Field Trial of UAV flight with Communication and Control through 5G cellular network

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***Abstract*— In the last few years UAVs have progressed considerably in terms of applications, moving beyond entertaining activities and use. Taking into account that the use of the UAVs is expected to be increased significantly in the forthcoming years, it is deemed necessary to adopt innovative communication technologies and features, towards the support and provision of reliable and secure command and control, as well as for the transmission of high data rates that specific UAVs' missions require. To this end, the combination of UAVs and 5G cellular networks is a promising approach for the effective opening of new fields of operation. This paper provides an overview of the 5G technology and its main characteristics as well its relationship with the communication aspects of UAVs. Moreover, it presents field trial results and measurements towards delivering the command and control of a UAV over 5G cellular network.**

***Keywords*— UAV, 5G, C2, drones, trial flight**

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) also commercially known as drones, are remotely piloted aircrafts, which can be operated by a person, or by pre-programmed operation systems, thus allowing them to fly autonomously. The unique features that the UAVs provide, such as flexible and ease deployment, high mobility and mostly the autonomous operation tend to find appealing solutions in a wide variety of applications including search and rescue, agriculture, civil, public safety, scientific data gathering and numerous others. Thus, UAVs already have a very high market potential which is growing rapidly [1]. Apart from the aforementioned applications, taking into consideration the challenges of the communication networks to handle the increased demand and support various services, UAVs also represent a quite promising solution to many issues in the networking domain. These solutions range from ensuring coverage in rural areas, to densifying the network for areas with density. However, in order to be effectively deployed, several challenges need to be tackled, such as limited energy, backhaul link, mobility and handover, C2 requirements etc. On the other hand, on some people's perception UAVs are also regarded as posing a risk comparable to that posed by current manned aviation. The lack of enthusiasm is most likely due to a lack of understanding of the technology, which has also been identified as the most common public concern, rather than the risks associated with its use.

However, as the UAVs' technology advances, it is mandatory to develop new wireless technologies with the aim to enhance UAVs' communications and moreover to realize the full potentials that they can provide. The deployment of fifth generation wireless technology envisions to achieve a wider variety of objectives in terms of higher multi Gbps data speeds, ultra low latency (URLLC), advanced reliability, increased network capacity and availability, as well as greater bandwidth and throughput (eMBB). In turn these innovative characteristics are being considered as ideal enablers for enhanced UAVs' capabilities towards cellular connected UAVs' communications and UAVs' assisted communications. A recent publication highlighted how 5G network can interact with UAV ecosystem by exploiting the U-space architecture [2]. In fact, standardization endeavors are progressively incorporating UAVs with 5G networks [3].

Thus, it is obvious that apart from the theoretical analysis of the aforementioned paradigms of UAVs and cellular technology, field trials are necessary in order to understand the performance of the 5G architecture in real world operation conditions. Taking into consideration the above observations, the current paper examines 5G connectivity in relation to the C2 communication for UAVs flights experimentally, taking into account the current state of 5G deployments.

The remainder of this paper is organized as follows. Section II, provides a 5G background analysis and a reference is made on the key points of 5G networks. In Section III, we present a classification of the main communication challenges towards the UAVs while Section IV investigates the integration of the two technologies based on 3GPP. Section V introduces the 5G infrastructure as well as the features for the realisation of the field trial flight. Finally, Section VI presents the field trials conducted along with the results that were produced and section VII concludes the paper.

II. 5G TECHNOLOGY BACKGROUND ANALYIS

A. 5G Technology Enablers

5G advances the wireless broadband communication capabilities, providing a dynamic and flexible framework of innovative technologies. In particular, it will deliver a wide variety of wireless services to the end user, spanned across multiple access channels as well as multi layer networks. To that end, it utilizes an architectural approach with Radio Access Networks (RANs) that are no longer limited by the proximity of the base station and the complexity of the infrastructure. Some of the technology enablers that support 5G networks are:

- 5G Spectrum and Frequency
- Multi Access Edge Computing
- Network Slicing
- Network Function Virtualisation
- Software Defined Networking
- 5G RAN Architecture
- Beamforming

B. 5G Core Network Architecture

As specified by 3GPP the 5G Network Core utilizes a cloud service based architecture (SBA) that covers the 5G functions namely authentication, session management and aggregation of the traffic for the end user. The specific architecture also highlights the importance of NFV by deploying virtualized functions in the MEC infrastructure. The main objective of the 5G core network is to separate the control plane from the data plane. Moreover, it aims to reduce any reliance between the Access Network (AN) and the Core Network (CN)as well as to modularize the function design, so as to provide an efficient slicing of the network. "Fig. 1" represents the reference architecture based on the 3GPP reference model with service-based interfaces within the control plane. Network functions that are included in the 5G core control plain can only use service-based interfaces for services that can be interacted by other network functions.

