On 5G support of cross-border UAV operations

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Abstract

The paper is devoted to 5G System (5GS) architecture enhancements enabling cross-border Unmanned Aerial Vehicle (UAV) operations. The proposed architecture provides integration of 5GS with UAV Traffic Management (UTM) system, incorporates both Home Routed (HR) and Local Breakout (LBO) roaming scenarios and describes specific UAV service enablers. The requirements relevant to ensuring safe and secure cross-border UAV operations have been identified and the implementation of two typical roaming scenarios within the outlined architecture along with corresponding procedures and interactions between the entities have been presented. Further research, development and standardization directions have been also outlined.

Index Terms

UAV, UAS, drones, 5G, roaming, UTM, U-space, cross-border operations, service architecture

I. Introduction

Vast expansion of drone industry can be observed recently. According to Federal Aviation Administration's (FAA) estimations [1], by the end of 2023 drone market could triple in size in comparison to 2019. The increased acceleration of the market in the upcoming years will be impacted mostly by the commercial Unmanned Aerial Vehicles (UAVs) sector in contrast to the significant slow-down in a non-commercial one, which is to face saturation by the end of 2023. With the extensive market progress, the widening spectrum of UAV-related services can be seen. Along with the small, local-area services offered by small and medium enterprises, the rise starts to concern global UAV services such as long distance transportation or cargo delivery.

The drone market expansion, however does not coincide with necessary facilitation of the 5G network, which is expected to be the main enabler for UAV applications. Together with incoherent UAV transmission requirements, several procedural issues can be observed including lack of UAV-adapted procedures covering radio signal loss situations or fast registration procedure for changing the Mobile Network Operator (MNO) during cross-border flights.

The paper presents the concept of a roaming 5G UAS (Unmanned Aerial System) service architecture enabling service support in cross-border UAV operations. The system takes into consideration the aspects of flight security, flexibility of the mobile network in terms of possible roaming implementations and diverse transmission requirements. Moreover, the architecture enhances communication between individual UAS Traffic Management (UTM) systems in cooperation with the 5G network. Additionally, traffic monitoring and service charging enhancements were described to enable transparent charging, thus strengthening the trust between MNOs.

The structure of the paper is as follows. The specificity of aviation-domain context is outlined in Section II. Section III describes related research and standardization work. In Section IV basic cross-border UAV operation scenarios are presented. Section V reflects on the correlation between presented UAS scenarios requirements and related 3GPP standardization. The UAS services architecture in 5GS roaming scenarios is proposed in Section VI. Finally, Section VII summarizes and concludes the paper.

II. Aviation-domain context

The explosion of interest in UAVs is founded both on technological development and wide spectrum of their possible applications: agriculture and forestry, logistics, monitoring and inspection, media production, geodesy, telecommunication, sport, entertainment, public safety, healthcare and many more [2]. Short-distance UAV traffic still dominates, due to limitations of remote controlling means and capacity of power sources used to supply UAVs.

The observed and foreseen increase of traffic volume and the expected technological development has triggered the legislative activities in many countries, aimed at regulating drone traffic issues, especially from the safety point of view (the absolute top priority in the aviation domain [3]). The legislative efforts progress gradually, following the technological development from one hand, and directing it from the other. Commonly recognized are: the types of UAS operations, i.e. visual line of sight (VLOS) and beyond VLOS (BVLOS) – for all of them the First Person View (FPV) – transmission from the on-board camera to the UAV pilot – may be used. Also are: remotely piloted or autonomous flights (following a predefined path, approaching autonomous navigation infrastructure or AI-supported for e.g. active collision avoidance). These types of operations, in conjunction with UAS characteristics and pilot/operator certification are subject to specific regulations regarding procedures, limitations etc. Many organizations and initiatives (e.g. ICAO, FAA, EASA, Eurocontrol, JARUS, CANSO) work on development of UAV regulations. There is a common consensus that the UAS ecosystem should be built around the UTM system, which high-level architecture and functional definition has already been published [4].

