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On Supporting UAV based Services in 5G and Beyond Mobile Systems

Tarik Taleb, Adlen Ksentini, Hamed Hellaoui, and Oussama Bekkouche

***Abstract*—While Unmanned Aerial Vehicles (UAVs) are expected to introduce disruptive innovations in our society, it is foreseen that the used communication technology is the key factor that can unlock their potentials. To this end, the upcoming generation of mobile networks, 5G-and-beyond, are envisioned to be the communication standards to support diverse UAV applications. This will also enable UAVs to benefit from the limitless progress achieved in mobile systems. To facilitate the support of UAV services in 5G-and-beyond networks, this paper introduces a framework that links the mobile telecommunication domain to the UAV domain. The proposed framework reflects an operational view enabling UAV operators to prepare and deploy their applications over different 5G mobile telecommunication networks. Moreover, the framework allows UAV operators to customize mobile systems in accordance with the specifications of their target services and to constantly receive analytical and statistical data on their running applications. Furthermore, in order to ensure network services (dedicated for UAV applications) over heterogeneous mobile systems, this article also discusses the federation of 5G networks.**

***Index Terms*—Index terms – 5G, 5G and beyond, UAV, Network Slicing, NFV, and Network Federation.**

I. Introduction

Over the last decade, Unmanned Aerial Vehicles (UAVs) have experienced an unprecedented expansion. Their market is estimated at USD 19.3 billion in 2019 and is projected to reach USD 45.8 billion by 2025. This reflects a Compound Annual Growth Rate (CAGR) of 15.5% from 2019 to 2025 [1]. In this regard, a number of factors show that the wireless communication technology is the key enabler to unlock UAVs' potentials. Indeed, the use of cellular networks as a communication infrastructure for UAVs will enable Beyond Visual Line of Sight (BVLOS) applications, whereby a UAV operator can fly its drones far from the control center. Furthermore, the advances achieved in 5G can support the conflicting needs of the different UAV services (e.g., reliable and low latency communications, high data transmission rate for video streaming). All those features can provide a huge support to meet the challenging requirements of UAVs' applications and to reach their expected potentials.

Launching UAV applications on the top of mobile telecommunication networks and remotely managing them is highly challenging. Indeed, such applications are associated with different service requirements which can vary not only by time, but also by geographical location. This is a direct consequence of their mobility nature and their diverse service provisioning character. Furthermore, conducting UAV applications requires the cooperation between different actors. In addition to mobile systems and cloud service providers, a dedicated entity, such as UTM (Unmanned aerial vehicles Traffic Management) is also needed to ensure safe and secure access to the airspace by the drones. UTM provides a set of services allowing to manage the flights of the drones, such as the approval of the trajectories, notification of possible changes, etc. It therefore requires a close coordination with the UAV operators. From these perspectives, it becomes apparent that a sophisticated and well-integrated architecture is therefore needed to support UAV services in mobile telecommunication networks.

This underpins the focus of this article, wherein the authors advance a framework that links the different actors. The proposed framework provides an operational view enabling UAV operators to prepare and deploy their applications over heterogeneous 5G mobile networks. In addition, this framework enables UAV operators to customize the 5G mobile systems as per the specifications of their envisioned UAV services, and constantly receive statistical and analytical data on their running applications. Furthermore, in order to ensure network services over heterogeneous mobile systems, this article discusses the federation of 5G networks and links it to the proposed framework. The present article also proposes potential optimizations for supporting UAV-based services in mobile systems.

II. Related Works

The use of mobile networks for UAVs has attracted a significant amount of attention from both scientific and industrial communities. This interest has been translated into different real-field evaluations and trials of cellular-based UAVs. For instance, 3GPP addressed in its technical report 36.777[1] the feasibility of using an LTE network to serve flying UAVs. The study focused on evaluating the radio aspect and identified further performance-enhancing solutions to optimize the LTE connectivity to the aerial vehicles. Moreover, in its technical specification 22.261[2], 3GPP identified UAV traffic needs dedicated to priority and QoS treatment. Furthermore, in its

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[1]3GPP TR 36.777, "Study on enhanced LTE support for aerial vehicles", 3GPP Technical Report, 2017.

[2]3GPP TS 22.261, "Service requirements for the 5G system", 3GPP Technical Specification, 2020.

technical report 22.825[3], 3GPP studied the identification and tracking of Unmanned Aerial Systems (UAS) linked to a 3GPP subscription. The study also identified the potential use cases and requirements for 3GPP to support remote identification of UAS and its usage. This would allow authorised users (e.g., air traffic control or public safety agencies) to query the identity and metadata of a UAV and its UAV controller via a UTM.

In another work [2], real field evaluations were carried out using an LTE network to realize uplink data and downlink control for a flying airborne. In [3], the authors used a mobile network to offload computation intensive tasks to a Multi-access Edge Computing (MEC) node on the ground. The study considered a face recognition operation and demonstrated how UAVs can be used for a crowd surveillance use case. In [4], Yuan et. al. studied and demonstrated a UAV swarm use-case whereby LTE networks are employed to provide broadband and cellular wireless network support.

