system that is referred to as u-MANO raises several challenges and issues in terms of ensuring the integrity and service continuity provided by the end-to-end network services. These challenges become even more complex when the end-to-end network services are deployed in collaboration with third-party MANO providers (p-MANOs). Hence, this paper addresses these challenges by proposing a new framework and methods that achieve seamless coordination between the u-MANO and the p-MANOs systems. Moreover, the feasibility of the proposed solution and its introduced gains in terms of reducing the communication overhead and the energy consumption of user domain infrastructure are evaluated in scenarios of using Unmanned Aerial Vehicles (UAVs) for providing network services.**

I. Introduction

The advent of 5G has opened up possibilities for introducing new use cases [1] and business models that could not be perceived with the previous generations of communication technologies. This is because 5G, with Network Function Virtualization (NFV) and Software Defined Networks (SDN) as key technology enablers [2], is based on an agile and programmable network infrastructure that caters to both human and Machine-type communications.

5G introduces a powerful networking paradigm, known as network slicing [3], that enables deployment and provisioning of differentiated Network Services (NS) with varying Quality-of-Service (QoS) requirements belonging to a variety of verticals (e.g., automotive, industry, smart city, e-Health, and logistics). This is made possible by the NFV technology, a key enabler of 5G, where network/application functions are deployed as virtualized instances, generally referred to, as Virtual Network Functions (VNF), over a shared NFV Infrastructure (NFVI) composed of compute, network and storage resources.

A NS is composed of one or more VNF instances interconnected over Virtual Links (VLs), where each VL is a logical connection that uses a well-defined data path in the physical network provided by the NFVI. A Management and Orchestration (MANO) system is required for the Fault, Configuration, Accounting, Performance, and Security (FCAPS) management and life cycle management (LCM) of NS instances. For this purpose, ETSI [4] has proposed a standard NFV-MANO system for the flexible and agile management of virtualized NSs that can be deployed across one or more NFVI-PoPs.

In this context, as it is designed to manage and orchestrate the NS instances and their associated resources, the NFV-MANO deployment is usually perceived and anticipated in the NFVI-PoPs consisting of Data Centers (DCs) located at the core/edge network of the mobile operator. Moreover, use cases and requirements have been specified in [5] [6] [7] to enable the NFV MANO system to manage the deployment, connectivity, and resource orchestration of the NS instances across multiple NFVI-PoPs that are distributed and federated over Wide Area Network (WAN) infrastructure. With respect to distributed NFV MANO systems, proposals have been made in [8] and [9] to provide end-users with their own MANO stack, referred to as tenant-MANO, that is under the control of a central MANO system to provide management autonomy to the users (i.e., NS and/or resource owners) based on negotiated Management Level Agreements (MLAs).

In all these proposals, the underlying assumption is that the NFV MANO systems, whether centralized or distributed, are deployed at fixed locations, referred to in this article as fixed NFVI-PoPs (fNFVI-PoP), which are located at the core/edge DCs of the overall network architecture. Moreover, the distributed MANO instances depend on a central MANO entity. However, in this article, we propose a novel MANO system referred to as user-MANO (u-MANO), that can be deployed on top of a mobile NFVI within the user domain, and that can operate in a fully distributed manner without dependence on any central MANO entity while ensuring the integrity and continuity of the provided network services.

The remainder of this article is organized as follows. Section II motivates the need for the u-MANO system and the challenges raised by such a proposal. Thereafter, the article introduces in Section III the proposed u-MANO framework. Section IV considers the use of the proposed framework for enabling a UAV-based network service that allows the remote management of a fleet of UAVs and provides insightful evaluation regarding the feasibility of the proposed solution and the gains introduced in terms of reducing communication overhead and energy consumption when pushing the MANO system to the mobile user domain infrastructure. Finally, conclusions are presented in Section V. Table I summarizes the abbreviations used in this article.

TABLE I
LIST OF ABBREVIATIONS USED.

Abbreviation	Description
AMF	Access and Mobility Function
BS	Base station
DC	Datacenter
FCAPS	Fault, Configuration, Accounting, Performance, and Security
FC-VNF	Flight Control Virtual Network Function
fNFVI-PoP	fixed NFVI-PoP
KPI	Key Performance Indicator
LCM	Life Cycle Management
MANO	Management and Orchestration
mNFVI-PoP	mobile NFVI-PoP
MLA	Management Level Agreement
NFV	Network Function Virtualization
NFVI	Network Function Virtualization Infrastructure
NFVI-PoP	NFVI Point-of-Presence.
NFVO	Network Function Virtualization Orchestrator
NS	Network Service
NSD	Network Service Descriptor
p-MANO	provider MANO
QoS	Quality-of-Service
RAN	Radio Access Network
SDN	Software Defined Network
SLA	Service Level Agreement
SMF	Session Management Function
sNS	sub Network Service
UAV	Unmanned Aerial Vehicle
UE	User Equipment
u-MANO	user MANO
VIM	Virtualized Infrastructure Manager
VL	Virtual Link
VNF	Virtual Network Function
VNFD	Virtual Network Function Descriptor
VNFFG	Virtual Network Function Forwarding Graph
VNFM	Virtual Network Function Manager

II. MOTIVATION

In view of some compelling and emerging use cases, the existing state-of-art does not consider use cases where a full or partial deployment of the NFV MANO stack is required to be deployed within the user domain. For example, there are situations where the NFVI is expected to be available within the user domain itself, such as inside the User Equipment (UE) and the end-user transport entity like mobile Base Station (BS), emergency and rescue vehicles (e.g., UAVs, fire engines, ambulances, and police vans), trains, buses, outside broadcast vans for live television broadcast services to name a few. We refer to such NFVIs that are within the user domain as mobile NFVI-PoP (mNFVI-PoP). Such mNFVI-POPs need to have their own MANO system, which we refer to as u-MANO, in order to instantiate, deploy, manage and orchestrate NS instances within their domains.

