5G-UASP: 5G-based multi-provider UAV platform architecture

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Abstract

The paper consists of a description of 5G-UASP, a multi-provider platform for drone services. It takes into account the involvement of air traffic management authority in all flight phases. We describe the core components of 5G-UASP and outline the procedures related to flight preparation, execution and termination phases. Instantiation of the concept is presented for 5G network. As it is shown, the usage of network slicing and MEC enables an immersive implementation of the architecture. Two options of instantiation of the reference architecture are included.

Index Terms

UAV, drone, 5G, MEC, network slicing, UTM

I. Introduction

Services based on Unmanned Aerial Vehicles (UAV) can be used in different economic sectors – from agriculture and logistics to safety and military [1]. The UAV services are currently offered locally (range <1 km) due to lack of reliable long-distance communication between UAV and its flight controller. The existing commercial UAV platforms (PixHawk, ArduPilot, DJI [2]) are usually based on open source projects. They typically use MavLink [3] or Real Time Publish Subscribe (RTPS) [4] protocols. They are oriented towards a single UAV operator and provide no interface to air traffic coordination authorities, i.e. UTM (UAV Traffic Management).

This work presents a concept of a platform, which integrates Unmanned Aerial Systems (UAS) of multiple UAV service providers with UTM and exploits the key features of the 5G System (5GS), like network slicing and MEC. The structure of the paper is as follows. Section II outlines the requirements of UAV services and related work. In Section III the 5G-UASP architecture and in Section IV its procedures are described. Instantiating of the proposed architecture is described in Section V. Finally, Section VI concludes the paper.

II. Related work

Numerous aviation institutions and initiatives (e.g. ICAO, FAA, EASA, Eurocontrol, JARUS, CANSO) work on the development of UAV regulations and operations framework, including UTM [5]. UTM functionalities comprise UAV registration, flight plans (dFP) approval, flight life-cycle management, and aggregation of all aeronautical data. In the EU, the UTM issues are addressed by projects CORUS [6], GOF USPACE [7] and by the SESAR organization, which coordinates UTM-related research at the EU level.

The 3GPP has already started works on the support of UAS by 5G. They concern requirements of the communication between the UAV and its Controller (UAC), the service-related transmission (e.g. video, sensor data, photos, etc.) and the communication with UTM [8]. The communication requirements [10] assume that for UAV control and interaction between UAS and UTM, the Command and Control (C2) link is used to support various steering modes (steering to waypoints, automatic flight, autonomous navigation infrastructure and direct stick steering) and telemetry and navigation data are transmitted. The Device to Device (D2D) links can connect UAVs in a swarm (a group of UAVs). An optional First Person View (FPV) 360° UHD video transmission from UAV to its pilot can be also used.

The 3GPP has already defined a reference architecture composed of UAV, UAC, UTM, authorized 3rd party and 5GS, which acts not only as a relay, but it exposes interfaces for interactions with other actors [11] to support UAV services. According to [8], the communication system shall support UAV operation at altitudes of 120 to 300 m above ground level with the maximum UAV speed of 160 km/h. The reliability of the C2 link should be >99.99%, the latency <10 ms for direct stick steering, and <500 ms for data exchange with UTM. The QoS targets for specific use cases have also been defined [8].

So far, none of the proposed concepts enables multi-customer and multi-provider services creation in cooperation with UTM and uses 5G mechanisms for efficient deployment of UAV-based services. The 5G!Drones project is the first attempt to integrate 5G with the UAS/UTM ecosystem [9].

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III. 5G-UASP ARCHITECTURE OUTLINE

The proposed 5G-UASP architecture (cf. Fig. 1) enables large-scale UAV-based services, which can be offered by multiple service providers. It assumes mobile network communication for UAVs and UTM for drone flights planning, monitoring and modification. The U-space term describes the control plane of UAVs, i.e. C2 interactions with UAVs, UTM, etc. The 5G-UASP architecture consists of:

1) UAV Services Portal (USP): is a portal and service broker used by UAV Service Customers (USC) to express their service needs and negotiate the offer details (via the PS interface). USP interacts with U-space Coverage Correlation (UCC) using the CS interface for estimation of communication links quality and indirectly with UTM for information about airspace availability. USC uses the information for UOP selection and establishing direct communication with it. USP is responsible for the collection of service accounting data.

