Utilizing Private Mobile Network for UAV Communication in Logistics

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Abstract—**Unmanned Aerial Vehicle (UAV) technology is evolving each year at a rapid pace and new innovative ways of utilizing UAV's are constantly emerging. Manufacturers are launching new solutions to the market almost each year. These technological solutions are making the use of UAVs safer and more versatile thus making them a potential technology to many business use cases and applications. There are still some challenges, such as the limitations to the UAV's connectivity that are limiting the use of UAV's in extreme operations. UAVs demand two different communication links for their operation, (1) a command and control link to control the drone and (2) a data link for the payloads higher throughput rate. A reliable data link is an essential part of UAV-based applications. It allows data transfer from payload devices such as sensors, cameras, to edge and cloud enabling real-time data gather for analysis and decision making. Although, UAVs are still mainly controlled by ISM band short-range radio controllers, for years there has been a discussion ongoing that the mobile network technology could bring a new way to control the UAV's in long-range operations. This paper studies the use of a mobile network for UAV communications in business applications. The focus of this paper is on logistics use cases in which the UAVs can enable more useful, faster and more efficient ways of delivering small packages. The paper also introduces UAV platforms that are designed and build on specific logistic use cases challenges related to their communications.**

I. Introduction

During the 2010s, the use of UAV's has rapidly gained popularity as a hobby equipment among enthusiasts as well as an efficient tool among researchers and companies. The amount of requirements for the use of UAV's has also increased in recent years to meet the needs of authorities and companies on a case-by-case basis for an expanding variety of applications. For example, UAV's are used for site surveys, radio interference measurements [1] and signal monitoring for in-situ antenna measurements [2]-[4] and network conditions by the mobile operators [5].

Logistics is one of the commercial domains for UAV usage. UAVs' role in logistics is special role and they can provide several advantages in many use cases such as home delivery [6], delivery of health care [7] and logistics in humanitarian operations [8]. Utilizing UAVs has several strengths, such as environmental impact to provide faster transportation in urgent deliveries and possibility to reach the areas that are difficult to access. Typically, there is an actual need to perform the flight operations in beyond visual line of sight (BVLOS) in UAV logistic operations. BVLOS flight operations need secure, capable, and reliable communication that is available on-demand for the flight operations. Reliable data connectivity for command and control (C2) link is one of the critical needs in BVLOS operations. The C2 link is a dedicated connection between the pilot's ground control station and the unmanned aircraft to ensure safe and effective UAV flight operations. In addition to the C2 link, there is a need for a reliable communication link for payload's data applications. The payload communication type depends on application, and it often requires a higher throughput rate than the C2 link. Data and connectivity disruptions can be critical for the C2 link but are inconvenience for the payload's data link. The C2 link can transmit diverse types of information, such as aircraft control messages, aircraft telemetry data, support for navigation aids, air traffic control (ATC) voice relays, air traffic services data relay, target track data, etc. for which the data rates are expected to be under 300 kbps [9]. 3GPP has made a technical specification document TS 22.125 for the UAS requirements. It is notable that, depending on the control mode and the vehicle's land speed, the end-to-end latency for the C2 link varies from 40ms to 1 s. The reliability requirements for C2 link vary also from 99% to 99.99% in same criteria as the end-to-end latency [10].

This paper focuses on studying how the mobile network can enhance the UAV's communication and data links in different application areas, for example in business applications. The study proposes using a mobile network solution developed for public safety authorities to UAV logistic use cases in long-range operations. The use of UAVs by public safety authorities is notably different from regular companies. Authorities utilize UAVs mainly to act as their eyes from the skies: companies can perform for example different technical inspections on properties and structures with UAVs, but also use in different logistics purposes. Thus, the main requirements for the C2 link are the same with logistics and with authorities, especially in long-range operations. The communication solution, which is introduced in this paper, enables using UAVs for the automation of intralogistics, package delivery or supply of medical goods in dense urban areas or hard-to-reach locations.

The rest of this paper is organized as follows. Section II describes the novel communication solutions and section III describes the utilizing communication solutions for logistics. The conclusion is given in section IV.

II. Novel Communication Solutions

In the PRIORITY research project, Centria University of Applied Sciences (later Centria) developed technologies for public safety authorities. It was discovered that those technologies are suitable for UAV-based communication. Subsection A describes a tactical bubble solution, which allows reliable UAV communications with private ad hoc-type network built with the 3rd Generation Partnership Project (3GPP)-based mobile technologies. Subsection B defines a solution developed for UAV communications using mobile broadband.