Besides instantiating and deploying NS instances within the local domain of the mNFVI-PoP, the u-MANO may also stretch the local NS instances with NS instances that are located within the edge/core NFVI-PoP(s) i.e., fNFVI-PoPs, in order to extend the functional/operational boundaries of its local NS instance(s). In such a situation, the end-to-end NS is composed of multiple sub-Network Service (sNS) segments, where the different segments are managed by different MANO systems. That is, the sNS segments within the user-entity are managed by the u-MANO while the sNS segments within the edge/core fNFVI-PoPs are managed by one or more provider MANOs (p-MANOs). In such a scenario, the u-MANO and p-MANOs are considered as different administrative domains, and the orchestration of network services on top of them inherits all the coordination challenges raised by the orchestration of multi-domain network services [7]. Furthermore, as will be discussed later in Section III, new challenges are raised by the mobile nature of the mNFVI-PoP that results in dynamic changes of the topology of the end-to-end NFVI composed of the mNFVI-PoP and the fNFVI-PoPs, which requires seamless coordination between the u-MANO and the p-MANO systems to ensure the service continuity and the end-to-end integrity of the NS. It is in perspective with the above challenges that we propose a framework that ensures the coordination between the u-MANO and p-MANOs to sustain the QoS of the end-to-end NS instances deployed over the mNFVI-PoP and the fNFVI-PoPs.

III. A FRAMEWORK FOR THE ORCHESTRATION OF NETWORK SERVICES ACROSS FEDERATED MOBILE INFRASTRUCTURES

A. A Use Case for User domain-based Network Services:

The proposed system and its embodiment will be explained with an example of a 5G use case. Fig. 1 depicts two use cases of the proposed mobile MANO system. Herein, we consider the first use case of a temporary network service deployed using a UAV during a rescue and emergency situation. A flying mobile-BS, equipped with computing and networking resources, serves as a mNFVI-PoP (i.e., mNFVI-PoP **A**). It may be required to set up an ad-hoc network and communication services at the accident/disaster site in order to coordinate other rescue units and also connect them to their respective headquarter or service providers (e.g., over-the-top service providers). For this purpose, the u-MANO **A** inside the mobile-BS will instantiate and deploy a virtualized Radio Access Network (vRAN) network service over the mNFVI-PoP **A**. This ad-hoc vRAN is then linked via a VL to a mobile core NS (e.g., virtual 5G Core) deployed in the edge/core fNFVI-PoP **A** and managed by a provider MANO (i.e., p-MANO **A**). This forms an end-to-end NS instance that is composed of two sNS segments: (i) an sNS segment managed by the u-MANO **A** and (ii) an sNS segment managed by the p-MANO **A**.

The concept of end-to-end NS is illustrated in Fig. 2(a) where the NS is composed of three sNS segments interconnected via VLs. The VNFs within each sNS segment are also linked to each other over VLs. With reference to our use case scenario, sNS-1 is deployed within mNFVI-PoP **A** domain and thus managed by u-MANO **A** inside the mobile-BS, whereas sNS-2 is deployed in the core/edge fNFVI-PoP **A** and thus managed by p-MANO **A** owned by the domain provider.

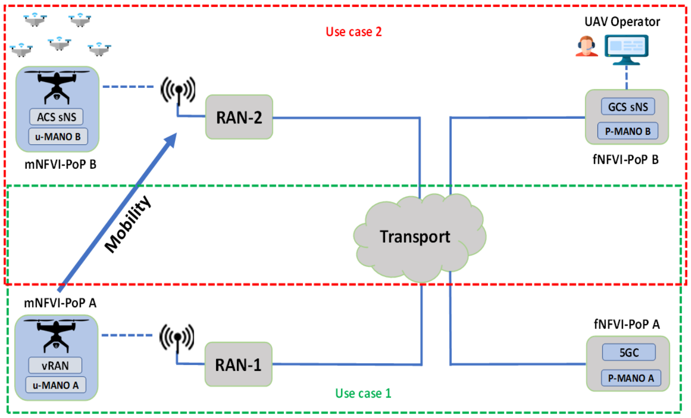
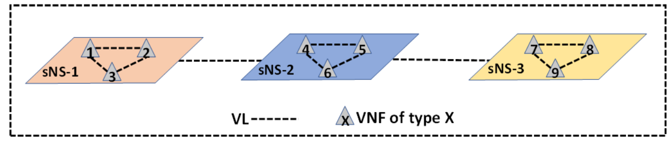


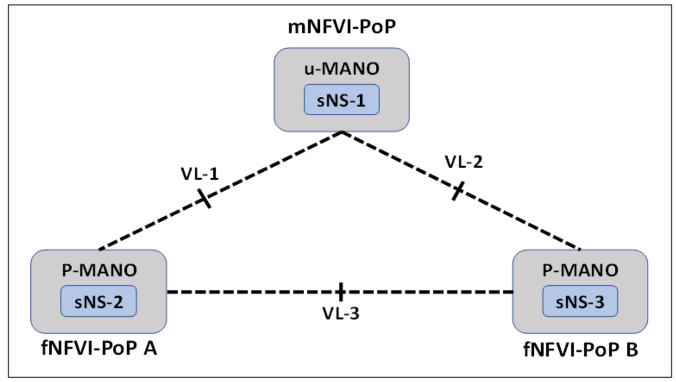
Fig. 1. Overview of the problem space.