Beside real field evaluations, different academic works have been conducted. In [5], the authors focused on the use of massive MIMO for UAVs. Different guidelines are provided to the Mobile Network Operators for realizing 5G-connected UAVs. In another work [6], authors studied cellular-connected UAVs by addressing the spectrum requirements, the design consideration and the enabling technologies for future generation of 3D heterogeneous wireless networks. Furthermore, several research works undertaken in the academia are studied in [7] with focus on the wireless communications. In these studies, the authors also investigated some underlying challenges in UAV-enabled wireless networks such as 3D deployment, performance analysis, channel modeling, and energy efficiency.

Whilst a wide library of research work has been carried out on cellular-based UAV control and management, to the best knowledge of the authors, none of the published work addresses the operational view linking the different actors (including air traffic management entities - such as UTM) and showing how 5G and beyond mobile networks can efficiently accommodate UAV applications. Indeed, in such cellular-based UAV services, different stakeholders can be considered including the UAV operators, the mobile systems, cloud service providers and the traffic management entities. The next section introduces the framework proposed for supporting UAV services over heterogenous 5G mobile telecommunication networks, while linking among the different stakeholders.

III. A FRAMEWORK FOR SUPPORTING UAV SERVICES IN MOBILE TELECOMMUNICATION NETWORKS

This section introduces the proposed framework. It first presents a use case scenario aiming to support the proposed framework.

1) An Example Use Case: A delivery company intends launching a new delivery service based on UAVs. The company targets shipping small-size packages to clients over medium distances using a fleet of UAVs. The UAVs are equipped with wireless devices that enable them to be reached remotely over the cellular networks and to be commanded and

[3]3GPP TR 22.825, "Study on Remote Identification of Unmanned Aerial Systems (UAS)", 3GPP Technical Report, 2018.

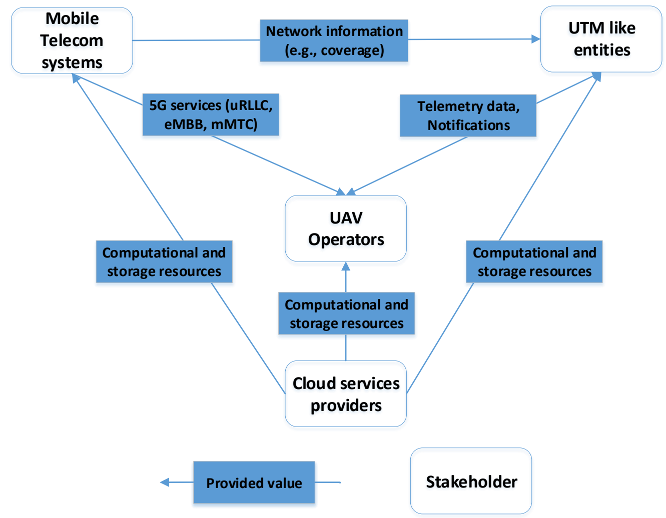

Figure 1: The involved stakeholders and the correlation among them.

controlled beyond visual line of sight. The mobile network operators provide the connectivity service, while the control of the drones is autonomously performed by a software flight controller administrated by the company. The software flight controller can be running in a cloud server within the premises of a cloud provider that ensures the required cloud resources. If needed, these cloud resources can be instantiated at the MEC level provided by the 5G mobile system. This would intuitively reduce the communication delay and allow quick interactions between the drones and the software flight controller. The delivery company would request a specific QoS to be ensured throughout the flying paths by the mobile networks with regard to the control of the drones (e.g., maximum delay) and also to the data payload sent from them (e.g., minimum throughput for the live stream of videos captured by the drones). Moreover, these communication requirements should be maintained throughout the flying paths of the different UAVs. This potentially implies using several mobile networks in the same time. Although the initial flight path for shipping an object can be pre-defined, changes may occur to the flight mission. Ensuring that the underlying telecommunication networks are adequately tailored to support such changes in the flight missions and to sustain the QoS required by UAV operations raises the need for efficient management and coordination between the different stakeholders, namely UAV operators, mobile network operators, cloud providers, and aerial traffic management entities (e.g., UTM). Figure 1 depicts the involved stakeholders and the correlation among them.

2) Need for operation over multi-administrative network domains: To support the launch and lifecycle management of a UAV service, a Network Slice Instance (NSI) shall be created on multiple technology domains. A NSI consists of one or multiple Network Slice Subnet Instances (NSSIs). These technology domains include, among others, the core network, the transport network, the radio access network, and the cloud. Ideally speaking, a NSI should be created on the infrastructure of one single 5G mobile system, and that is to avoid the complexity and incurred overhead in terms of cost and performance. However, there could be situations when a single 5G mobile network cannot allocate sufficient resources to create an optimal NSI that can satisfy the functional and operational requirements of the UAV service. These situations can be due to: *i)* part of the UAV mission is carried out in a region which is out of the original mobile operator service area; *ii)* or the optimal embedding of one or more NSSIs cannot be achieved because of the limited resources in the underlying infrastructure of that single mobile operator. To cope with this issue, it becomes important to explore the possibility of stretching NSIs across multiple-administrative domains that belong to different mobile operators. Indeed, since the heterogeneous nature of infrastructures is abstracted using virtualisation technologies, it would be possible for each operator to enable a generic resource usage for third parties. Such approach allows mobile operators to federate their resources, satisfying the Service Level Agreements (SLAs) of verticals and reducing capital and operational expenditures (CAPEX and OPEX). For instance, a mobile operator can easily extend its service area for serving a UAV or a swarm of UAVs, by simply deploying the RAN related NSSIs in another operator infrastructure.