In the European Union (EU) there are numerous initiatives under the SESAR JU program. The "U-space" – a framework of services and procedures for support of large numbers of drones in a common European airspace has been defined and its implementation is broken down into 4 phases (U1-U4) [5]. Projects dedicated to UTM research/definition [6], demonstration [7], [8] and testbed creation [9] were established. The required UAV capabilities for interactions with U-space during its implementation phases have been also specified [10]. The fundamental ones, required since the phase U1, comprise of e-identification of UAVs and their pilots/operators in UTM (following previous e-registration), geofencing (obedience to geographical, altitude and time restrictions), telemetry and tracking. Existence of more than one U-space services provider in one area is potentially possible. Hence, their UTM systems have to be interconnected to provide exchange of information about registered drones and pilots, as well as flight planning and tracking. Moreover, cross-border operations are foreseen and "*any drone operator or pilot from anywhere in Europe should be able to operate in any European country, as long as national laws and local rules are followed*" [11]. The trial cross-border flight (Estonia-Finland over the Baltic Sea) has been demonstrated [8].

The first common EU regulation on the rules and procedures for the operation of unmanned aircraft will enter into force on the 1st of July 2020 [12]. It stipulates implementation of U1 phase elements: UAS registration as well as geo-awareness and remote identification of UAS. It also assumes information exchange between local UAS traffic management authorities in countries and puts the first legal EU foundations for cross-border operations or operations outside the state of registration, according to the paradigm of "Single European Sky".

III. Related work

The 5G network is a commonly considered candidate for an UAS communication platform [13], facilitating both Command and Control (C2) including also the pilot/operator-supporting transmission (FPV camera, sensors etc.) and "business" transmission (exchange of data related to specific use case, e.g. live 4K video from an on-board camera etc.). In addition to some individual reserch efforts on the topic, there are currently two EU 5G PPP projects: NRG-5 [14] exploring i.a. aerial inspection of infrastructures with video transmission (eMBB) and 5G!Drones [15] dedicated to trials of various UAV use cases in vertical ecosystem comprised of 5G network and aviation domain (including UTM) and to validation of 5G-UAS services' KPIs. Comprehensive reviews of issues of UAV communications in 5G and beyond can be found in [16], [17].

The 3GPP has already started the standardization efforts related to support of UAS communication services by the 3GPP 5G system (5GS). The definition of the 5GS architecture [18] provides various concepts and functions important for UAS. First of all, it is inclusion of network slicing (NS) to provide separate and optimized virtual networks for different classes of services utilized by specific use cases and/or tenants. The support of NS includes network slice instance (NSI) selection and admission control on per-IMSI level. The initial classification of 3GPP slice service types was based on three classes: eMBB, URLLC and mMTC, as defined by ITU-R [19], but it has been recently extended with separate class V2X in the Release 16. Future adding of separate UAV slice service type is also possible. The User Plane (UP) is no more only a user traffic tunnel anchored at the Packet Data Network (PDN) gateway, with user mobility. The UP Function (UPF) is now a service- and/or network slice-specific chain of functions processing the user traffic (e.g. firewall, Deep Packet Inspection – DPI, classification, redirection and alteration), i.e. the 4G SGi LAN functionalities are now incorporated to the 5GS UP. The service-oriented architecture of 5GS Control Plane (CP) includes i.a. Network Slice Selection Function (NSSF), Session Management Function (SMF) – a UPF control agent and Application Function (AF) – the way to embed external or service-augmenting functions within the 5GS CP, Network Data Analytics Function (NWDAF) – mobile network monitoring center, Network Exposure Function (NEF) – an access gateway to CP functions for external environment.

Apart from general 5GS architecture framework, the 3GPP works on issues specific to UAS support by 5G 3GPP system. The 3GPP studies on remote identification of UAS (5G only) [20] and enhancement for UAVs (LTE and 5G) [21] are already complete. Currently, the standardization document on UAS support in 3GPP [22] is maturing, and two new studies on supporting UAS connectivity, identification and tracking [23] and on application layer support for UAS [24] are sill at infancy stage. The 3GPP conceptual model of UTM and UAS, i.e. UAV and its flight controller (UAC) is presented in Fig. 1.

It is worth a mention that at the moment of writing of this paper, the issue of supporting cross-border UAS operations specificity within the international UAS-UTM-5G ecosystem was absent both in research and 3GPP standardization.