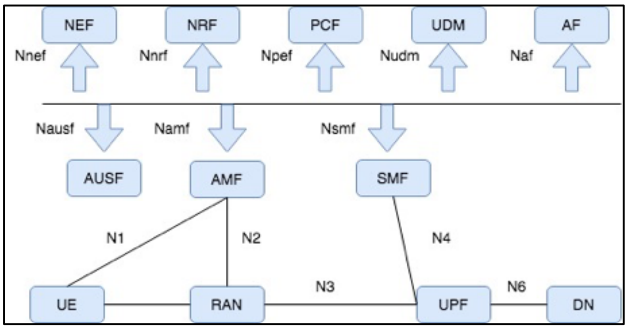

Fig. 1. 5G Reference Architecture

III. UAV COMMUNICATION CHALLENGES

Regarding the communication aspects between the UAV and the Ground Control Station (GCS) and taking into consideration the diversity of the applications that can be benefited by the deployment of UAVs, they can be classified to two main categories: the command and control (C2) and the payload communication.

A. C2 Link

The C2 link establishes communication between the UAV & the Ground Control Station (GCS) or other ground systems such as the radio controller. It must facilitate highly efficient, low-latency, and bidirectional secure communications, usually with low data rate requirements, so that critical information can be shared between the UAV flight controller and the ground control station.

TABLE I. KPIS FOR C2 LINK

Traffic Type for C2	Bandwidth	Latency
Command and Control	0.001 Mbps	VLOS: 10 ms Non-VLOS: 360 ms
Telemetry	0.012 Mbps w/o video	1 sec
Real-Time	0.06 Mbps w/o video	100 ms
Video Streaming	4 Mbps for 720p video 9 Mbps for 1080p video [30 Mbps for 4K Video]: optional	100 ms
Situation Aware report	1 Mbps	10-100 ms

The C2 link does not include, or interact with payload related data, such as cameras, LIDAR, etc. There can be various types of C2 links to connect the GCS or radio controller to the UAV. Some of the options are 433 MHz (Europe), 915 MHz (USA), 868 MHz, 2.4 GHz, 5.8 GHz, LTE band, and more recently, 5G bands. 3GPP has recommended specific KPIs for the C2 link communication for various types of data shared between the UAV and the ground control systems, as depicted in Table I [4].

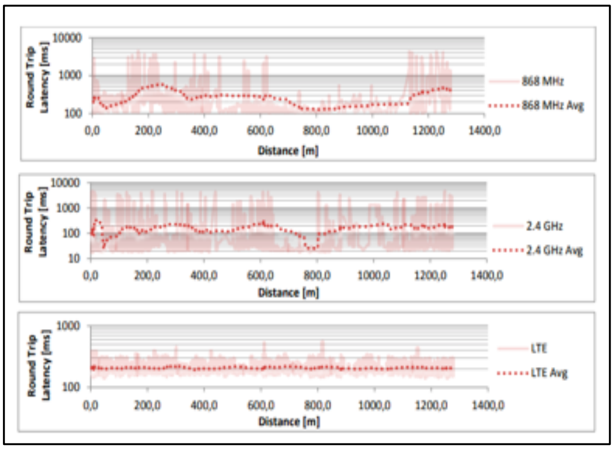

Fig. 2 Round trip latency for C2 link and LTE

Through several experiments, the latency for various C2 bands have been identified and validated as illustrated in "Fig. 2". For example, the 868 MHz band showed an RTL (Round Trip Latency) of 110 to 600 ms. The 2.4 GHz has an average latency ranging from 22 to 310 ms, while the LTE band has an average latency of around 200 ms [5].