3) The proposed framework: The high level architecture of the proposed framework to support UAV services over mobile networks is depicted in Figure 2. The framework operates over multi-administrative domains and its components and modules can be hosted in a centralized fashion on one single dedicated cloud or in a distributed fashion across multiple clouds. In case of the latter, requirements on the maximum latency for two components to interact should be met. By design, the envisioned framework interacts with the users (UAV operators) and deals with their specifications related to the UAV operations to be conducted and the services to be offered. On the other hand, it coordinates with the 5G networks and provides the customized network specifications to be supported. The framework also interacts with drone traffic management entities, like UTM, for the validation of the requested missions. As shown in Figure 2, the framework is divided into four functional blocks, namely the Operations/Business Support Systems (OSS/BSS), the execution engine, the enforcement module and the data collection & analytics module. These functional blocks and the interactions among them are described in the remainder of this section.

The OSS/BSS module is the main module through which the different UAV service providers interact with the framework to run their UAV applications on the top of the mobile telecommunication networks. It allows introducing the information related to the application to be performed. For this purpose, it exposes a blueprint to the users (UAV service provider). This blueprint allows introducing information about the operation to be conducted by the drones (e.g., target UAVs, their paths, the time of the operations, etc.) and also about the network service requirements, including the requested QoS such as latency and throughput. It is also worth noting that the OSS/BSS module allows users to describe or introduce their Virtual Network Functions (VNFs) to be used for their applications.

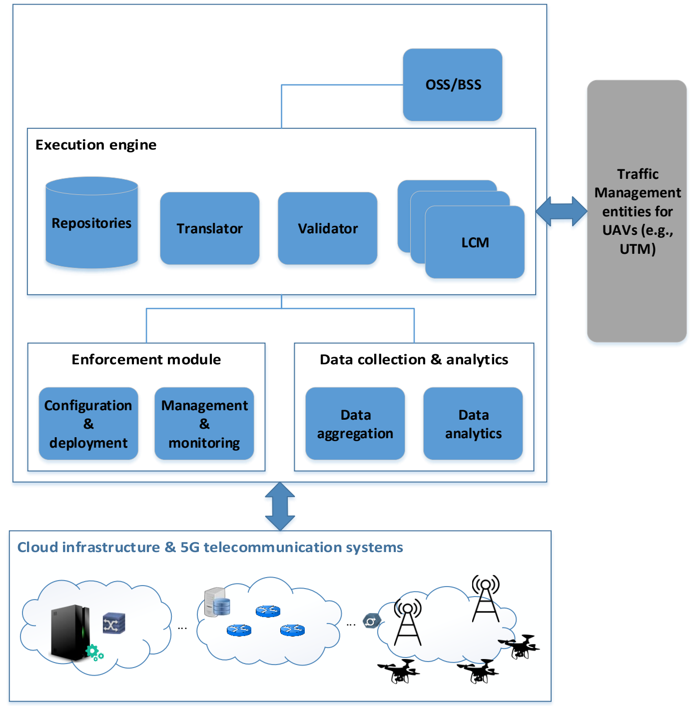

Figure 2: The proposed operational view architecture for 5G-based UAV applications.

On the other hand, the OSS/BSS module also exposes the different static and dynamic information on the running UAV applications to the corresponding users, including telemetry data, cloud resource status, achieved throughput, data packet losses, and delay.

The *execution engine* is responsible for managing the execution of the different UAV applications which are running on the top of the 5G networks. In order to perform its operations, the execution engine is composed of three sub-modules, which are the translator, the validator, and lifecycle manager (LCM). Furthermore, a number of repositories are considered for the execution engine in order to perform its tasks at different levels. These repositories are the 5G system repository, the UAV repository, the VNF repository, and the mission repository.

The 5G system repository captures different information about the 5G networks that can be used to accommodate UAVs' operations. These information include, among others, the network capabilities, the addresses of the different interfaces, and the coverage of the mobile systems. These information are exposed by the mobile telecommunication networks and help the execution engine in selecting suitable 5G networks that can accommodate a specific UAV application. The VNF repository holds, or points to, different VNFs that can be used to perform the requested operations and ensure the required services. This includes the UAV software used to command and control the drones (UAV software flight controller), as well as VNFs for processing and analyzing the data captured from the drones. As mentioned earlier, the users can also upload their VNFs via the OSS/BSS module. Some generic VNFs can be hosted in the VNF repository and used for different applications. The UAV repository holds information about the UAVs which will be addressed to conduct the mission. It also includes information about their on-board devices (e.g., sensors, thermal camera, and AI chip) that can be used to provide the requested services. As for the mission repository, it holds information about the UAV missions which are validated and running or planned.