IV. Scenarios

Following the mentioned EU regulation [12], two basic but representative scenarios will be described and analyzed: (A) UAS operation outside the state of registration and (B) cross-border UAS operation. Only a successful course of scenarios without exception handling will be assumed. It should be noted that during the flight, the aviation domain is interested in transmission parameters in accordance with the QoS, which was promised at the planning stage in the given 4D (3D and time) Operational Volume. Therefore, it is of premium importance for MNO to provide information on the extreme possible network parameters (latency, bandwidth, number of supported devices) resulting from the nature of the telecommunications network,

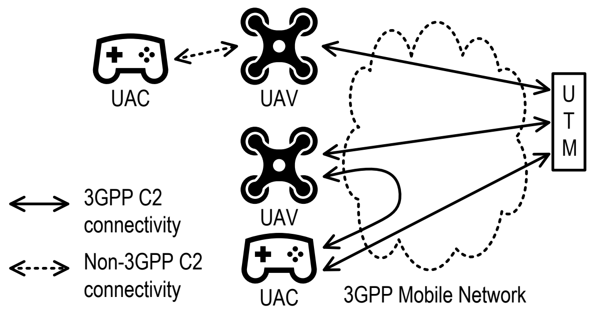

Fig. 1: 3GPP view of UAS-UTM ecosystem

so that the competent authorities can issue flight conditions. All extreme but probable scenarios are taken into account in flight risk assessment and are included in contingency planning (cf. [25]). In particular, refusal of registration at UTM or lack of connection to UTM will prevent the flight starting.

A. *UAS operation outside the state of registration*

The UAV Operator licensed in country C1 comes to country C2 with the UAS registered in country C1 to execute the planned and approved flight in country C2. The flight will be manually controlled, BVLOS with FPV aid. Therefore, a 5G network will be the communication platform, especially as the operator has no license for non-3GPP radio channel. After switching on and initial self-testing, both UAV and UAC obtain 5G connection for mutual C2 exchange and for attachment to the involved UTM entities. The channel for FPV video is also active and working. Then the flight can proceed.

The high-level UAV/UAC-UTM exchange flow is presented in Fig. 2 (HUTM – Home UTM, VUTM – Visited UTM). The flow can be simplified, if the UAV/UAC is aware of a proper UTM to be used in a visited country and the way to access it.

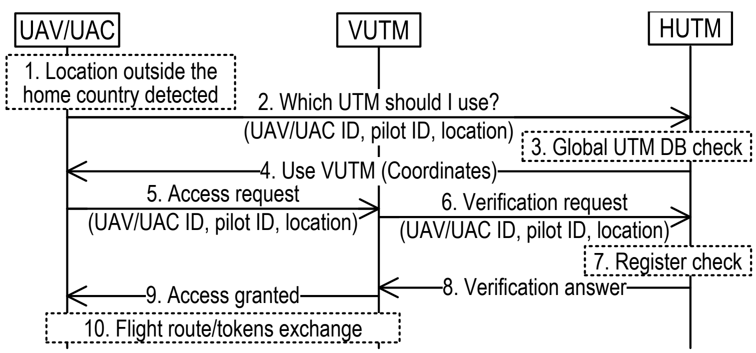

Fig. 2: High-level view of UAV/UAC-UTM exchange initiation during the UAS operation outside the state of registration

B. *Cross-border UAS operation*

The UAV registered in country C1 flies from country C1 to country C3 through country C2. This is a planned and pre-approved automatic flight on UTM. The UAV is approaching the C2/C3 border, and before entering the area of country C3, it starts the procedure of attaching to the C3 UTM to get necessary route data and geofencing tokens. The UAV, still maintaining the connection with the C2 UTM, requests access to the C3 UTM available at the C3 PLMN. After successful exchange, the flight is continued over the territory of country C3 and the exchange with the C2 UTM is closed.

The high-level UAV-UTMs exchange flow during the change of serving UTM is presented in Fig. 3. In a special case VUTM1 or VUTM2 can be equal to HUTM, i.e. when leaving or entering the area managed by HUTM.

V. Discussion on UAS roaming scenarios and 3GPP standardization

A. *Roaming support*

According to [18], the 5GS supports two scenarios for roaming: Home Routed (HR) and Local Breakout (LBO). In case of HR, the UPF consists of VPLMN part connected to Radio Access Network (RAN) and then is continued and anchored at HPLMN, where the traffic enters the Data Network (DN). In case of LBO, the entire UPF is implemented at VPLMN, and only Policy and Charging Functions (PCFs) of both MNOs interact. The high-level principle of both scenarios is exactly the