Another possibility could be for the mobile-BS to aggregate resources and/or services offered by different providers by having the u-MANO connecting the local sNS segment to two or more sNS segments in different fNFVI-PoP domains. In this case, it might be also required for the u-MANO to stitch the sNS segments running in different fNFVI-PoP domains together. This concept of resource/service aggregation is depicted in Fig. 2(b). In such a situation, the u-MANO has to coordinate with two different p-MANOs systems. With reference to our use case scenario, the u-MANO **A** can coordinate with both p-MANO **A** and p-MANO **B** for deploying different parts of the mobile core network functions. For example, p-MANO **A** can be used for deploying an sNS segment composed of control plane VNFs such as the Access and Mobility Function (AMF) and the Session Management Function (SMF), whilst p-MANO **B** can be used for deploying an sNS segment composed of the data plane VNFs such as the User Plane Function (UPF) [10].

The challenge, as pointed out before, is to ensure the service integrity of the end-to-end NS instances and to ensure seamless connectivity between the sNS segments hosted in mNFVI-PoP and the sNS segments hosted in fNFVI-PoPs, especially in the event of mNFVI-PoP mobility. Indeed, a mobility event can result in changes in the underlying data paths used by the VLs connecting the sNS segments hosted in mNFVI-PoP to the sNS segments hosted in fNFVI-PoPs. These changes, in turn, can result in increased latency or the failure of the VLs, which means that the services provided by the end-to-end NS instances will be of degraded quality or will be interrupted. In order to cope with this challenge, the u-MANO must be able to transparently and seamlessly reconnect and reconfigure the local sNS segments with the sNS segments that are within the fNFVI-PoPs while ensuring the continuity of services at the same QoS level. To ensure QoS compliance, the u-MANO may also negotiate with different fNFVI-PoPs providers to provide the same sNS(s), in case the original fNFVI-PoPs are



(a) Conceptual overview of end-to-end Network Service.



(b) Service extension of sNS-1 segment inside the mobile user domain with sNS segments of multiple provider domains.

Fig. 2. Distributed end-to-end Network Service.

not able to provide the expected QoS, either due to increased latency factors or if they are no longer accessible due to the mobility of the mNFVI-PoP.

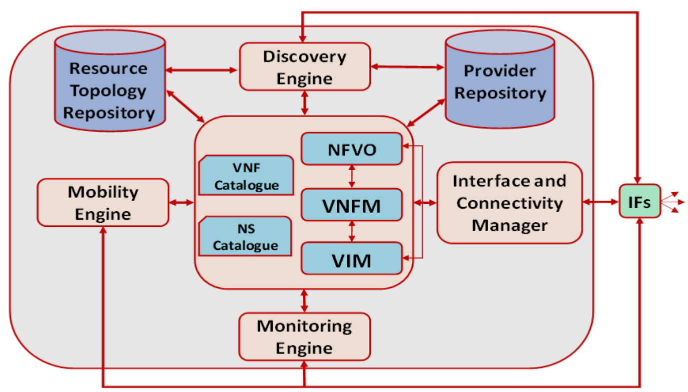


Fig. 3. u-MANO Functional Architecture.

B. User domain Management and Orchestration Framework

The envisioned functional architecture of the u-MANO system is illustrated in Fig. 3, consisting of the following components:

- *MANO system* can be for example the standard ETSI NFV MANO stack [4] which is composed of the NFV orchestrator (NFVO), one or multiple VNF Managers (VNFM) for the LCM of VNFs, local catalogues (i.e., VNF and NS catalogues), and the Virtualized Infrastructure Manager (VIM) to control the different networking and computing resources in the local mNFVI-PoP domain.

- *Provider Repository* contains the list of fNFVI-PoP providers that the user has a subscription to. It stores the provider details including the user's contract and subscription information, the catalogue of services types that the respective fNFVI-PoPs support, and also the functional capabilities of their respective p-MANO systems.
- *Resource Topology Repository* stores the resources and topology details from the local mNFVI-PoP domain as well as from the domains provided by p-MANOs.
- *Interface and Connectivity Manager* responsible for configuring and managing the interfaces within the mNFVI-PoP. These interfaces are used by the u-MANO for communicating with the p-MANOs for discovery, contract negotiation, and NS(s) management purposes.
- *Monitoring Engine* collects monitoring data from the local sNS segments and receives anomaly reports from the p-MANOs.
- *Mobility Engine* performs mobility-related actions such as handling the standard handover process and/or the handover process between the p-MANO systems. The handover may be network-based or host-based, or even a hybrid. In the case of hybrid handover, the mobility engine may override the handover decision made by the standard process (e.g., 3GPP handover decision) in case it does not fulfil the performance requirements and may choose a different access point within the available range to reconnect to the sNS segments of the serving p-MANO domains.
- *Discovery Engine* discovers the p-MANOs that are reachable from the current location of the mNFVI-PoP, including not only the ones that the u-MANO has subscribed to and that are already stored in the Provider Repository, but also the ones the user has not subscribed to and may negotiate a service contract including Service Level Agreement (SLA) negotiations upon demand. During the discovery process, the Discovery Engine tries to collect the necessary information of the provider networks on their offered resources/services types, availability, and the capabilities of their p-MANOs.