The translator is responsible for building a descriptor file starting from the specifications introduced by the users (i.e., the UAV service provider) via the OSS/BSS module. This descriptor is intended to be the base reference serving for preparing the execution of the mission on the top of the 5G mobile networks. Therefore, the descriptor generated by the translator will target specific 5G networks that can accommodate the UAV application, depending on the specification introduced by the users and the capabilities of the 5G networks (exposed in the 5G system repository). It is the role of the translator to decide on the target mobile networks (i.e., in case there are multiple mobile operators to select from) when producing the descriptor. To this end, the translator will make use of the flight paths of UAVs to decide the potential 5G networks that can accommodate the underlying UAV application. Effectively, the target 5G networks can be selected in a way to ensure communication coverage and acceptable throughput for all the flying UAVs throughout their flying paths. It shall be stated that in case of a UAV service involving multiple UAVs, flying over a relatively wide area, different 5G networks, covering different regions in the service area, may be selected to support that particular UAV service. When a UAV service provider requests short delay, the translator can consider the availability of a MEC within the target mobile networks. It shall be noted that the process of defining the target mobile networks that can accommodate the UAV application is automatic and transparent to the UAV service provider. Once the target 5G networks are defined, the translator will map the UAV operator specifications to a NSI (Network Slice Instance) offered by the selected 5G network. This NSI can be defined across federated 5G systems, where each 5G network domain is associated with a NSSI (Network Slice Subnet Instance). The translator will map the requested specifications by preparing network slice templates to be addressed to the target networks.

Once the descriptor is produced by the translator, the validator will thereafter be in charge of validating or rejecting the UAV application. Two steps will be considered for this purpose. First, the validator will coordinate with the target 5G networks on the availability of the resources needed to perform the mission. To this end, the validator communicates to the Network Slice Management Function (NSMF) of each mobile network the requirements of requested NSSI, along with the desired time. The 5G networks may thereafter reserve the resources for the estimated duration of the mission. When the requested resources are not available, the translator may be requested to adjust the descriptor to propose another mapping that maintains the initial specifications. Another possible solution to overcome the unavailability of the resources that can satisfy the service requirements indicated in the mission descriptor, is the adjustment of the flight path of the UAV, taking into consideration the availability of resources along the new flight path [8]. This could involve some negotiation with the UAV service provider through the OSS/BSS module. In the second step, the validator will also request the approval of the mission from the UTM. The latter will therefore be provided with information on the mission, including the trajectory, the time of the mission, etc. The UAV application can be validated only if it is approved by the UTM and there are sufficient resources at the target mobile networks. The process of validating a UAV application is illustrated in Figure 3. Once the mission is validated, the descriptor will thereafter be inserted in the mission repository and a LCM will be associated and dedicated to the UAV application.

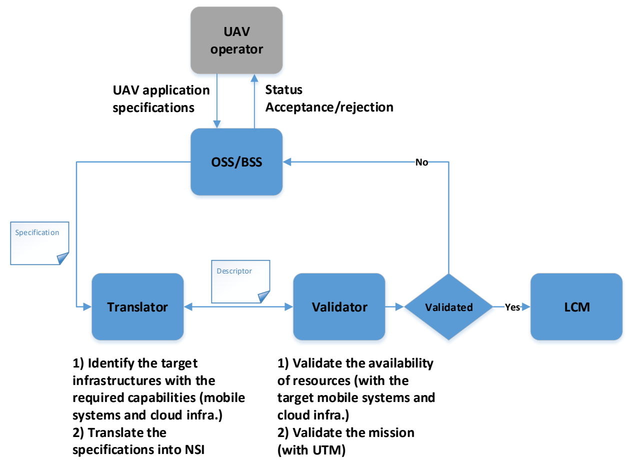

Figure 3: Process of translation and validation of UAV applications.

A *life-cycle manager* is in charge of managing the execution of a UAV application once validated. When different UAV applications are executed in the same time, separate LCMs will be created and each will be in charge of handling its respective UAV application. A lifecycle of an application is defined from its validation by the validator until it is terminated. To this end, the LCM sends requests for slice deployment and VNF on-boarding to the enforcement module. The latter interacts with target mobile systems via the interfaces exposed by them. At this level, the LCM uses NSI association to the application which can be extracted from the descriptor. Moreover, once VNFs are on-boarded, the LCM requests the enforcement module to enforce the mission (e.g., sending the mission plan). Furthermore, the different inquiries for updating the running application will be handled by the LCM and new requests will be accordingly sent to the enforcement module. This includes inquiries for modifying the configuration of the NSIs running the application, as well as inquiries for modifying the mission conducted by the UAVs, such as changing their flying paths or migrating their services running in the cloud from a cloud host to another.