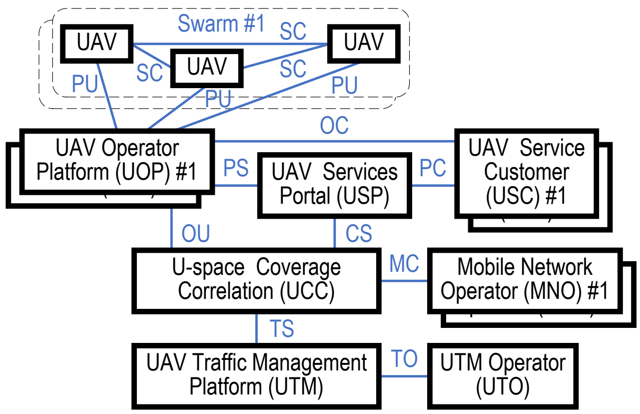

Fig. 1. Overall system architecture.

2) U-space Coverage Correlation (UCC): is used by USP and UOPs to interact with MNOs and UTM. During flight planning, UCC acquires from UTM the information about the feasibility of flight between specified locations and from MNOs the expected radio signal coverage in those areas. The information can be complemented by past flights data stored in the UCC database. UCC may also request from MNOs the dynamic radio coverage adaptation if such mechanisms (e.g. beamforming) are supported. UCC acts as UTM proxy, reporting UAVs' position to UTM during flights.

3) UAV Traffic Management (UTM): is an integrated platform for U-space traffic management. It includes functionalities required for dFPs approval, flight management (from take-off readiness report to the landing report), UAVs real-time tracking, etc.

4) UTM Operator (UTO): is an entity responsible for maintenance and management of the UTM platform.

5) UAV Operator Platform (UOP): consists of the functional blocks for (i) UAV Command and Control (C2) and gathering UAV type-specific information; (ii) management and control of the UAV fleet, (iii) communication with UCC and UTM (via UCC) for submission of a dFP; (iv) handling of own dFPs, and (v) management of UAV-based services and customers. UOP follows the flight change orders received from UTM. During service deployment, UOP may create a direct communication channel to its service customer (OC). UOP can use the channel to transmit data from UAV (e.g. video) to USC, send service-related (e.g. camera zoom) or flight change requests. The latter case requires approval by UTM and UCC for radio coverage verification. USC uses the OC interface for service termination.

6) Mobile Network Operator (MNO): is an operator of public mobile network. It is expected that MNO will provide some statistical data in 3D space regions related to the radio signal conditions or achievable QoS by UE data streams (i.a. throughput). Moreover, the signal strength should be improved on UCC's request, by mechanisms such as beamforming and beamsteering.

7) UAV Service Customer (USC): uses UAV services by interaction with USP during flight preparation (via the PC interface) and during the service, interacts directly with UOP to collect data from UAV or send orders related to new flight schedule or UAV's onboard devices configuration.

8) Unmanned Aerial Vehicle (UAV): is equipped with the PU interface for the communications with UOP (a long-range wireless interface) and may have an additional short-range radio interface (SC) that is used in a case of a service realized by a swarm. This interface can be used for correction of relative swarm members' position or replication of information concerning swarm (received via the PU interface) to increase the reliability of communications over the PU interface. UAV should support at least the PU interface, execution of C2 commands received from UOP and flight modes described in Section II. The PU interface can also be used to transmit service-related information to USC via UOP (using the OC interface) if real-time transmission is needed. In case of e.g. cargo-UAVs, such transmission does not need to be implemented.