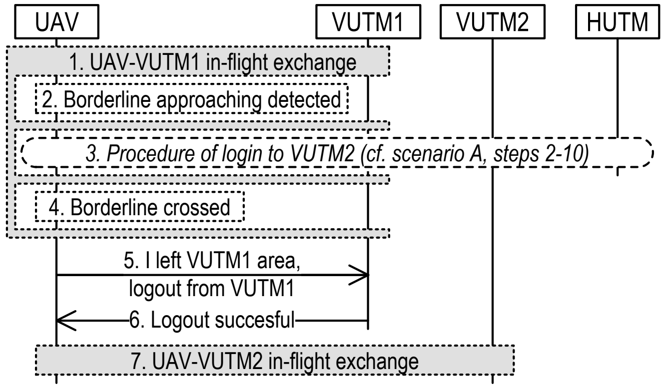

Fig. 3: High-level view of UAV-UTM exchange during the cross-border UAS operation – change of serving UTM

same as in case of LTE. The weakness of LBO in LTE is the lack of the alternative way for HPLMN to verify the received PCF information. This is the reason for practical nonexistence of LBO scenarios in LTE implementations.

However, the LBO scenario is very important for support of those UAS services in roaming, which are latency-sensitive or related to access to a local UTM. LBO option – to be implementable from the MNO's point of view – has to have the ways of support of the mutual trust between them developed.

B. UAS services' requirements relevant to roaming

Among the requirements for UAS support in 3GPP [22], especially those for QoS targets for "business" transmission channels utilized by UAVs, there are several ones of high relevance to UAS operations outside the HPLMN:

- Latency – for flight control, the most challenging use case is manual control with FPV: 20 ms for UAC-UAV C2 and 100 ms for UAV-UAC FPV live video; for all UTM-UAS exchanges the latency limit is 500 ms; for positioning [27] the maximum is 150 ms.
- Service status monitoring – the 3GPP 5G has to provide to UTM real-time monitoring of UAS links status and performance for all served UASes, regardless they are home users or visitors.
- Early warning about possible communication loss – UAS operator or UTM should be warned before the UAS leaves the 5G UAS services' authorization space (altitude, coverage area etc.).
- UAS service and its NSI admission – access to UAS services should be secured only for validated users and this validation should be facilitated by the 3GPP 5GS, both for home and visiting users.
- MNO as a trusted 3rd party (TTP) – the PLMN should testify the identity and location reported by UAV/UAC to UTM, as well as the integrity of the transmission.

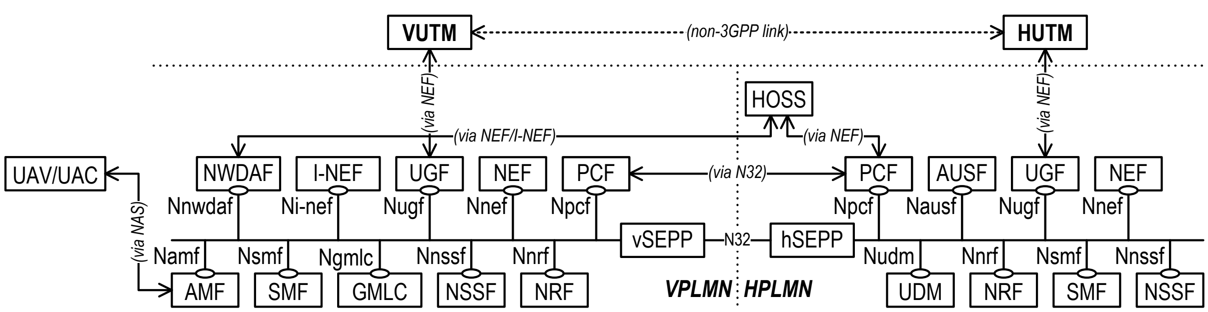

Fig. 4: Overall 5G UAS service roaming architecture – CP view

VI. Roaming 5G UAS services architecture

The 5G UAS service architecture in roaming is shown in Figs. 4 and 5 (CP and UP view respectively). Its design is driven by two fundamental principles: shortening the UAS links' paths (for the sake of latency and reliability) and simplification of the overall implementation of the international UTM-5G environment. For these reasons the LBO roaming architecture is used and UTMs have interfaces with local PLMNs in their countries only (manageable amount of interfaces). Additional assumption is giving to UTM a role of UTM DN manager, which makes decisions about admission of a mobile station to access the UTM DN.