The enforcement module receives requests from the LCMs and interacts accordingly with the target mobile networks via their exposed interfaces. In this regard, the enforcement module will be in charge of sending slice instantiating requests to the 5G networks in addition to requesting the on-boarding

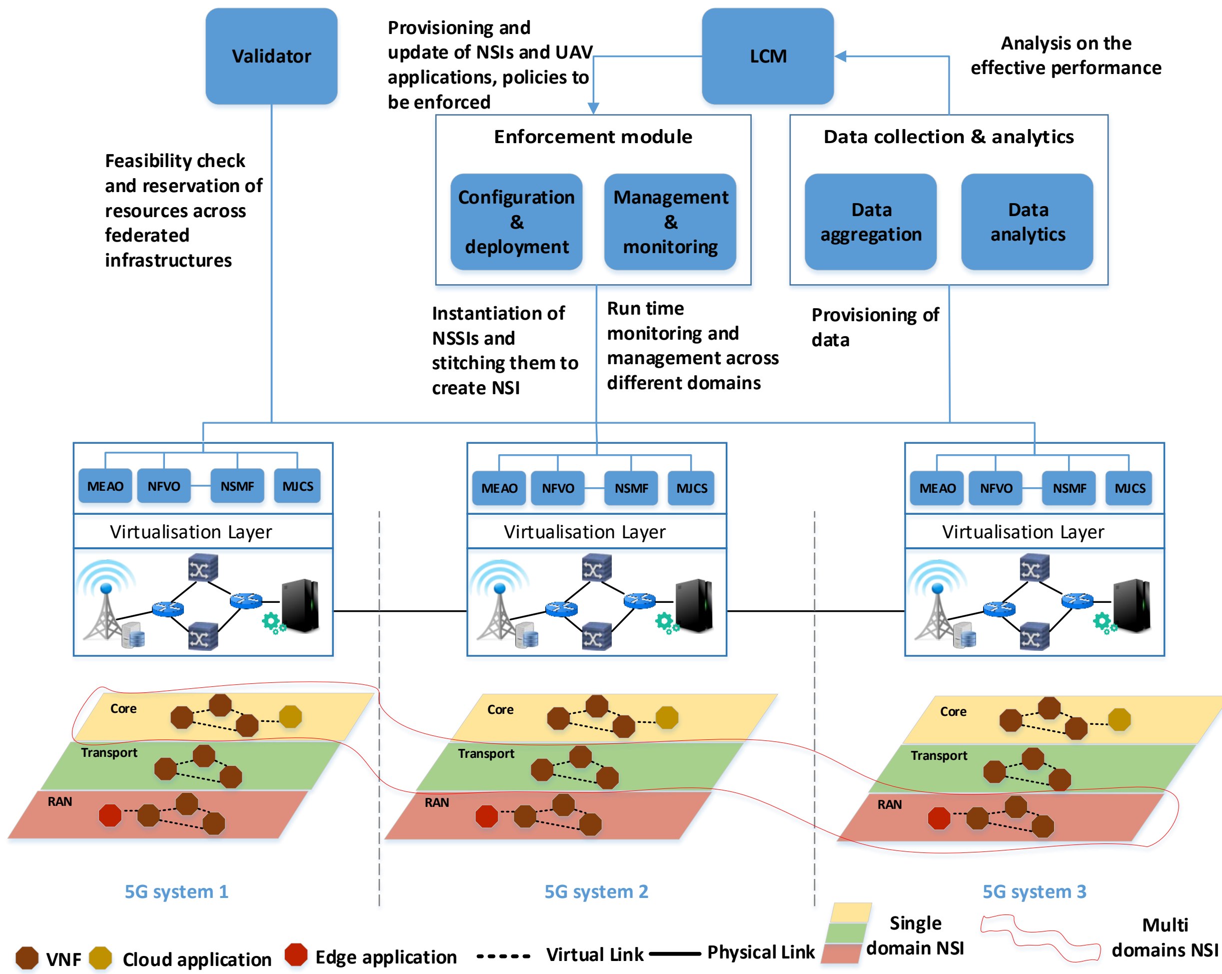

Figure 4: Establishment and management of network slices across multiple administrative domains.

of the different VNFs. Through interfaces to the target mobile networks and VNFs, this module will enforce the execution of the UAV application. The enforcement module includes two sub-modules as shown in Figure 2. The configuration & deployment sub-module is responsible for instantiating the different NSSIs in each target 5G network. In addition, and as it is detailed in the next section, this sub-module is also responsible for stitching the NSSIs to form a NSI. As for the management & monitoring module, it monitors and manages the resources related to the created NSI. It therefore plays a role of a mediator among the different domains allowing re-adjustments to compensate with possible degradation. These adjustment requests come from the LCM sub-module and, when needed, may involve interactions with the UAV service providers through the OSS/BSS module.

As for the *data collection & analytic* module, it is responsible for collecting data on the conducted UAV applications and performing advanced analytics. This module will collect data from different sources, including the mobile telecommunication systems and UAV operators. Indeed, while some data may relate to networking/computation usage (e.g., CPU and memory consumption, throughput and delay) and slicing (e.g., slice deployment duration and service relocation duration), other data types can be also considered. In particular, the telemetry data that allows providing information on the status of the flying UAVs such as their geographical positions, their speed, and their energy consumption. Based on the collected data, different statistics and analysis (e.g., based on Machine Learning - ML) can be performed and exposed to the corresponding users. Furthermore, being in the center of UAV application lifecycle, LCM will make use of the analysis conducted by this module to sort out optimized configurations of the network slices to ultimately meet the requested specifications of the UAV operators (as illustrated in Figure 4). For instance, by applying ML techniques to resource usage data, it would be possible to predict the expected load on the network during a certain time window, and hence it would be possible to automate the scaling up or scaling down of cloud resources and NSIs running some UAV services/applications.