C. u-MANO Process Flow

The essential functional steps that are necessary to implement our concept are illustrated in the process flow of Fig. 4. The details of each step are presented below:

1) The NS deployment process starts with a service request sent by the user to the u-MANO. The user, in this case, can be the administrator of the mNFVI-PoP (e.g., the mobile-BS) who wants to set up a specific network service.
2) After receiving the service request, the u-MANO evaluates the service requirements (i.e., functional, operational, and resources requirements) specified in the request and parse the Network Service Descriptor (NSD) and/or VNF Descriptor (VNFD) files, for example, to identify the relevant VNFs and VNF Forwarding Graph (VNFFG).
3) The u-MANO uses the Resource Topology Repository and the local NS and VNF catalogues to check whether the scope of the requested NS is local or it extends beyond the mNFVI-PoP.
4) If the scope of the requested NS is local, then the u-MANO will resolve the user request to instantiate and deploy the NS as per the standard process specified by the ETSI NFV [4]. The u-MANO will use the parsed NSD/VNFD files to instantiate, deploy, configure, and interconnect the composing VNFs to set up the active NS instance within its local domain, i.e., within the mNFVI-PoP.
5) In case the u-MANO identifies that the scope of the requested NS extends beyond the mNFVI-PoP, either in terms of resources or functional components (e.g., VNFs), the u-MANO will then solicit the p-MANOs listed in *Provider Repository*. It is assumed that the u-MANO has subscriptions with multiple mobile network service providers, and it is already connected to the mobile network infrastructure for data services. The u-MANO will send the service solicitation request over well-defined interfaces that are configured by the *Interface and Connectivity Manager* to the contracted p-MANO instances. The p-MANO may be provided by the same mobile network service provider or by another NFVI provider with which the u-MANO has a subscription contract.
   Then, the u-MANO sends the service request to the available p-MANOs indicating the service type and containing performance/reliability/QoS requirements (e.g., latency, bandwidth, and error rate). It may also include the details of the NS that is local to the mNFVI-PoP, including the current location IDs (e.g., IP addresses) and the attached mobile network provider. Each of the solicited p-MANOs will then send a reply indicating whether it accepts/rejects the NS request. .
6) The u-MANO will then wait for the responses of the solicited p-MANOs.
7) In case the u-MANO does not get any positive response, it will start the p-MANOs discovery process using the *Discovery Engine*. During the discovery process, the u-MANO may update the *Provider Repository* with newly discovered p-MANOs or update the information for the existing p-MANOs entries with the latest resource/service status (i.e., pull mode) in order to expedite the future NS management and orchestration decisions. Alternatively, the p-MANOs can also periodically update the u-MANOs *Provider Repository* with their latest resource/service status (i.e., push mode).
8) In case the u-MANO receives acceptances from multiple p-MANOs and based on the information available in the *Resource Topology Repository*, it will then select the one or more p-MANOs that are appropriate to its requirements. For instance, not all p-MANOs may be

able to fulfil all service requirements. In this case, the u-MANO will select p-MANOs that are able to fulfil its extended service requirements and aggregate the provided resources (including sNS segments) into a single end-to-end NS.