A. Tactical bubble offers reliable communications links

In Finland, the public safety authorities are using a government official radio network called VIRVE, that is based on the Terrestrial Trunked Radio (TETRA) standard. VIRVE network is a narrowband network that supports only critical speech and text messages. Nowadays, the public safety authorities also require broadband communications services (i.e. mission critical (MC) voice, data and video services) in their high-risk operations. Mobile network technologies are broadly coming into use to offer communications services for the public safety domain. The reliable communications services need to be offered in different environment, e.g. city centers and rural areas. The challenges in these environments are typically related to the available capacity, since the mobile network can be congested with heavy usage.

One solution for this problem is to deploy a private mobile on-site network to guarantee the MC communications for the public safety authorities' operations. This kind of private mobile network was implemented in PRIORITY project's proof-of-concept (PoC) field trial, which involved rapidly deployable Long-Term Evolution Time-Division Duplex 2.3 GHz mobile network with fully functioning 4G Evolved Package Core (EPC) [11]. Fig. 1 shows the tactical bubble solution that has a backhaul connection to external MC services through the commercial mobile network. This tactical bubble network requires its own SIM-cards that are dedicated only for the public safety authority's usage.

One use case for the public safety authorities is to gather data from accident operation scenery by utilizing an UAV, and enhance the situational awareness. The use of UAVs for enhancing the situational awareness has become a new way to oversee the situation at hand. The possibility to use UAV in these operations has increased and a new kind of applications and services are being developed to support the authorities' needs even further. However, most of the UAV manufacturers do not have the necessary equipment's available for the authority's operational needs.

B. Mobile network as part of UAV operations

Only a few UAV manufacturers enable the use of mobile broadband technology in their drones. However, some UAV enthusiasts have developed their own solutions from various hardware and software components to supplement their needs. Centria has also developed its own technical solution for the UAV, which can then utilize the mobile network as a C2 and payload link.

Centria's UAVs C2 link has been implemented in two methods. First method, using a single board computer, which acts as a mobile network gateway, while enabling the C2 link between the UAV's ground controller station and the UAV point-to-point, Fig. 2. The single board computer can also be harnessed for the payloads use, if it is necessary to use additional computing power for the payload. Second method is using a traditional radio controller (TX) in 2.4 GHz ISM frequency and receiver (RX) as a backup connection if there are connection problems with the first method.

While using the first method, it is possible to connect directly from the UAV's ground controller station to the UAV's single board computer IP-address to form the point-to-point connection between the devices. This way the UAV's MAVLink protocol-based control messages are encapsulated inside the IP data while using standard 4G encryption. In addition to 4G encryption it is also possible to enhance the cyber security properties by adding IP-tables and firewall options.