IV. Management and Orchestration of Mobile Networks

This section discusses the federation of multi-administrative and technological domains, forming one or multiple 5G mobile systems [9], to support the launch and lifecycle management of UAV services using the envisioned framework. Hereafter, we

Table 1: Interfaces provided by mobile systems.

Category	Interfaces
Network slices management	• NSSI feasibility check interface: used by the validator sub-module to check whether the NSSI requirements can be satisfied by a given 5G system at the starting time of the UAV's mission. • NSSI creation interface: used by the enforcement module as per a request from the LCM to deploy a NSSI. This includes the reservation and configuration of all resources required by the NSSI. • NSSI activation interface: used by the enforcement module to change the state of a NSSI to the *active state*, which means that the NSSI is ready to provide communication service to the UAV application. • NSSI modification interface: used by the enforcement module to modify the running NSSI. This can map to several workflows, e.g. changes of NSSI capacity, changes of NSSI topology, and NSSI reconfiguration. • NSSI deactivation interface: used by the enforcement module to change the state of a NSSI to the *deactivated state*. which means that the NSSI is not available for providing communication services. NSSI deactivation is mandatory before a NSSI modification. • NSSI termination interface: used by the enforcement module as per a request from a LCM to terminate its respective NSSI. This mainly includes releasing the resources originally allocated for the NSSI.
VNFs management	• VNFs packages management interfaces: used by the enforcement module to on-board, enable, disable, delete, and fetch a VNF package. A VNF package is the file that includes the software image of the VNF and the VNF descriptor (VNFD). Initially, it is stored in the VNFs repository at the level of the execution engine module. • Network services descriptors (NSDs) management interfaces: used by the enforcement module to on-board, enable, disable, update, delete, and fetch an application descriptor (i.e., network service descriptor) that describes how the application must be deployed, i.e., constituent VNFs and the interconnections between them, as well as service characteristics such as SLAs (i.e., specific properties for instantiating a virtual link according to a specific flavor). • Network Services (NS) management interfaces: used by the enforcement module to instantiate, scale, update, and terminate an application deployed as a network service.
MEC applications management	• Applications packages management interfaces: this set of interfaces allows the management of the applications packages that bundle the files required for the instantiation of the UAV applications. The interfaces used by the proposed framework for the management of applications packages are as follows: – Application package on-boarding interface: used by the enforcement module to make the application package, stored in the VNFs repository, available to the MEC system. – Application package enabling interface: used to mark the application package as available for instantiation. – Application package disabling interface: used to mark the application package as not available for instantiation. – Application package deletion interface: used to delete the application package from the MEC system. • Applications instances management interfaces: – Application instance creation interface: used to create a new instance of an application whose package has been already on-boarded and enabled. – Application instance operation interface: used to start and stop an already created application instance. – Application instance termination interface: used to delete a running application instance.
KPI monitoring	• Measurement job creation interface: allows the creation of one measurement job that can collect the values of one or multiple KPIs. • Measurement job termination interface: used to terminate a running measurement job after the end of the UAV mission. • List measurement jobs interface: used to list the running measurement jobs.

list the interfaces required by the different functional blocks of the proposed framework, grouped in four categories. It is worth noting that 3GPP standards concentrate on slices deployed and managed by a single administrative entity and do not address the federation of 5G networks across multiple administrative domains. Figure 4 depicts the interfaces between the proposed framework and the mobile telecommunication systems.

A. *Network slices management interfaces*

These interfaces are mainly used by the enforcement module to manage the lifecycle of NSSIs on the different 5G systems. According to 3GPP's Technical Specifications 28.531[4], NSSIs can be managed using a set of interfaces provided by the Network Slice Management Function (NSMF) of each 5G system. This includes interfaces for NSSI feasibility check, NSSI creation and activation, NSSI modification, NSSI deactivation and termination. Table 1 provides a short description of these interfaces and links them to the proposed framework.

B. *VNFs management interfaces*

This set of interfaces is ensured by the NFVO (Network Function Virtualization Orchestrator) and allows the proposed framework to manage the lifecycle of VNFs needed to support a UAV application. Indeed, in addition to communication services, 5G systems can provide the UAV service providers with the ability to deploy their own applications, either at the edge of the mobile network or at distant data-centers (i.e., private data networks). The set of interfaces presented in this category are mainly for managing the lifecycle of UAVs' applications in the operator private data network, and are based on ETSI Group Specifications, namely NFV-IFA 013[5]. As

[4]3GPP TS 28.531, "Management, orchestration, and provisioning of 5G networks", 3GPP Technical Specification, 2020.

[5]ETSI GS NFV-IFA 013, "Network Functions Virtualisation (NFV); Management and Orchestration; Os-Ma-Nfvo reference point - Interface and Information Model Specification", ETSI GROUP SPECIFICATION, 2016.

provided in Table 1, these interfaces include VNFs packages management, Network services descriptors management, and Network Services management. Note that, ETSI terminologies are used to describe the lifecycle of UAVs' applications, wherein each UAV application is considered as a network service composed of one or more VNFs.