9) The u-MANO will then send a formal service extension request including its location and the details of the connection point to the local sNS. This information can provide assistance to the p-MANOs for selecting the fNFVI-PoPs that are best suited to host the NS extensions.
10) The u-MANO waits for service confirmation from the solicited p-MANOs.
11) If any of the solicited p-MANOs reject the request sent by the u-MANO, this later will send new solicitation requests to the p-MANOs available in the *Provider Repository*, ignoring the p-MANOs that have rejected the formal service request. The new service request concerns only the sNS segments for which no confirmation has been received.
12) When a p-MANO accepts the service request sent by the u-MANO, it will first check whether it has an active sNS instance with which the mNFVI-PoP local sNS can connect in order to create an end-to-end NS.
13) If a selected p-MANO does not have an active sNS instance, it will first instantiate it by deploying, configuring, and connecting the VNFs.
14) If a selected p-MANO already has an active sNS instance, it sends the necessary information for NS stitching to the u-MANO (e.g., sNS features, capabilities, and connection points).
15) After instantiating a new sNS, the p-MANO executes the same actions as in Step 14.
16) The u-MANO connects the local and remote sNS instances by instantiating VLs to form an end-to-end NS.
17) Regular service provisioning will start soon after the different sNS segments are stitched together to form an end-to-end NS. During the lifetime of the NS, the u-MANO will periodically monitor the performance of the NS using the *Monitoring Engine*.
18) The requirements of the SLA are checked against the current measured KPIs.
19) If the SLA is respected, then no actions are triggered and the system continues the periodic monitoring process as per Step 17.
20) If the service performances degrade below the SLA, the u-MANO may trigger orchestration actions on its local sNS segments or signal the p-MANO instances to trigger appropriate orchestration actions on their respective sNS instances to ensure continued service integrity. Both the u-MANO and the p-MANO should coordinate the orchestration actions to ensure optimal decisions. In order to take appropriate orchestration actions, the u-MANO will first check whether the service degradation is caused by a mobility event (e.g., 3GPP-based handover) of the mNFVI-PoP.
21) If the service performance did not degrade because of a mobility event, the u/p-MANO collaboratively identify the saturated resources and/or the failed components (e.g., VNF, VL, CPU, and Memory) and then take appropriate orchestration actions. The orchestration actions may include the scaling in/out/up/down of the sNS instances, relocation of one or more sNS instances, and the re-optimization of the resource allocation by decomposing and splitting one or more sNS instances into multiple constituent sNS segments and reshuffling their composing VNFs among the mNFVI-PoP and the fNFVI-PoPs.
22) In case the service performance degrades because of a mobility event that causes the failure of the VLs between the sNS segments hosted at the mNFVI-PoP and the sNS segments hosted at the fNFVI-PoPs, the u-MANO will take relevant actions to restore the VLs.
23) The u-MANO checks whether the service performance, reliability, and QoS parameters are restored and are complying with the SLA.
24) If the service performance is complying with the SLA, the u/p-MANO proceeds to performance monitoring described in Step 17
25) If the service performance still not complying with the SLA even after restoring the VL, it is necessary to relocate the impacted sNS instance managed by p-MANOs to new fNFVI-PoPs that are near to the new access point connecting the mNFVI-PoP. Each concerned p-MANO first checks whether it has enough resources near to the new access point in at least one of its fNFVI-PoPs.
26) If enough resources are available in one of the fNFVI-PoPs managed by p-MANO, u-MANO starts an intra-administrative domain relocation process in which it informs the p-MANO of its new location and/or of the degraded service quality, and requests association with another fNFVI-PoP that belongs to the same administrative domain of the current hosting p-MANO. The p-MANO can then relocate the existing sNS segments to the new fNFVI-PoP and instructs the u-MANO to establish connectivity with it, by providing the location and connection details necessary for the u-MANO to establish connectivity between its local sNS segment and the new fNFVI-PoP sNS segments.
27) In case the current hosting p-MANO(s) does not have sufficient resources near the new access point, it will indicate this to the u-MANO, which, through its interfaces, will start the solicitation process (i.e., starting from Step 5) of new p-MANO(s) that can meet its service resource/functional/operational requirements.

D. Challenges and Enhancements

The adoption of the u-MANO framework for the management of NS instances that are fully deployed in the user domain has the advantages of ensuring a higher management autonomy to the end-users, reduced service provisioning time, and a Quality-of-Experience similar to the one offered by