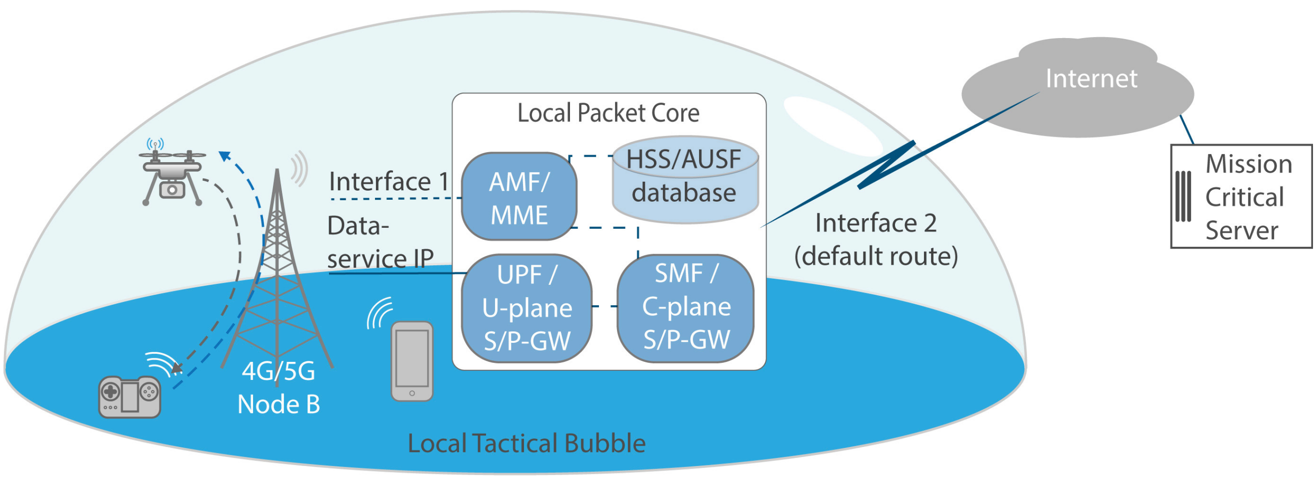

Fig. 1. UAVs C2 link implemented in tactical bubble.

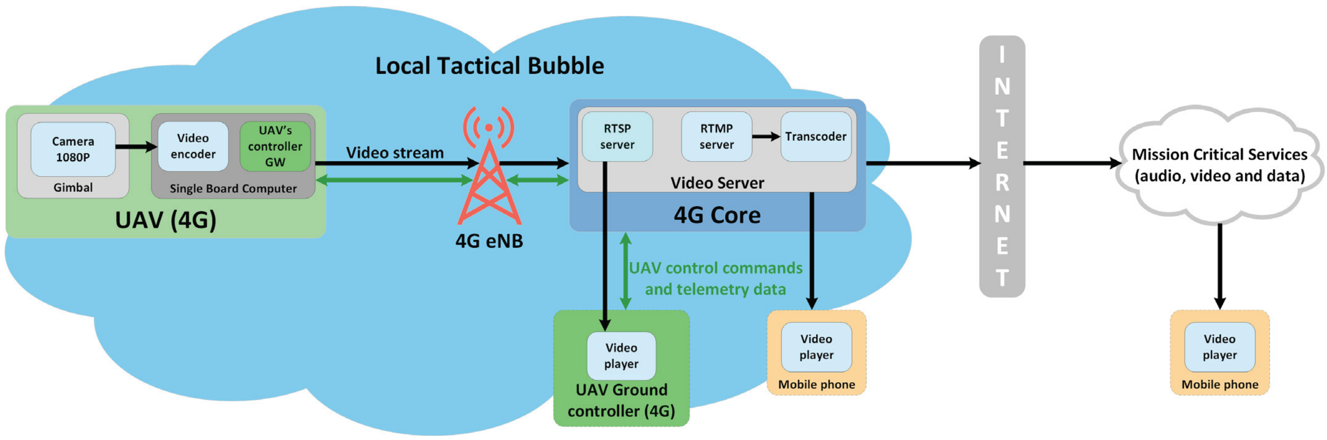

Fig. 2. UAV and video server components in tactical bubble.

The custom-made UAV used in the PRIORITY project had the capability to stream a video from Flir Duo Pro R camera to multiple users. The UAV's video source encoder, encoded the live video from the camera and streams it to the RTMP and RTSP video servers, which were located in the local Evolved Package Core (EPC). The video servers would then transmit the video to the Mission Critical Service applications, from where the video could be sent to the selected authority's mobile devices. In addition to this, the video stream could be sent from the 4G EPC's RTSP server directly to the UAV's ground controller station. This way it is possible to prioritize the data transmissions so that the pilot sees the video stream in low latency before the other users.

The single board computer, which acts as a mobile network gateway can be used in any of Centria's custom-made UAVs. This device is capable of making a connection to any given mobile network, in addition to the rapidly deployable tactical bubble that is using (4G) LTE frequencies [11]. Meaning that the commercial mobile network can be harnessed for the C2 link usage, when necessary. This allows the pilot to be located in any geographical location while controlling the UAV via the mobile network. The only major problems will be the interruptions and delays in the mobile network, which should be mitigated in order to avoid accidents. Mobile network coverage can also cause problems since the base stations are usually planned for the ground level users. While the UAV is utilizing the mobile network as the C2 link, it will carry a signaling mobile device (i.e. USB modem etc.) with a SIM-card that has the possibility to cause interference to the mobile network, since the networks are not optimized for flying user equipment's. In Finland, there is need to get a radio license for this type of use. Generally, it is not allowed to use mobile network terminals on board of the UAV if they are not used for public administrative functions, search operations, rescue operations, emergency medical or first response services, monitoring, or supervision functions vital for the security of supply [12].