IV. PROCEDURES

The operations concerning UAV services can be split into three phases: UAV flight preparation, execution and termination. In all the phases, C2 messages responsible for UAV control and associated functions are exchanged between different blocks of the architecture. During flight execution phase an exchange of service-related information between UOP and its USCs is also needed. The details have been described below.

1) Flight preparation phase: In this phase, USC sends its service requirements to one of the existing USPs. USP converts the request to the form of dFP inquiry and via UCC interacts with UTM to check the flight feasibility. If there are no U-space resources for the requested flight, USP receives and passes the information to USC, terminating the request. In case of positive UTM answer, UCC inquires all MNOs about coverage parameters (e.g. link QoS) in specified areas. The acquired information is sent to USP, which inquires each of the cooperating UOPs about their availability and conditions of service provisioning (including cost). The information obtained from USPs is then exposed to USC, which is now able to select UOP for its flight. After selection of UOP and ordering flight service, UOP contacts USC directly, informing about the start of service. It sends a dFP approval request to UTM via UCC. When dFP is approved, UCC interacts with the respective MNO, requesting preparation of 5G services for flight support. Then UOP sends service deliverability confirmation and negotiated schedule to USC.

2) Flight execution phase: During flights, there is a continuous communication between UOP and its associated UAV (or swarm) realizing the mission. It is related to C2 and service data transmission (e.g. video streaming). The service data are transferred in the real-time from UOP to USC. The role of UOP in the process is not only to be a proxy, but possibly to select or modify the data format (e.g. video transcoding). USC may also be able to change the configuration of selected components of UAV to alter service properties (camera zoom, focus, etc.). The UAV operator continuously interacts with USC to provide USC with the actual information about UAV (or swarm) position and the PU interface quality (QoS). UCC stores the information about PU interface quality in its database and informs the UTM about UAV position. UTM stores this information in its real-time database of active UAV flights in the administered area. In case of needed flight modification (collision avoidance, etc.), UTM sends a proper notification to UOP via UCC. Then UCC interacts with MNO to acquire proper radio coverage of the new path. The order received from UTM is confirmed back by UOP and USC gets change notification. dFP can also be changed by USC via the OC interface, but in such case UOP has to obtain a dFP approval from UTM.

3) Flight termination phase: When the flight is finished, UOP notifies UTM and UCC, which informs involved MNO(s) that the individual arrangements of 5GS for specific flight support can be released. All statistical information about the mission is sent by UOP to USP for the purpose of service charging. A similar procedure is used in case of abnormal flight termination.

V. INSTANTIATING OF THE ARCHITECTURE IN 5GS

The 5G-UASP concept implementation may benefit from the mechanisms offered by 5GS, like network slicing, Mobile Edge Computing (MEC), and the programmability of the 5G Core Network (5GC). 5G network slicing allows the creation of multiple, isolated networks that are customized for a specific data traffic category, like streaming (eMBB slice), reliable, low-delay control (URLLC slice) or massive IoT traffic (mMTC slice). The 5GC makes slice selection, authentication, and, to a certain extent, can be sliced as well. The instantiation of each network slice (based on a template) is made by the orchestrator [12], [13]. The coverage area of each RAN slice can be defined and updated. Single User Equipment (UE) can be simultaneously attached to up to 8 slices. The 5G-UASP uses URLLC slice for C2 information exchange and another slice for the transmission of UAV service-related data. The latter slice is type- and service-dependent. The SC interface does not need to be sliced. This short-range interface can be implemented using Proximity Services (ProSe) or other networks (i.a. WiFi, 802.11p). ProSe is now standardized for 4G [14] and its usage in 5G is still under study [15].

MEC enables (orchestrates) deployment of MEC applications that may use the following MEC (REST-based) APIs:

1) Radio Network Information Service (RNIS) API: provide radio signal measurements (i.e. RSRP, SINR), Layer 2 measurements (PLR), RAB information, etc.

