4G/5G performance of a multi-RAT UAV for medical parcel delivery

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***Abstract*—Unmanned Aerial Vehicles (UAVs) are being developed and researched to be used in different areas and diverse use cases. The delivery of medical parcels is an emergency service that avails from the air traffic for the fast delivery of critical health content. Besides 5G networks being the target communication technology for the UAV parcel transport, the infrastructure is still not optimized for ground-level User Equipments (UEs). Using multiple Radio Access Technology (RAT) by UAVs is an alternative solution for scenarios where the 5G network is unstable or not yet fully deployed. In this paper, we present bench-marking of 5G and 4G networks on unideal radio scenarios to understand the real latency and throughput delivered by these technologies in worst-case scenarios. The results show that the 5G network can provide the necessary Quality of Service (QoS) for UAV operations even with Reference Signal Received Power (RSRP) in the order of -90. In comparison, the preliminary data for the 4G network validates that the 4G network could not provide the required latency.**

***Index Terms*—5G, UAV, 4G, multi radio access technologies**

I. Introduction

The delivery of medical parcels is an emergency service between hospitals most often to transport vital contents for health professionals and patients. The delivery of the medical parcels is mainly done on the ground by cars and ambulances because of the nonexistence flying delivery service. However, Unmanned Aerial Vehicle (UAV) is already being studied and implemented to be the new method to deliver medical parcels due to the time constraints of on-ground delivery because of characteristics such as traffic jams.

For this delivery method change, the UAV's communication needs to be of the Ultra-Reliable and Low-Latency Communications (URLLC) type to maintain seamless and continuous communication with the Command & Control Center (C2C). 5G networks are capable of providing the required Quality of Service (QoS) for medical parcels delivery. Nonetheless, the setup of the macrocells in current cellular networks is known to be optimized for ground usage [1], [2]. Therefore, the usage of multi-Radio Access Technology (RAT) is a possible solution for the instability of cellular networks at high altitudes. Multi-RAT solutions use the capability of changing radio technology to maintain the QoS of the service based on the current quality of the network [3]. Furthermore, the usage of multiple RATs enables load balance and packet duplication through different networks, increasing the quality of the overall QoS.

HAI-SCS is a project funded by the Brussels innovation agency Innoviris, as well as by Flanders Innovation & Entrepreneurship (VLAIO), which combines forces and collaborates with VIL (Flanders innovation cluster for logistics) [4]. This project researches on multi-RAT UAV for medical parcel delivery. The HAI-SCS UAV uses three different RATs as communication channels to the UAV: C-Band Mesh Network, 4G, and 5G networks. These technologies have complementary characteristics which we avail from. The C-Band Mesh Network is developed exclusively for UAV usage. This technology was built using the C-Band spectrum (4-8GHz), which is recommended for UAV usage by the International Civil Aviation Organization (ICAO) because this band is a protected spectrum and the importance of the service and the constant communication with the server [5].

The 4G network comes as the commercially deployed option, which will provide the highest coverage of the three options mentioned above. Finally, we have the 5G network, which is currently a testbed network not integrated with the 4G commercial network. The 5G testbed network still doesn't have a 4G network fallback feature which prevents UAVs from performing handovers between 5G and 4G networks by default. Therefore, it was necessary to have a solution that enables the handover not only between C-Band and cellular network but among 5G and 4G and the C-band mesh network. ORCHESTRA is a software solution that allows handovers to load-balancing and packet duplication among several RATs [6], [7]. This software enables us to maintain the UAV connected to the C2C while covering any of the three RATs available.

In this paper, we present part of our roadmap to a fully multi-RAT UAV for medical parcel delivery. We first describe the UAV services QoS requirements that the network needs to provide. Furthermore, we present our multi-RAT UAV prototype description and the experiment setup. Finally, we present our preliminary results. The experiments in this paper aim to validate on ground-level that our experimental network setup can provide the necessary QoS for the UAV operations. Therefore, we cross-evaluate the Reference Signal Received Power (RSRP) received for 5G and 4G networks and the experienced Round-trip Time (RTT) and throughput on both networks. Our main contributions are *(i)* to provide an understanding of the functional connectivity requirements for a delivery service of medical parcels by UAVs; *(ii)* to present the first results of the UAV prototype by benchmarking the used technologies.; *(iii)* to show the future work for the experiments on the multi-RAT UAV.

II. UAV SERVICE REQUIREMENTS

In this section, we describe the UAV service requirements that were gathered by the HAI-SCS project partners during their tests.