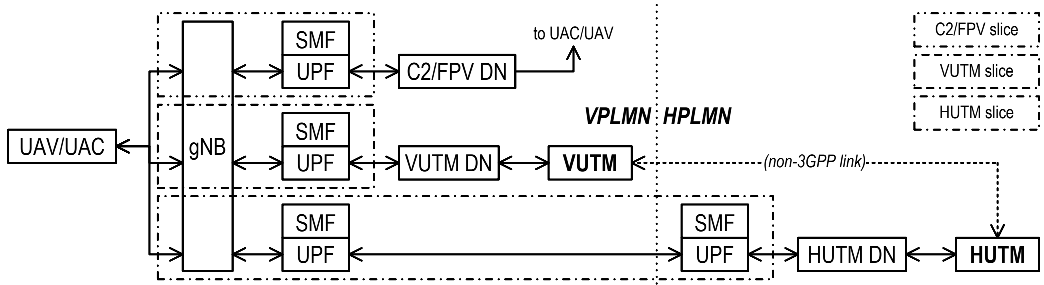

Fig. 5: Overall 5G UAS service roaming architecture – UP view

A. Description of architectural entities

The architecture presented in Fig. 4 combines both roaming models (HR and LBO) and contains CP Network Functions (NFs) employed in both roaming architectures (cf. [18]). There are however additional or special NFs, which enable support of specific UAS-related requirements mentioned above:

1) Network Data Analytics Function (NWDAF): This NF is used here for a real-time monitoring of UAS links, threshold-based detection of possible communication loss and identification of problematic behavior of connected UAS components. It can also provide per IMSI statistics, including UP traffic.

2) Gateway Mobile Location Centre (GMLC): This NF represents here the 5G Location Services (LCS) reference architecture [26] and serves as a gateway point to these services. It should be noted that normally in a roaming case the GMLC at the VPLMN is a "slave" of a GMLC at the HPLMN, because it is used by the HPLMN for locating the roaming mobile station. Here, the visitor is localized within the VPLMN for VUTM, i.e. the non-roaming LCS reference architecture view applies.

3) UTM Gateway Function (UGF): This new NF is a special case of a generic AF defined within the 5GS architecture. Here, it is a mediator (exposed via NEF) of all UTM interactions with the 5GS – it subscribes to the NWDAF services, sends Immediate Location Requests to the GMLC, interacts with management of security measures for UAS-UTM traffic and participates in UTM DN admission procedures with cooperation of CP NFs.

4) Home Operations Support System (HOSS): This system of management-layer is interconnected with the 5GS via the NEF. It facilitates FCAPS management of the home PLMN, but may be also interfaced with CP services of another PLMN, which are exposed via (I-)NEF. Here, it is used for end-to-end monitoring of own customers in roaming and for increasing mutual trust between MNOs: home and visited one.

5) Visited and Home UTM: The proposed architecture assumes a direct exchange between UTMs, which is also a part of the end-to-end procedures' flows. Existence of interfaces facillitating this exchange (non 3GPP-based) is assumed.