2) Location API: provides the location of a UE, the distance between specified UEs, the distance between a specified location and UE, list of UEs in a particular area, etc.

3) Bandwidth Management API: allows prioritization of certain data streams and thus guarantee delivery of predefined services (bandwidth allocation).

4) UE Identity API: allows registering a tag for each UE and define traffic rules that ensure low-latency communication, with each rule linked with a specific tag.

The work on the integration of network slicing with MEC is ongoing [16], [18]. Despite the lack of the standard-based solution, it is possible to outline how MEC can be exploited for UAV services [17]: the MEC Orchestrator (MECO) can be implemented as 5GC Application Function (AF) and MEC Hosts can be deployed at the edge of 5G RAN or connected to UPF via 5GCN6 interface. The first option provides lower delays. For the purpose of the paper it is assumed that RNIS and Localization APIs are available. Both APIs play a crucial role in UAV control and both UCC and UTM operations. It is also assumed that User Plane QoS is provided by network slices and that 5GS has two orchestrators – one for network slices and another one for MEC applications. In the following subsection we will outline the architecture instantiation options that use

MEC and without MEC. In the second case the UAV-based localisation mechanisms and information about the signal strength will be used instead. It is also assumed that for the same UAV two UACs exist: Slave UAC that is directly connected to NR as 5G UE (used when the UAV operator has direct visibility of UAV) and Master UAC that is a part of the UOP platform. Using the Master UAC, UTM is able to take over the UAV control – it has a higher priority than Slave UAC.

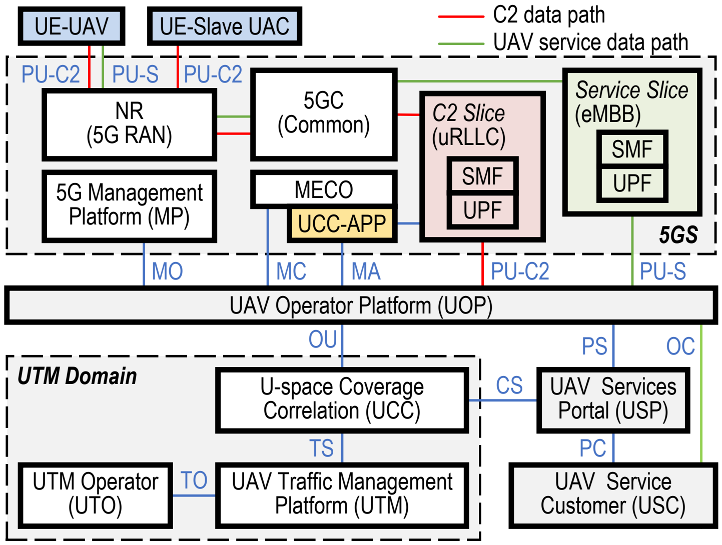

Fig. 2. Option 1 of 5G-UASP instantiation (UOP external to 5GS).

A. 5G-UASP Option 1: UOP/UCC external to 5GS

In this option (cf. Fig. 2), the UOP is external to 5GS and the overall architecture is similar to one presented in Fig. 1. 5GS is a standalone 5G network, which Management Platform (MP) provides slice orchestration. For single UOP, two different slices are needed: a C2 Slice for C2 communications (URLLC slice) and a Service Slice (typically eMBB slice) for UAV service data stream. The slices provide appropriate QoS of the data path. The MEC Orchestrator (MECO) is used during the flight preparation to deploy a UCC-APP on the UOP request. UCC-APP is a MEC application and its main function is to use RNIS and Location APIs of MEC and send the customized data about radio link quality and localization of UAV to UOP and UCC (indirectly to UTM). In "no-MEC" case, UCC-APP has to be created as a Network Function (NF) of the C2 Slice.