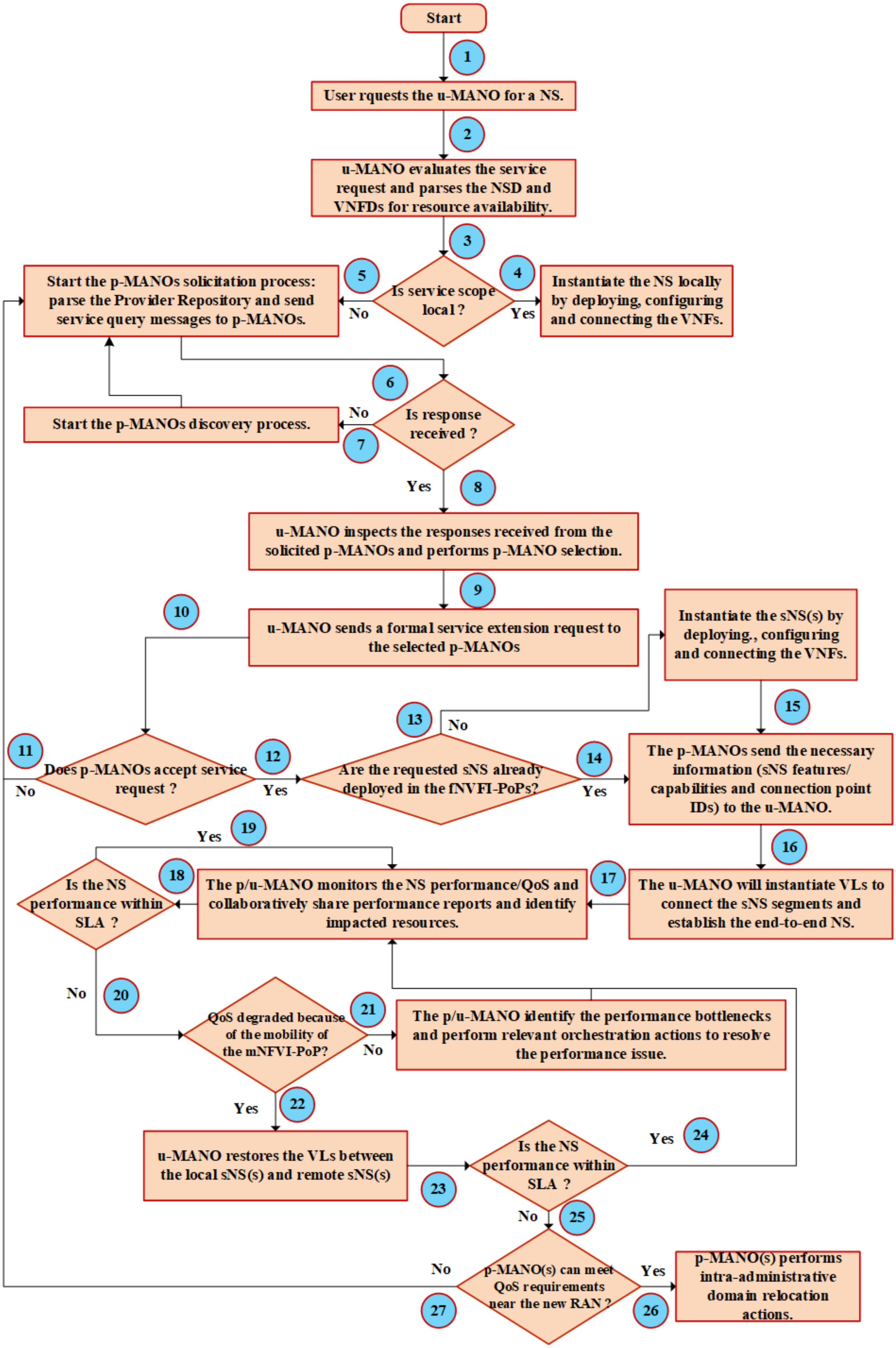


Fig. 4. Process Overview.

Edge Cloud systems [11]. Nevertheless, when considering NS instances that are distributed across the user domain and the edge/cloud domain, the u-MANO framework may suffer from increased service provisioning time and service unavailability. This is mainly due to the delay overhead introduced by the p-MANOs solicitation and discovery processes that are triggered during service provisioning and mobility events.

It has to be noted that the above proposal can be extended to include the collaboration between multiple u-MANOs in different mNFVI-PoP domains to create end-to-end NS. The p-MANO must also have necessary architectural provisions in order to support the functional interfaces with the u-MANOs. For example, the p-MANO must maintain the identities, locations, security certificates, SLA conditions/bounds, and configuration information, for the various u-MANOs that are subscribed to its services. Moreover, the p-MANO must also maintain service states for the NS instances that are active between the p-MANO and u-MANO. With reference to the ETSI NFV MANO framework [4], these can be provisioned either within the existing repositories, or a separate repository can be maintained for this purpose. The active state of the end-to-end NS instances that are jointly managed between the u-MANO and p-MANOs can be maintained inside the existing NFV *Instances Repository* with the provision to map the sNS segments of the jointly-managed NS to the corresponding p-MANO and u-MANO instances. However, the details of the extended architectural provisions of both u-MANO and p-MANO are out of the scope of this work and are left for future work.

IV. On the use of mobile MANO for enabling UAV-based network services

In this section, we showcase the feasibility of our proposed system for the management and orchestration of UAV-based network services. Indeed, as discussed in [12], UAVs can be used to provide a wide range of 5G-based network services, this includes, among others, flying RAN stations, flying RAN components (e.g., Distributed Unit and Centralized Unit), 5G control plane functions (eg., AMF and SMF), and user domain cloud [13], [14]. As depicted in the second use case of Fig. 1, we consider a use case where the u-MANO is used for managing the network services of an Aerial Control System (ACS) [15]. In such a system, we consider a fleet of UAVs, where a UAV, denoted m-UAV, with higher resource capacity (i.e., computing, networking, and energy resources) is assigned as an airborne mNFVI-PoP (i.e, mNFVI-PoP B) that hosts a set of VNFs. Each VNF instance denoted Flight Control VNF (FC-VNF), is responsible for monitoring and controlling one UAV in the fleet by exchanging Command & Control (C2) messages with that UAV and forwarding them to Ground Control Services (GCS) deployed in edge/core fNFVI-PoP **B**. The GCS allows the UAV operator to manage the fleet of UAVs remotely. Hence, the end-to-end NS is composed of a set of FC-VNFs hosted in mNFVI-PoP **B** and managed by the u-MANO **B** and a set of ground control services hosted in fNFVI-PoP **B** and managed by the p-MANO **B**.

In order to demonstrate the feasibility and the advantages of the proposed solution, we analyse via testbed implementations the performances and gains of u-MANO based system in the context of the aforementioned ACS application. The developed airborne u-MANO implements partial functionalities of the framework discussed in Section III, wherein a light-weight and self-contained implementation of ETSI NFV is considered as follows:

- **VIM**: Allows the management of mNFVI-PoP resources. In our testbed, we considered the use of LXD, which is a next-generation system container manager as VIM.
- **VNFM**: Allows the management of the life-cycle of VNF by enforcing the LCM instructions in the VIM. In our testbed, the VNFM was implemented as Python service that communicates with the VIM using the PyLXD library.
- **NFVO**: Allows the life-cycle management of NS instances and the management of traffic rules between the composing VNFs. In our testbed, the NFVO was implemented as Python service that exposes its capabilities via a RESTfull API.
- **The NFV Infrastructure**: Provided by a companion computer on-board the m-UAV. Our testbed adopted the Intel UP Squared as a companion computer, which achieves a trade-off between performance and size. It is equipped with Intel Atom X7-E3950 processor (Quad core), 8GB RAM, and 64GB eMMC, with a dimension of 3.37” x 3.54” and with an 802.11n WI-FI dongle used for communication with other UAVs in the fleet.