III. Utilising Communication Solutions for Logistics

Centria has utilized custom-made quad- and hexacopters, customized from commercial hardware components, which can perform autonomous missions for research purposes for several years. These UAVs are capable of handling a multitude of different payloads for operational purposes, but they are not specifically designed for logistical purposes – however they can be used for that purpose, if required. Centria also has the capability to design and manufacture UAVs for various logistic purposes and for different flight operations.

In the Arctic Airborne 3D (AA3D) project Centria has developed and designed three different prototypes for varying logistics use cases. These logistic specific uses cases have included various food deliveries that actors in tourism sector could provide as part of their services in the future. These use cases have emerged from the needs of business. Prototypes have different shape, size, take-off mass, max flight time and speed, flight distance and payload requirements, depending of the use case requirements. Detailed prototype features and calculated values and can be found in the Table I.

Fig. 3 shows the UAV prototypes of AA3D project. Type 1 is Vertical Take-Off and Landing (VTOL) UAV, which can hover, take off and land vertically, but otherwise fly like aircraft. VTOL (type 1) is shown on the left. It is tailored for coffee package delivery. Type 2 is Lift Body UAV, where the UAV design has streamlined body in which contains a cargo box inside. It is designed for the pizza delivery use case (in the middle). Fixed-wing (type 3) UAV flies by utilizing the lift produced by the UAV's forward motion and the shape of the wings. Bottle delivery UAV, type 3, is shown on the right.

TABLE I. UAV PROTOTYPES AND FEATURES FOR LOGISTICS

	Type 1 - VTOL	**Type 2 - Lift Body**	**Type 3 - Fixed Wing**
Use case	Coffee package delivery	Pizza delivery	Bottle delivery
Take-off mass (incl. battery)	5.5 kg	4 kg	2 kg
Flight distance	18 km	5 km	40 km
Flight time (max.)	30 min with 10000mAh battery	16 min with 2 x 5200mAh batteries	30 min with 10000mAh
Flight speed	15 m/s	5-7 m/s	22 m/s
Payload capacity	500g – 2000g	500 g	300 g

Prototypes have been tested and demonstrated only in short distance operations using the commercial short-range radio controllers to proof that the designed frame of each UAV is

Fig. 3. Logistic UAV prototypes from left to right: Type-1 is VTOL UAV, type-2 is lift body UAV and type-3 is fixed wing UAV

working properly and can carry the load which it has been designed for.

Reliable short-range UAV communication solution can be built with the tactical bubble for example the intralogistics use cases. A reliable long-range communication solution is needed for BVLOS operations where packages are delivered to some challenging locations, such as islands. Solution for long-range communication can be built by chaining several interconnected bubbles. The same type of solution can also be built with the public mobile network, where communication reliability needs to be ensured by for example means of network slicing or prioritization. The network needs to be planned so that the UAV gets to access the cellular network from the sky.

IV. Conclusion

Objective of this paper was to introduce the study of potential reliable C2 link for long-range UAV logistics usage. The C2 link has been developed and tested in Centria in a PoC field trial in critical communication use case. The PRIORITY project showed promising results in the use of the tactical bubble for UAV communication. The used C2 link in the tactical bubble is adaptive and it has been developed to meet the needs of future mobile networks and wider area operations.

The logistic demonstrations of the AA3D project show that the custom designed UAVs have the potential for logistics solutions, when the design is tailored for the needs and requirement of the business. Logistics demonstrations were limited by communication link to the short-range operations, however, BVLOS operations are the most typical logistical operations, whether the package to be delivered is food, other consumables or medicine transportation.

The alternative C2 link is becoming very important in long-range logistics solutions, where a reliable long-range link is a prerequisite for safe operations. The long-range communication solution can be built on chained tactical bubbles or by exploiting the commercial mobile networks in the long-range operations. The long-range communication solutions can extend the UAS operational range significantly, when compared to the ISM frequencies as a C2 link, where the operating range is only from few kilometers up to 30 kilometers. While utilizing the commercial mobile network for the C2 link, would also enhance the operational range of the UAV to tens of kilometers, theoretically as far as the network coverage is reaching. Using commercial or private mobile networks as C2 link in parallel with traditional radio control link increases the safety features in BVLOS operations, when using two-different command and control links. This will minimize the risk of communication failure to avoid accidents and collisions.

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