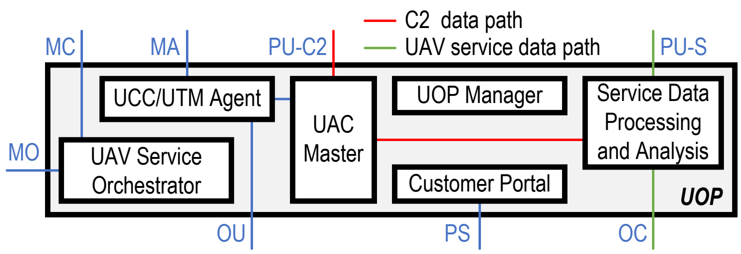

Fig. 3. Internal structure of UOP.

The UOP (cf. Fig. 3) is internally decomposed into:

1) Master UAC: responsible for the overall control of UAV (position, status, etc.) if Slave UAC is not in use; it can be used by UOP in case of connectivity issues with Slave UAC or when UTM retakes the UAV control.

2) UAV Service Orchestrator: used during UAV service preparation and termination phases, is responsible for sending orchestration request via the MO interface to MP in order to create C2 and Service slices, it uses the MC interface to ask MECO to deploy the UCC-APP.

3) Customer Portal: used by USC in order to select UOP, which will handle the USC request.

4) Service Data Processing and Analysis Component: used to process the data obtained from UAV (i.e. aggregation or compression). If no processing is performed, the service data stream is forwarded to USC.

5) UCC Agent: responsible for transferring UAV position/coverage information obtained from UCC-APP to UAC Master and UCC formatting data if necessary.

6) UOP Manager: responsible for the coordination of UOP operations and its management (performance analysis, fault detection). When a flight session is terminated it sends the flight track record to USP.

UCC, UTM, UTO, USP and USC functionalities are the same as in Section 1. It is assumed that UOP, UCC and USP components are permanent entities that for the sake of scalability are implemented in a cloud and interconnected via secure and QoS-based connections. In case of multiple UOPs, each UOP has its PU-C2, PU-S and OC interfaces, but other interfaces of the UOP are comon for all UOPs. UCC-APP instances can use the same template.

B. Option 2: UOP partly implemented in a slice

Option 2 enables dynamic instantiation of the UOP platform. Such operation is of a premium value, e.g. if the cargo-UAV requires no interaction with USC during its flight; therefore, the flight control can be automated. Moreover, some 5G-UASP components are now a part of a slice (e.g. UOP). The placement of some components of UOP presented in Fig. 3, as well as their functionalities have been modified and some new components have been added: (i) Customer Portal and UAV Service Orchestrator of UOP have been moved to USP (their new role and functions will be described later); (ii) Master UAC, UOP Manager and modified UCC-APP components have been moved to C2 Slice; (iii) Service Data Processing and Analytic component has become a part of the Service Slice; (iv) UOP/USP Portal has been integrated with USP, the UOP Phantoms and UOP/UAV Database components have been added (they will be described later on); (v) UAV Operator Console (UOC) has been added.

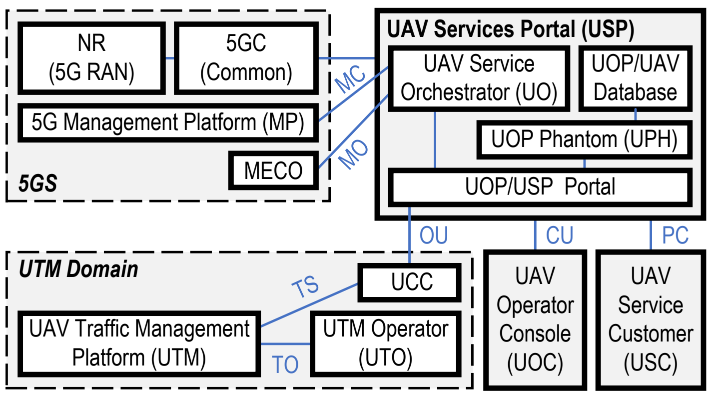

Fig. 4. Option 2 of 5G-UASP instantiation – components used in flight preparation phase only.