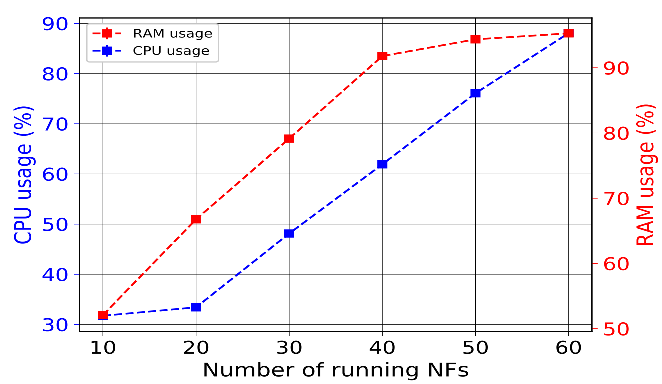
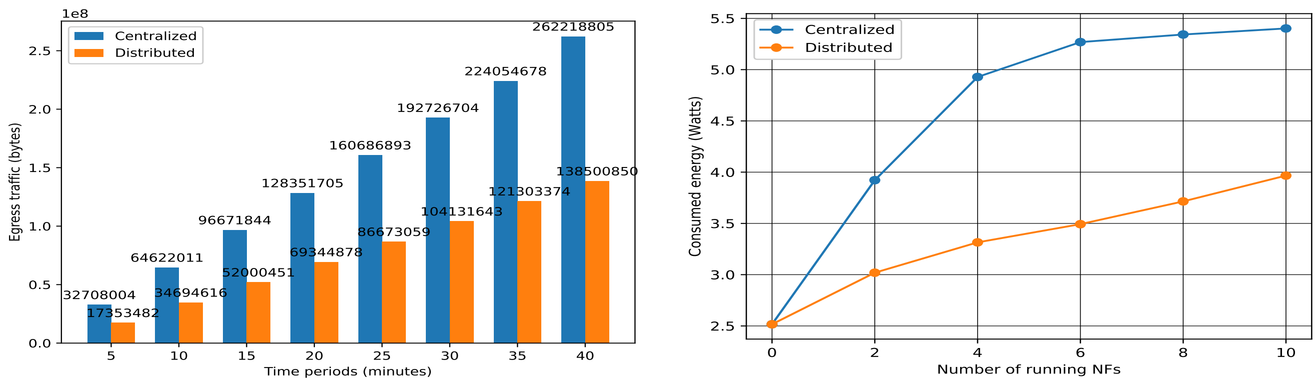


Fig. 5. u-MANO resources consumption.

In order to demonstrate the feasibility of adopting the proposed u-MANO based system for managing NS within the user domain NFVI, which is often characterized by resource scarcity, we evaluate the scalability of the u-MANO testbed by measuring the resources consumption in terms of CPU and RAM, considering different sizes of fleets (i.e., different numbers of running FC-VNFs). It has to be noted that the UAV emulator SITL has been used to emulate different numbers of UAVs. Meanwhile, a real UAV has been used as an mNFVI-PoP.



(a) Egress traffic measurements.

(b) Energy consumption measurements.

Fig. 6. Introduced gains in terms of communication overhead and energy consumption.

The workload of one single FC-VNF consists of: i) exchanging telemetry traffic with one UAV using MAVLink protocol at an average rate of $8.5Kbps$; ii) forwarding the traffic received from the UAV to the GCS deployed in the edge/core fNFVI-PoP; and iii) running a lightweight web-server that exposes interfaces to the GCS for sending control commands to the UAV. Fig. 5 depicts the usage evolution of CPU and RAM as a function of the number of UAVs in the fleet. The RAM usage is characterized by a logarithmic evolution where it reaches 95% of the total available RAM for 60 FC-VNF instances. Whereas, the CPU usage increases linearly along with the increase of the number of FC-VNF instances until it reaches a total usage of 88% for 60 FC-VNF instances. The extracted slope shows that each instance consumes around 1.40% of the total CPU time. In our experimentation, it is noticed that the maximum number of FC-VNFs instances running on-board the m-UAV cannot surpass 60; otherwise some FC-VNF instances will lose the telemetry connection to the controlled UAVs.

Moreover, in order to provide an insight into the gains that can be introduced when the MANO stack is moved to the user domain NFVI, we measured the amount of outgoing traffic from the user domain mNFVI-PoP during different time periods, under two cases. In the first case, the mNFVI-PoP is managed by a remote and centralized MANO system. Whereas, in the second case the mNFVI-PoP is managed by a local u-MANO system that can autonomously manage network services.

Fig. 6(a) depicts the obtained results. We observe that the amount of egressing traffic is reduced by around 50% when adopting the distributed u-MANO approach. This can be explained by the fact that in the first case, the amount of traffic exchanged between mNFVI-PoP and the centralized MANO includes **data plane traffic** (i.e. FC-VNFs communicating with ground control services.) and **control plane traffic**. The control plane traffic consists of KPIs and information collected by the centralized MANO system from the mNFVI-PoP for FCAPS purposes and it includes the status of the VNFs, CPU usage, memory usage, storage usage, and network usage. Whereas, in the second case, since the FCAPS operations can be performed locally by the u-MANO, the traffic exchanged between the mNFVI-PoP and the centralized MANO system (i.e., a p-MANO system in this case) include only the data plane traffic. Such degradation in the communication overhead will not only save the network resources but will also save the energy consumed by mNFVI-PoP which is a critical factor when considering user domain NFVI that is characterised by limited energy resources (e.g., UE, UAV, and Autonomous vehicles).