B. Payload Communications

On the other hand, the payload communication link is used for transmitting data applications and usually supports high data rates, thus requiring high throughput. The type of data may include image, video, relaying or backhauling data packets, heavy LIDAR data in LAS format, etc. The application scenario each time indicates the type of payload communication to be used, as well as the capacity requirements. Moreover these types of link are usually characterized by higher tolerance and security requirements in comparison to the C2 communication links. To cite an instance, in case of an application that requires video capturing, the UAV will transmit the captured video to the end users via payload communication.

TABLE II. DATA RATES FOR PAYLOAD COMMUNICATIONS

Data Rate	***Value***	***Application***
	Uplink 4 Mbps	1080p video transmission
	Uplink 30 Mbps	4K HD video
	Uplink 60 Mbps	8K HD video
	Uplink 1 Gbps	AR/VR

To transmit a full high definition video from a UAV to a Ground Control Station (GCS) the transmission rate requires several Mb/s, while the transmission rate for a 4K video can exceed 40 Mb/s. For supporting an application with wireless backhauling the UAV communcation requirements can be in the scale of Gb/s. Table II summarizes the requirements regarding the data rates for the payload communication. For a typical transmission of an image or video the end-to-end latency can potentially include delays regarding coding decoding and processing. Moreover latency includes the air-interface as well the latency of the core network. The indicative values related to the latency for image or video transmission are illustrated in Table III.

TABLE III. LATENCY FOR PAYLOAD COMMUNICATIONS

Latency	***End to end latency***	***Network***	***Application***
	<400ms	<40ms	Image/Video Transmission

C. QoS and UAS Services

Based on the 3GPP requirements, Command and Control indicates the consideration of safety concerns, including the risk of collision or the risk of loss of control of a UAV. Therefore, to avoid the safety risks, when considering the 5G network as the transport network, it is important to provide Quality of Service (QoS) for the C2 communication towards UAV services. The new enablers that the 5G cellular networks introduce, can provide an end-to-end QoS system consisting of characteristics such as network slicing that has the potential to respond better to the needs of the increasingly diverse UAVs' applications. Each slice created on top of a physical infrastructure stands for a complete logical network consisting of network capabilities as well as associated resources which can provide specific end-to-end enhanced service capabilities [6]. In the light of the above by allocating a dedicated slice for the connected UAV, we can separate the service and the radio resource management for the UAV from those allocated for the terrestrial infrastructure. Moreover, it is possible to provide service differentiation for a diversity of UAVs' operations, for example by using different slices to support control signaling and applications for specific data services (image/video transmission).

IV. INTEGRATION OF UAVS WITH CELLULAR NETWORKS

A. 3GPP Related work

To cover the needs of the rapidly growing sector of UAVs, the 3GPP Working Groups (WGs) are active towards the mapping of the 5G system and the connectivity requirements of unmanned aerial systems (UAS). In Release 15 of their standard LTE Aerial, 3GPP has conducted studies on the consequences of serving low altitude UAVs using LTE radio. The result of the studies was the publication of report 36.777 Enhanced LTE Support for Aerial Vehicles [7], on January 2018. The main focus of the specific report is to investigate the efficiency of the LTE radio networks to provide services to low altitude UAVs and moreover how the LTE performance can be affected by the use of User Equipment (UE) in UAVs. A preliminary analysis focusing on the service criteria for UAV identification is included in Release 16 entitled Remote Identification of Unmanned Aerial Systems (FS_ID_UAS) [8]. A final report 22.825 Study on Remote Identification of Unmanned Aerial Systems was generated as a result of this work [9].

Following this report the primary aim of the Release 16 UAV study is to define standards for UAV operators, law enforcement, regulatory bodies, and OEMs around the world. The research is focused on the idea of defining a UAV by using control data that can be sent over the 3GPP network. The transmission may take place between a UAV or a UAV controller and a network-based UAV Traffic Management system [10]. Release 17, enhancements for UAVs (FS EAV), describes the Key Performance Indicators (KPIs) related to UAVs and the enhanced requirements for the UAV services. Some of the aspects that the study covers are as follows: Release 17, enhancements for UAVs (FS_EAV), describes the Key Performance Indicators (KPIs) related to UAVs and the enhanced requirements for the UAV services [11]. Furthermore, the objective of this research is to come up with new scenarios that cover both commercial and hobbyist UAV applications. Some of the aspects that the study covers are as follows:

- Requirements for UAV applications in terms of latency, reliability, and mobility, including communication with the UAV Traffic Manager (UTM) and cloud servers.
- Consideration of using a physical infrastructure's network slicing function as a dedicated virtualized slice for an application.