To simplify the description of this Option, the components, which are active during flight preparation and execution phases, are presented separately in Fig. 4 and Fig. 6, respectively.

During the flight preparation phase, there is no UOP platform, yet – UOP is created in the result of the phase execution. USP is the only entity that interacts with USC. It is composed of the following entities:

1) UOP/USP Portal: interacts with UOP Phantoms for negotiation with USC concerning the requested flight.

2) UOP Phantom: uses UOP profiles stored in UOP/UAV Database and information about UOPs available for this flight, their UAVs and UOP-specific algorithms for flight contract negotiations with USC. After selecting UOP it interacts with UAV Service Orchestrator to deploy required network slices and MEC services.

3) UAV/UOP Database: for each UOP that can be instantiated for the requested service the database is used for storing the status of its UAVs (in-flight/idle, location, features, battery status), operator profile and its negotiation policy. It is used by UOP Phantom to negotiate the contract.

4) UAV Service Orchestrator: on UOP/USP Portal request, interact with 5G Management Platform and MEC Orchestrator to deploy required network slices and UCC-APP in the C2 slice.

The UAV Operator Console (connected to USP) can be used for human-based flight negotiation, but its primary role is to update UOP/UAV Database and to realize the manual (operator-based) flight control (if needed). Fig. 5 presents a simplified message exchange chart of the flight preparation mode in case of successfull flight negotiation.

After deployment and configuration of slices, the service execution phase can be started. The architecture and components used during this phase are shown in Fig. 6. Nearly all UOP components (except UAV Operator Console) that are used in this phase are now implemented as components of slices (cf. Fig. 6). Therefore, the data exchange is now within a slice. The overall communication delay in C2 is reduced. Communication with UTM and USC is external, but according to the requirements mentioned in Section II, delays about 500 ms are admissible. Fig. 7 presents simplified data flows of this phase in the case of the involvement of UAV Operator Console and two UACs. The Slave UAC can be used for manual UAV control, and the Master UAC for the automated one that includes an object tracking by UAV. The Master UAC monitors and validates the manual control.

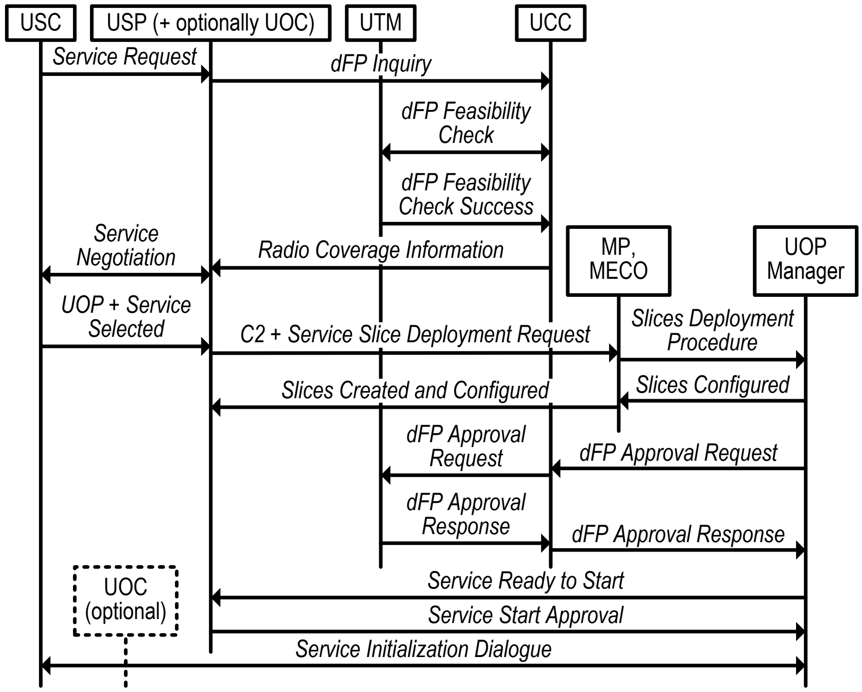

Fig. 5. Option 2 of 5G-UASP instantiation – a simplified message sequence chart of flight preparation phase.