Fig. 6(b) shows the average energy consumed (in Watts) by the mNFVI-PoP as a function of the number of deployed FC-VNFs considering the two previous cases. From this figure, we observe that the absence of the control plane traffic can reduce the energy consumption up to 26%. For example, when the number of FC-VNFs deployed in the mNFVI-PoP is set to 10, the measured consumed energy is equal to $5.4\ Watts$ when the mNFVI-PoP is under the control of a centralized MANO system, and $4\ Watts$ when the mNFVI-PoP is under the control of a local u-MANO system.

V. Conclusion

This article proposes a new architecture framework for the management and orchestration of end-to-end mobile network services, where the aim is to ensure sustainable QoS when the NS instances are fully or partially deployed in mobile user domain infrastructures. In this regard, this article introduces a novel MANO system referred to as u-MANO, that can be deployed within the user domain and that can coordinate with third parties' MANO systems referred to as p-MANOs to provide end-to-end network services. Moreover, the article provides solutions to the problem of coordination between the u-MANO and the p-MANOs systems, where the challenge is to ensure the integrity and service continuity provided by the end-to-end NS during the mobility events of the mobile infrastructure. The feasibility of the proposed solution and its introduced gains in terms of reducing the communication overhead and the energy consumption of the user domain infrastructure were evaluated on a UAV-based network service testbed. The obtained results showed that the proposed solution could be implemented in constrained user domain infrastructures by adopting light-weighted orchestration technologies (e.g., containers). Also, the obtained results showed that pushing the management and orchestration services to the user domain infrastructure could help to significantly reduce the control plane traffic and related energy consumption.

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References

[1] M. Shafi, A. F. Molisch, P. J. Smith, T. Haustein, P. Zhu, P. De Silva, F. Tufvesson, A. Benjebbour, and G. Wunder, "5g: A tutorial overview of standards, trials, challenges, deployment, and practice," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 6, pp. 1201–1221, 2017.

[2] F. Z. Yousaf, M. Bredel, S. Schaller, and F. Schneider, "Nfv and sdn—key technology enablers for 5g networks," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 11, pp. 2468–2478, 2017.

[3] J. Ordonez-Lucena, P. Ameigeiras, D. Lopez, J. J. Ramos-Munoz, J. Lorca, and J. Folgueira, "Network slicing for 5g with sdn/nfv: Concepts, architectures, and challenges," *IEEE Communications Magazine*, vol. 55, no. 5, pp. 80–87, 2017.

[4] ETSI GS NFV-MAN 001, "Network Functions Virtualisation (NFV); Management and Orchestration," *ETSI GROUP SPECIFICATION*, 2014.

[5] ETSI GR NFV-IFA 022, "Report on Management and Connectivity for Multi-Site Services," *ETSI GROUP REPORT*, 2018.

[6] ETSI GR NFV-IFA 028, "Report on architecture options to support multiple administrative domains," *ETSI GROUP REPORT*, 2018.

[7] T. Taleb, I. Afolabi, K. Samdanis, and F. Z. Yousaf, "On multi-domain network slicing orchestration architecture and federated resource control," *IEEE Network*, vol. 33, no. 5, pp. 242–252, 2019.

[8] I. L. Pavon *et al.*, "Deliverable D3.3 5G NORMA network architecture - Final report," 5G-PPP, Tech. Rep., 2017.

[9] F. Z. Yousaf, V. Sciancalepore, M. Liebsch, and X. Costa-Perez, "Manoaas: A multi-tenant nfv mano for 5g network slices," *IEEE Communications Magazine*, vol. 57, no. 5, pp. 103–109, 2019.

[10] 3GPP TR 23.501, "System architecture for the 5g system (5gs)," Rel.16, mar. 2021.

[11] T. Taleb, K. Samdanis, B. Mada, H. Flinck, S. Dutta, and D. Sabella, "On multi-access edge computing: A survey of the emerging 5g network edge cloud architecture and orchestration," *IEEE Communications Surveys Tutorials*, vol. 19, no. 3, pp. 1657–1681, 2017.

[12] O. Bekkouche, K. Samdanis, M. Bagaa, and T. Taleb, "A service-based architecture for enabling uav enhanced network services," *IEEE Network*, pp. 1–8, 2020.

[13] N. Motlagh, T. Taleb, and O. Arrouk, "Low-altitude unmanned aerial vehicles-based internet of things services: Comprehensive survey and future perspectives," *IEEE J. on IoT*, vol. 3, no. 6, pp. 899–922, Dec. 2016.

[14] O. Bekkouche, M. Bagaa, and T. Taleb, "Toward a utm-based service orchestration for uavs in mec-nfv environment," *in Proc. IEEE Globecom, Hawaii, USA, Dec. 2019*.

[15] H. Hellaoui, O. Bekkouche, M. Bagaa, and T. Taleb, "Aerial control system for spectrum efficiency in uav-to-cellular communications," *IEEE Communications Magazine*, vol. 56, no. 10, pp. 108–113, 2018.

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