V. 5G ENABLED UAS ARCHITECTURE

5GENESIS experimentation platform has been validated as part of 5G-PPP Phase 2 for execution of 5G trials [12-13]. This section provides details on the 5G infrastructure that was used for the needs of this paper in order to realize the deployment of the scenario and further validate the feasibility of delivering the C2 connectivity to the UAV over 5G, under the scope of the 5G!Drones project. Through the proper adaptation and optimization, we have conducted 5G-assisted UAV experiments that encapsulate and reuse the existing capabilities of the platform.

A. 5GENESIS Mobile Core

Amarisoft Core Network is a proprietary LTE deployment solution, which is widely used at NCSRD campus. Amarisoft Core supports lots of features such as Multimedia Broadcast Multicast Service (MBMS), Multi-Operator Core Network (MOCN) and Narrow-Band IoT. MOCN in particular is a key capability that shall be used widely in our future deployments about LTE Network Slicing. The Core component can also be accessed via a remote API. The API can be used for monitoring and configuring the Amarisoft EPC. Amarisoft Core is 5G NR Release 15 compliant. Connectivity with gNBs is implemented through the standard NG interface using NGAP and GTP-U protocols. The 5GC includes built-in AMF, AUSF, SMF, UPF modules handling UE procedures and providing direct access to the IP network. This 5G Core implementation is now in operation in the Athens platform.

B. 5G Radio Access

The eNB/gNB can run several cells, which can be configured individually and share the same S1 interface with the Core Network. Amarisoft Radio Solution is an LTE/NR base station (eNodeB/gNodeB) implemented entirely in software and running on an x86 Linux-based host. Amarisoft RAN interfaces with the LTE Core Network through the standard S1 interface and with a 5GS Core Network through the standard NG interface. In particular, the Amarisoft Core Network is release 15 compliant and it provides support both for FDD and TDD transmission at FR1 and FR2 frequency bands. Bandwidth configuration varies between 5 to 50 MHz with MIMO options for up to 4x46. Both the Core and RAN functions are software defined and can be hosted on Linux-based systems. Core and RAN Networks provide the option to be hosted separately, enabling the capability of an EPC/5GC cloud deployment. Currently, an all-in-one system is deployed and operating in Athens platform, running on a x86 node, using Fedora 30 operating system.

C. 5G User Equipment

Samsung A90 5G Smartphone supporting 4G LTE band 1(2100), 3(1800), 5(850), 7(2600), 8(900), 20(800), 34(2000), 38(2600), 39(1900), 40(2300), 41(2500) and 5G band 41(2500), 78(3500); NSA.

D. UAS Elements

The elements of the UAS along with the deployed 5G infrastructure, as described in the previous section, are comprised of the UAS deployed in the Edge cloud, the UTM deployed off-site, the Streaming server deployed in a private cloud and two drones, one for patrolling and one for infrastructure. DJI MAVIC drone dedicated for patrolling was used to measure the radio network quality (QoS). The infrastructure drone was a tethered custom made drone which offers unlimited power supply and secured data transfer for safer operations. According to the defined scenario, we have adressed two variants. In the first variant, the drone will be carrying a 5G base station (gNB), and will have an RF backhaul link to the ground 5G Core. In the second variant his drone will be carrying two lightweight 5G UEs. The first one is used for control plane. The second UE provides connectivity to the users by creating a Wi-Fi hotspot and is used for data plane as it utilizes the 5G technologies as a backhaul between the Wi-Fi hotspot and the gNB. The field trial flight that is described in this paper is a feasibility test towards the first variant.