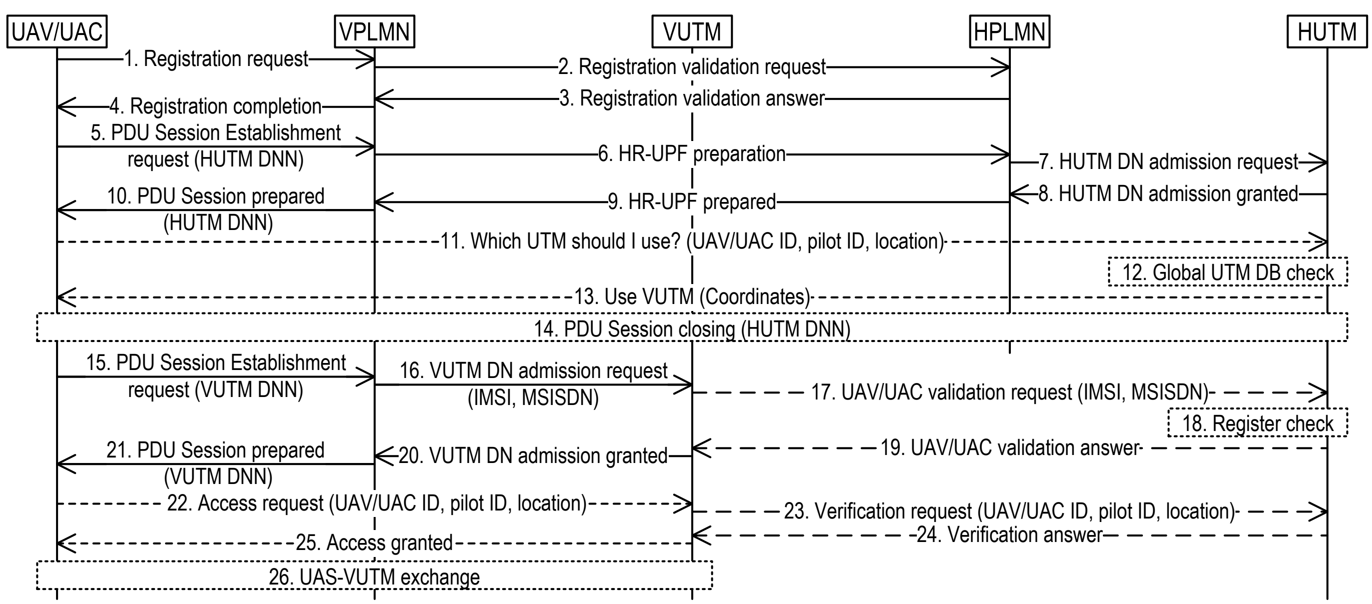

Fig. 6: High-level interactions between UAV/UAC, VPLMN, VUTM, HPLMN and HUTM (solid arrows – CP flow, densely dashed arrows – UP flow, sparsely dashed arrows – non-3GPP link flow

B. UP issues

1) Network slicing: The UP view presented in Fig. 5 assumes that specific UAS communication links will be delivered through separate NSIs. UAV/UAC has to be network slicing-aware and information for UAV/UAC about UTM to connect should contain both Single Network Slice Selection Assistance Information (S-NSSAI) and Data Network Name (DNN) – according to [18].

The UP should be adapted to the requirements of each communication link: the LBO scenario will be used, whenever the UAV data-consuming party is located near to the UAV (especially when MEC [28] is used) and/or the latency target is low. In case of UAV-UAC communication, the VPN-like link should be delivered. In case of UAS-UTM exchange, links to dedicated UTM DNs will be delivered in LBO option for VUTM and HR option for HUTM. The NSIs at different PLMNs have to provide mutual UPF compatibility for supporting UAS services in roaming.

2) UAS-UTM communication integrity assurance: Apart from anti-spoof measures available at the CP level, the PLMN can assure the UP data flow integrity by connection of the UTM interface to a separate DN with enhanced admission procedures, but also through implementation of DPI in the UPF chain, which allows e.g. "stamping" of traffic by the PLMN as a TTP with additional UAS identity information to certify the exchange.

3) "Business" channels: Their delivery model (either LBO or HR) depends on specific use case, business solution architecture and QoS class according to [22]. The detailed design of these channels is not the subject of this work, but it will be concerned by similar considerations as mentioned above in the context of flight control and management channels.

C. Control flows

The proposal of interactions between UAV/UAC, VPLMN, VUTM, HPLMN and HUTM is presented in Fig. 6. The description is conceptual and high-level, but it refers to 5GS procedures, as defined in [29]. The fundamental principle is that each UTM is the owner of admission process to its DN. The flow can be divided into the following stages:

1) 5G network registration: During the steps 1-4, the typical procedure is performed with involvement of UAV/UAC, VPLMN and HPLMN.

2) PDU Session Establishment – with HUTM DN: HR UPF to HUTM DN with involvement of HUTM as a decision maker is delivered during the steps 5-10.

3) Query about VUTM to connect: UAV/UAC obtains details of the relevant UTM in the country of operation during the steps 11-13.

4) Closing the PDU Session with HUTM DN: During the step 14, the procedure is executed. Here, it is not determined, which actor initiates the procedure.

5) PDU Session Establishment – with VUTM DN: Based on the information obtained in the step 13, LBO UPF to VUTM DN is delivered during the steps 15-21 with involvement of VUTM as a decision maker.

6) Accessing the VUTM: During the steps 22-25, the access to VUTM is granted to UAV/UAC with involvement of HUTM as a consulted party.

7) UAS-VUTM exchange: The step 26 contains the entire further in-flight management exchange (which may also include the logout procedure).