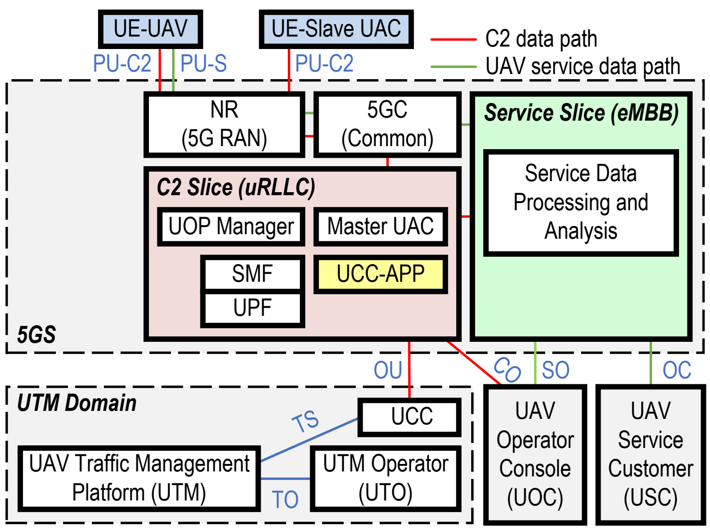

Fig. 6. Option 2 of 5G-UASP instantiation – components used in flight execution phase.

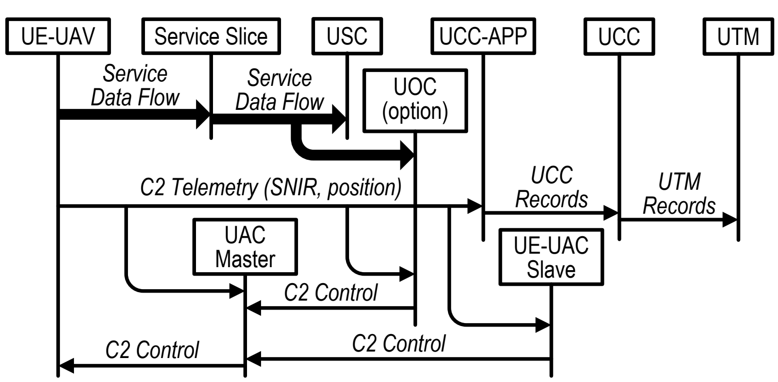

Fig. 7. Option 2 of 5G-UASP instantiation – a simplified message sequence chart of flight execution phase.

After finishing a flight (UOP reports it to USP), USP starts flight termination phase: (i) USP informs UTM (via UCC) about flight end; (ii) UOP Manager sends the flight track record to USP; (iii) UAV Service Orchestrator (part of USP) sends the slice termination request to MECO and to the 5G MP; (iv) UAV/UOP Database records concerning the position and status of UAV(s) used for the flight are updated. As the message sequence of the phase is relatively simple, the chart is not provided here.

VI. Conclusions

The paper presents a multi-provider platform for UAV services that uses the standalone variant of the 5G network. To our best knowledge, the described concept is the first complete one, which takes into account multiple service providers, virtually instantiated service providers for automated flights and involves UTM into flight planning and execution process. We have proposed to use MEC that is beneficial for UAV services; however, until the MEC-5GS integration is finished, the 5G-UASP can be implemented without MEC.

We plan to deploy a simplified, single operator-based version of Option 1 without MEC in the laboratory environment. We assume to use 4G+, slicing-ready OAI Platform, open-source UAC and the UTM emulator. Later on, the UOP components will be replicated to obtain multi-provider support and the USP component for UOP selection will be added. Finally, we will modify and reuse the previously developed components to obtain Option 2 compliant solution.

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