VI. FIELD TRIALS AND RESULTS

Under the scope of EU H2020 5G!Drones project, feasibility trials of UAV flight with 5G network were conducted at the Stavros Mavrothalassitis stadium of the Municipality of Egaleo. The realisation of the 5G enabled UAS is presented in “Fig. 3”. UAV drone flight control (C2) software UGCS [14] was installed on a 5G Edge server and a flight mission was sent to the drone controller over the 5G network [15-16].

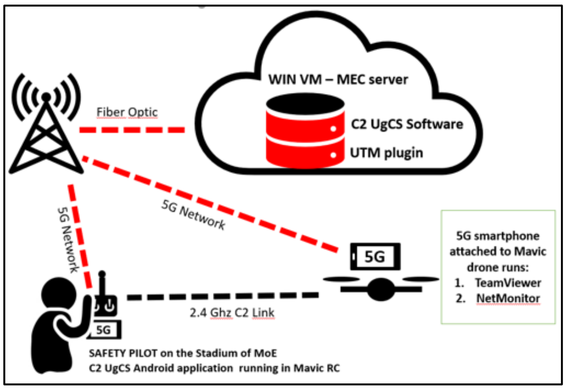

Fig. 3. 5G-UAS Architecture of automated flight trials

In addition, C2 system was connected to UTM (Unmanned Traffic Management) test system, which in real life distributes drone locations to air traffic services and other drone operators. In this way, UAVs can fly together simultaneously, in the common airspace, avoiding collisions and accidents. Moreover, based on policy enforcements, the UTM via its integration with the 5G system, can mandate instantly the UAV landing, if a security incident occurs or a regulation bans flights over a specific location. Afterwards, experimental measurements at the height of 10m were performed in order to assess the coverage of the 5G network and the impact of the antenna pitch to the flight performance and accuracy of the UAV. The 5G coverage measurements were performed using a 5G-enabled smartphone attached to the patrolling drone, and utilizing the Ookla Speedtest application to assess the uplink and downlink rates. “Fig. 4” visualizes the experimental results of the coverage of an automated flight following a circular trajectory around the center of the stadium.

Fig. 4 Coverage area with uplink and downlink values

The greener the spots, the better the reception quality and the 5G coverage, while the yellow spots refer to medium reception quality and finally the red ones at bad reception quality. The different coverage levels are also depicted in the respective throughput rates in the uplink and downlink, where the maximum download rate in a good coverage point was 142 Mbps, while the respective value was significant lower, in a bad reception point, i.e. 13 Mbps. Respectively, the uplink rate was measured from 37 Mbps, down to 22 Mbps as illustrated in “Fig.4”. Moreover, the average latency of the C2 signals over the 5G channel, was measured and found equal to approx. 30ms, which is a significant improvement in comparison to the respective round-trip latency measured for C2 link over LTE in “Fig.2”.

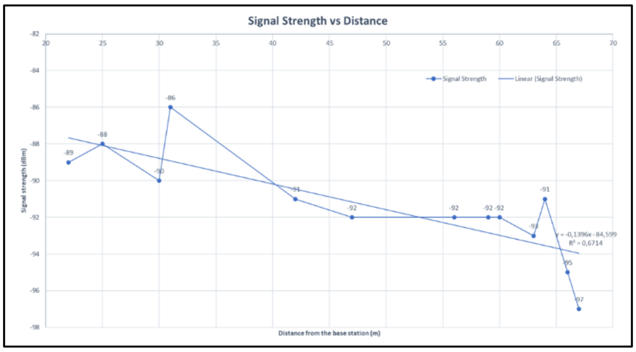

Fig. 5 Signal strength vs gNB distance

Measurements of the signal strength were performed using the NetMonitor application. “Fig. 5” plots the signal strength as a function of the distance from the gNB during the automated flight. As we can see there is a smooth decay of the signal strength as the drone moves away from the base station. It is also important to note that the UTM integration worked smoothly and the location of the Patrolling drone was visible in real time in the UTM system.

VII. CONCLUSION

In this paper, we present a background analysis towards 5G enablers and showed the communications aspects between the UAV and the GS. Moreover, the paper presents the expected KPI requirements for payload and control traffic, as well as the latency occurred for C2 over different access technologies. Then we described the field trial flights performed with C2 over 5G cellular network, as part of the feasibility trials under the scope of EU H2020 5G!Drones project, showing that 5G reduces further the latency of delivery C2, allowing the support of advanced missions.