Note: the presented flow can be easily transposed to accommodate the Scenario B. The 5G de-registration from the previous network can be then considered as an additional step to happen when UAV leaves a country.

D. Cross-border UTM connection continuity

The fundamental requirement for cross-border operation scenario is the mentioned UAS-UTM communication latency limit of 500 ms. This requirement refers to assuring the safety separation distance between UAVs defined as 50 m at the maximum velocity (150 km/h). It has to be noted that the time needed for maneuvers (e.g. for collision avoidance) is higher than this calculated as quotient of separation distance and velocity of mutual approaching. The inertia of flying UAVs is related to their momentum, which must be taken into account by UTM to be able to react.

As the de-registration and re-registration procedures last much longer than 0.5 s it is necessary to use a dual-SIM terminal (User Equipment – UE) to provide UTM link continuity instead of landing of UAV at the border (cf. Fig. 7). The coverage areas of different country PLMNs usually overlap at the border, so the procedure shown in Fig. 6 has to be initiated in advance. The width of coverage area abroad and maximum time to complete the procedure will imply the planned velocity of approaching to the border (e.g. 15 s of flight at 150 km/s implies a minimum width of 625 m). Moreover, the maximum time of registration in roaming has to be standardized.

E. Mechanisms for building inter-MNO trust

As it was mentioned above, the implementation of LBO roaming architecture needs additional objective means for raising the mutual trust between HPLMN and VPLMN, because of consequences of charging data errors or even frauds. Below are proposed two solutions to the problem:

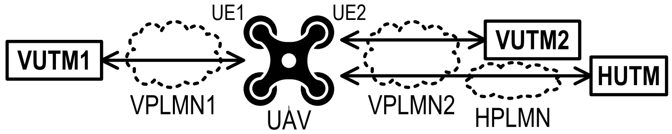

Fig. 7: UAV connections during the Scenario B

1) NWDAF-based: The HOSS may subscribe to VPLMN NWDAF service to acquire real-time readouts of own users' traffic counters. Acquisition of own users' monitoring data can be also useful for end-to-end monitoring of QoS.

2) "HPLMN-enclave LBO": Hereby, the inclusion of HPLMN traffic probing component within the LBO UPF in the VPLMN domain as an "enclave" is proposed. Such component would have its own HPLMN-controlled SMF. Such probing component might also serve for remote troubleshooting of own customers' problems in roaming.

VII. Summary and Conclusions

This work presents the 5G services architecture for cross-border UAS operations and UAS operations outside the state of registration, as permitted by the EU regulation. Based on two scenarios, current 3GPP standardization has been analyzed and the architecture has been proposed to support UAS operations in roaming. The described architecture is based on general 5GS framework, but a deep integration with international UTM ecosystem has been assumed and a specific use of CP functions in the context of UAS services has been pointed out. Involvement of MNO as TTP in UAS-UTM exchange has been included. The new component, UGF has been proposed as a mediator between the 5GS CP and UTM. As the fundamental roaming architecture needed for UAS support is LBO, the issue of building a trust between MNOs related to mutual charging has been also addressed – a solution based on exposing the VPLMN NWDAF to HPLMN OSS and the "HPLMN-enclave LBO" mechanism have been described.

The analysis also showed that the topic of 5G support for cross-border flights needs further research, development, trial and standardization efforts, i.a.:

- implementation, trial and validation of UGF together with subscribed 5G CP mechanisms, as well as inter-MNO trust development mechanisms for LBO roaming scenario;
- common work of 3GPP and UTM-development organizations, dedicated to defining and standardization of UTM-5GS interface and UTM agent (UGF) embedded within the CP;
- defining a reference UPF design for 5G UAS services for compatibility of services at different PLMNs;
- standardizing maximum delay in procedures of switching between PLMNs;
- enhancements to 5G network registration procedure to lower the inter-PLMN handover time.

Popular 5GS implementations, e.g. OpenAirInterface [30], Open5GCore [31] or free5GC [32] – used by majority of R&D projects, implement solely the fundamental functionalities of the 3GPP 5G architecture. NEF, NWDAF or LCS are missing in these solutions. Handover support can be problematic to some extent. For non UE-based positioning, the Network-Assisted Positioning Procedure needs to be supported by gNB (positioning based on RAN measurements, cf. [26]). Implementation of missing enablers needs individual efforts or a common initiative on public-domain tools.

Acknowledgment

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