C. MEC applications management interfaces

In addition to the applications deployed in the operator's data networks, UAVs may need to communicate with applications characterized with uRLLC requirements (e.g., UAV flight control services) that cannot be satisfied when the applications are hosted in distant data centers. Therefore, the proposed framework requires access to interfaces that allow the management of such applications at the edge of 5G systems, i.e., nearby the base stations. The interfaces required for the management of edge applications' lifecycle are defined in ETSI MEC 010-2[6] and exposed by the Mobile Edge Application Orchestrator (MEAO) of each 5G system involved in the NSI needed to launch the considered UAV service. This includes applications packages management interfaces as well as applications instances management interfaces, as provided in Table 1. It shall be highlighted that the MEC architecture is defined to run independently from VNF environment. However, in order to take advantage of the VNF environment to operate MEC components and edge applications, ETSI GR MEC 017 [7] has analyzed different scenarios of MEC deployments in VNF environment with regard to the architectural impact and the needed specification work.

D. Key Performance Indicators KPI(s) monitoring interfaces

In addition to NSSIs and applications management interfaces, the proposed framework requires access to interfaces that allow the real-time collection of performance data. Indeed, the collected data will be used by the *data collection & analytic* module to analyse the effective performance so to take the appropriate actions accordingly (e.g., reconfiguration of the running NSSIs). In the Technical Specification 28.550[8], 3GPP specifies how the performance of 5G systems can be monitored by third parties' applications. The described procedure consists of creating measurement jobs on generic objects (e.g., NSI, NSSI, or a VNF instance), and waiting for the data stream to be sent to the stream target specified in the measurement job creation request. Hence, the proposed framework requires access to a set of interfaces exposed by the Measurement Job Control Service (MJCS). As provided in Table 1, these interfaces include measurement job creation, measurement job termination, and list measurement jobs.

[6]ETSI GS MEC 010-2, "Multi-access Edge Computing (MEC); MEC Management; Part 2: Application lifecycle, rules and requirements management", ETSI GROUP SPECIFICATION, 2019.

[7]ETSI GS MEC 017, "Mobile Edge Computing (MEC); Deployment of Mobile Edge Computing in an NVF environment", ETSI GROUP REPORT, 2018.

[8]3GPP TS 28.550, "Performance assurance for 5G networks", 3GPP Technical Specification, 2019.

V. OPTIMIZATION POTENTIALS

Given their mobility nature, constantly sustaining the requested QoS by a UAV application is challenging for a mobile network. In this regard, the proposed framework can make use of UAVs' flight plans and attach them to the NSI creation request. Such information about the mobility of UAVs can be harnessed by the mobile operators to create cost- and performance-effective NSSIs. Indeed, since NSSIs are embedded on top of distributed virtualisation infrastructures (i.e., Slates) characterized by certain virtual compute and network resources (i.e., CPU, RAM, Storage, network interfaces, logical links, virtual switches, etc) [9], it is challenging to find an optimal (i.e., in terms of deployment cost and performances) embedding of the NSSIs that can ensure the QoS required for the NSI, especially for serving User Equipment (UEs) characterized with relatively high mobility, which is the case of UAVs. Indeed, the quality of the communication ensured by a NSI can deteriorate rapidly when a UAV moves away from its initial location, changing the access point and the mobility anchor. In the usual case where the mobility patterns of UEs are not known a priori, this can be handled either by updating the underlying topology of the NSSIs (i.e., allocating new VNF instances, adding new logical links, and updating the traffic rules) [10] or by changing the serving NSI to a more appropriate one. Nevertheless, both solutions are costly in terms of signaling overhead and overall network performance.

In the proposed framework, the flight paths of UAVs are introduced by the UAV operators via the OSS/BSS module, validated by the UTM or alike, and finally made available in the mission descriptor. Hence, it would be possible to send the mobility plans of UAVs in the NSSIs creation request either as part of the network slice template or as a separated complementary information. It is worth noting that the standardized Generic Network Slice Template (GNST) V2.0 [11] is already specified to include such an information (i.e., *device velocity*). Although this parameter is optional, its use is highly recommended for the support of uRLLC services under high mobility scenarios. Extending such standard by adding information related to the exact mobility plans of devices (UAVs) would even achieve a better mobility-driven network slicing.

A concrete example showcasing the benefits beneath using UAV mobility plans for optimizing NSSIs allocation procedure consists in the creation of a uRLLC network slice instance. In such a case, the User Plane Functions (UPFs; alternatively Packet Data Network Gateways and Serving Gateways in case of 4G core network - Evolved Packet Core - EPC) can be placed at the edge of the network, nearby the access points, reducing the communication latency and ensuring a higher reliability. However, in the case where the mobility patterns of UAVs are not known or subject to frequent changes during the flights, and in order to sustain the communication QoS, multiple UPFs can be allocated for the NSI, whereby each UPF is used to serve the UAVs flying in the proximity of its corresponding access points. The increase of the number of UPFs implies not only the increase of the deployment costs, but also the increase of the occurrences of UPF reallocation process, introducing additional delays during handovers and signaling overhead. Nevertheless, when the mobility patterns of UAVs are known by the mobile operator, it is possible to predict accurately the set of access points that UAVs will connect to, and accordingly an optimal number of UPFs will be instantiated at the right places/regions and resources can be immediately released once the UAVs fly away from the specific regions.