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REFERENCES

[1] L.Godage,Global Unmanned Aerial Vehicle Market (UAV) Industry Analysis and Forecast (2018-2026), Montana Ledger (2019).

[2] Srinivasan Gokul, et. al., “Supporting UAV Services in 5G Networks: New High-Level Architecture integrating 5G with U-space”, IEEE Vehicular Technology Magazine, 10.1109/MVT.2020.3036374

[3] V. Marojevic, I. Guvenc, R. Dutta, M. L. Sichitiu, and B. Floyd. Advanced wireless for unmanned aerial systems: 5G standardization, research challenges, and AERPAW experimentation platform. IEEE Vehicular Technology Magazine, (Early access), 2020.

[4] 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Enhancement for Unmanned Aerial Vehicles; Stage 1 (Release 17), 3GPP TR 22.829 V17.1.0 (2019-09)

[5] Volkert, Andreas, et. al. “Flight Tests of Ranges and Latencies of a Threefold Redundant C2 Multi-Link Solution for Small Drones in VLL Airspace”, 2019 Integrated Communications, Navigation and Surveillance Conference (ICNS), DOI: 10.1109/ICNSURV.2019.8735265

[6] Michail Alexandros Kourtis; Themistoklis Anagnostopoulos; Slawomir Kuklinski; Michal Wierzbicki; Andreas Oikonomakis; George K Xilouris; Ioannis Chochliouros; Na Yi; Alexandros Kostopoulos; Lechosław Tomaszewski; Thanos Sarlas; Harilaos Koumaras, “5G Network Slicing Enabling Edge Services”, VI IEEE Conference on Network Function Virtualization and Software Defined Networks, 9th November 2020, Madrid, Spain

[7] 3GPP TR 22.829, Technical specification group Services and Systems aspects: Enhancement for Unmanned Aerial Vehicles (V17.1.0, Sept, 2019)

[8] 3GPP Technical Report 36.777, “Technical specification group radio access network; Study on enhanced LTE support for aerial vehicles (Release 15),” Dec. 2017.

[9] 3GPP New Study on Remote Identification of Unmanned Aerial Systems (UAS), SP 180172.

[10] 3GPP Technical Report 22.825, Study on Remote Identification of Unmanned Aerial Systems (UAS), (Release 16), Sept. 2018.

[11] 3GPP Technical Report 22.125; 22.261, 5G Enhancement for UAVs, (Release 17), April 2020.

[12] H. Koumaras et al., "5GENESIS: The Genesis of a flexible 5G Facility," 2018 IEEE 23rd International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), Barcelona, 2018, pp. 1-6, doi: 10.1109/CAMAD.2018.8514956.

[13] A. Díaz Zayas, G. Caso, Ö. Alay, P. Merino, A. Brunstrom, D. Tsolkas, and H. Koumaras, “A Modular Experimentation

Methodology for 5G Deployments: The 5GENESIS Approach," Sensors, vol. 20, no. 22, p. 6652, Nov. 2020.

[14] UGCS, https://www.ugcs.com

[15] F. Alvarez, D. Breitgand, D. Griffin, P. Andriani, S. Rizou, N. Zioulis, F. Moscatelli, J. Serrano, M. Keltsch, P. Trakadas, T. K. Phan, A. Weit, U. Acar, O. Prieto, F. Iadanza, G. Carrozzo, H. Koumaras, D. Zarpalas, D. Jimenez, ""An Edge-to-Cloud Virtualized Multimedia Service Platform for 5G Networks", IEEE Transactions on Broadcasting,Vol. 65(2), pp.369 – 380, 2019

[16] M.-A. Kourtis, B. Blanco, J. P. Romero, D. Makris, M. J McGrath, G. Xilouris, D. Munaretto, R. Solozabal, A. Sanchoyerto, I. Giannoulakis, E. Kafetzakis, V. Riccobene, E. Jimeno, A. Kourtis, R. Ferrús, F. Liberal, H. Koumaras, A. Kostopoulos, I. Chochliouros, "A Cloud-Enabled Small Cell Architecture in 5G Networks for Broadcast/Multicast Services", IEEE Transactions on Broadcasting, Vol.65(2), pp: 414 – 424, 2019