Prior knowledge on UAVs' mobility plans can also be considered to optimize the placement of the different VNFs used to run the UAV applications (e.g., flight controller software, video transcoding for real time streaming, AI processing, etc.). This is particularly required to ensure and maintain uRLLC services. Based on the mobility patterns of the UAVs and the latency associated to the different VNFs, the latter can be reshuffled during the UAV flight within the same cloud domain or over multiple-administrative cloud domains. This implies service migration and reallocation from an edge cloud to another edge cloud while ensuring a smooth and zero-downtime migration of the VNF and the underlying uRLLC service [12]. Indeed, the prior knowledge on the mobility patterns of the UAVs can be used to address two challenges related to service migration and reallocation: *i)* deciding when to trigger the service migration/reallocation process; *ii)* deciding where to migrate/reallocate the service. Moreover, the concept of service migration can be extended to network slices. In this context, a whole NSI or NSSI can be migrated between different administrative domains. While MEC service mobility support is under definition by standardisation bodies (e.g., ETSI GS MEC 021[9]), slice migration is more challenging as it concerns a group of services and UAVs at the same time. Compared to a simple service mobility, network slice migration is associated with different mobility patterns (full slice mobility, partial slice mobility) [13]. In addition to the optimized service/slice migration based on the prior knowledge on UAVs' mobility plans, the proposed framework can enhance the service migration process using ML/AI techniques applied to the real-time data collected by the *data collection & analytic* module, by deciding when, where and which service/slice should be migrated.

VI. Conclusion

This article proposed a framework to support the launch and lifecycle management of UAV services in 5G and beyond mobile systems. The proposed framework enables UAV service providers to prepare and deploy their applications over multi-administrative 5G systems, while supplying them with statistical and analytical data on their running applications. Furthermore, in order to ensure network services over multiple 5G mobile networks, this article also introduced and discussed the different methods for federating resources on the underlying networks and that is while leveraging current specifications and minimizing impact on the standards. Exploiting the prior knowledge on the mobility patterns of UAVs and the network and cloud resources needed for their services, along with the usage of artificial intelligence, can bring potential optimizations to the framework, ultimately to the 5G-based UAV services. A thorough investigation of such optimizations is highly needed. This defines one of the authors' important future research directions.

[9]ETSI GS MEC 021, "Multi-access Edge Computing (MEC); Application Mobility Service API", ETSI GROUP SPECIFICATION 2020.

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References

[1] Markets and Markets. (2019) unmanned aerial vehicles market - global forecast to 2025. [Online]. Available: www.marketsandmarkets.com

[2] B. V. Der Bergh, A. Chiumento, and S. Pollin, "Lte in the sky: trading off propagation benefits with interference costs for aerial nodes," *IEEE Communications Magazine*, vol. 54, no. 5, pp. 44–50, May 2016.

[3] N. H. Motlagh, M. Bagaa, and T. Taleb, "Uav-based iot platform: A crowd surveillance use case," *IEEE Communications Magazine*, vol. 55, no. 2, pp. 128–134, February 2017.

[4] Z. Yuan, J. Jin, L. Sun, K. Chin, and G. Muntean, "Ultra-reliable iot communications with uavs: A swarm use case," *IEEE Communications Magazine*, vol. 56, no. 12, pp. 90–96, December 2018.

[5] A. Garcia-Rodriguez, G. Geraci, D. Lopez-Perez, L. G. Giordano, M. Ding, and E. Bjornson, "The essential guide to realizing 5g-connected uavs with massive mimo," *IEEE Communications Magazine*, vol. 57, no. 12, pp. 84–90, December 2019.

[6] Y. Zeng, J. Lyu, and R. Zhang, "Cellular-connected uav: Potential, challenges, and promising technologies," *IEEE Wireless Communications*, vol. 26, no. 1, pp. 120–127, February 2019.

[7] M. Mozaffari, W. Saad, M. Bennis, Y. Nam, and M. Debbah, "A tutorial on uavs for wireless networks: Applications, challenges, and open problems," *IEEE Communications Surveys Tutorials*, vol. 21, no. 3, pp. 2334–2360, thirdquarter 2019.

[8] O. Bekkouche, T. Taleb, M. Bagaa, and K. Samdanis, "Edge cloud resource-aware flight planning for unmanned aerial vehicles," in *2019 IEEE Wireless Communications and Networking Conference (WCNC), Marrakesh, Morocco*, 2019.

[9] 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.

[10] I. Afolabi, J. Prados, M. Bagaa, T. Taleb, and P. Ameigeiras, "Dynamic resource provisioning of a scalable e2e network slicing orchestration system," *IEEE Transactions on Mobile Computing*, 2019.

[11] GSM Association. (2019) generic network slice template version 2.0. [Online]. Available: https://www.gsma.com/newsroom/wp-content/uploads/NG.116-v2.0.pdf

[12] B. Mada, M. Bagaa, T. Taleb, and H. Flinck, "Latency-aware service placement and live migrations in 5g and beyond mobile systems," in *2020 IEEE International Conference on Communications (ICC), Dublin, Ireland*, 2020.

[13] R. A. Addad, T. Taleb, H. Flinck, M. Bagaa, and D. Dutra, "Network slice mobility in next generation mobile systems: Challenges and potential solutions," *IEEE Network*, vol. 34, no. 1, pp. 84–93, January 2020.