Service	**Downlink Throughput (kbps)**	**Uplink Throughput (kbps)**	**Maximum one-way latency (ms)**	**Impact of Packet loss**
Command & Control	300	300	100	High
Telemetry	58	58	100	High
Network Control	58	58	200	Medium
FPV	1024	5120	200	Medium
FPV Control	300	300	100	High

Table I: UAV services QoS requirements

1) Command & Control

The command and control is the communication channel between the C2C and the autonomous pilot in the UAV. As changes in the trajectory and last-time information can be sent to the drone, the traffic type has been classified as bursty. The latency should be not high than 100 ms not to affect fast changes in the trajectory or the overall drone functioning.

2) Telemetry

The telemetry channel will send monitoring data gathered by all sensors installed in the UAV to C2C, enhancing navigation awareness. The data packets sent through this channel are not significant and have periodic behavior sending information about the UAV status from time to time.

3) Network Control

The network control channel will enable communication between the UAV and a connectivity controller. The messages should be periodic to inform the status of the network, and occasional control messages from the centralized unit should be sent through the same channel to adjust settings considering a global view of the network.

4) First Person View (FPV)

FPV is a service to provide video streaming from UAV to C2C. This service will enable remote visualization of what is happening around UAV, and, possibly, a pilot located beyond the line of sight will be able to make the best decision upon the given scenario. The video streaming network traffic is mostly bursty and requires high network throughput to send video frames. This service does not need high network reliability because minimal losses of frames are not too prejudicial when remote controlling a UAV.

5) FPV Control

The FPV Control is the service that will enable the remote control of the FPV together with the FPV service, which will provide the video streaming. The service is highly impacted by packet loss since the application's packets are sending navigation commands to UAV.

III. CONNECTIVITY ENABLERS

In this section, we describe the software and possibilities in setting up a network infrastructure that will be used to create reliable network connectivity.

A. ORCHESTRA

ORCHESTRA is a software-defined framework that relies on network virtualization to cope with heterogeneous challenges and support inter-technology management [7]. This framework allows for optimizations like intra and inter-technology handovers, load balancing, and dynamic path reconfiguration.

B. 5G Network

The new 5G networks posed the challenge of defining the strict requirements of several use cases, including UAV operations, such as URLLC and enhanced Mobile Broadband (eMBB). Techniques on radio and architecture are being researched to meet these requirements decreasing network latency and throughput. Furthermore, the isolation of the network traffic in shared infrastructures is essential for maintaining the quality and privacy/security of these services. Network Slicing (NS) is the research area included in 5G networks that study techniques to share resources and provide the expected QoS for the connected clients. For this paper, we used a testbed 5G network to configure a private NS based on the UAV service requirements provided in the previous section.

C. 4G Networks

The 4G network is the current the more popular commercially deployed cellular network the present. It provides sufficient data rates for video streaming and can offer good coverage in urban environments. The role of 4G networks within the HAI-SCS project is to be the primary connectivity provider to the UAV since this technology is provided by the current network infrastructure and provides coverage to most cities.

D. C-Band

The C-Band radio used for this project is a mesh network using the C-Band licensed spectrum. Using a private network infrastructure in licensed-spectrum enables a low-interference communication between C2C and UAV. However, the coverage of C-Band will be limited due to the costs of deploying a whole network infrastructure. Therefore, the extension of the network coverage is achieved by using a support UAV to work as a tactical bubble, providing service connectivity by bridging the UAV with the ground station.

IV. EXPERIMENT SETUP

The objective of this paper experiment is to evaluate the real-world performance of the 5G testbed and the 4G network Access Point Name (APN) of the project. We used the real-world data to validate the capabilities of the network for UAV communication. Moreover, we study the relationship between the Reference Signal Received Quality (RSRQ) and Reference Signal Received Power (RSRP) and the throughput/latency experienced for the network. We will use this data for ORCHESTRA decision making, which will receive as input the RSRQ and RSRP of the networks, and based on the relationship between throughput and latency with the received signals, ORCHESTRA will change the used RAT.

We performed the experiments in the final UAV setup, Figure 1. The UAV prototype includes an iWave board[1]. The module used for the 5G and 4G experiments is the Quectel RM500Q-GL[2] combined with the evaluation board Quectel RMU500-EK[3]. The evaluation boards were plugged using a USB 3.0 cable to the UAV iWave board. The 4G network used for the experiments was from a commercial Belgian network operator connected through a private APN for this project. The 5G network used in the experiments was a 5G network with a 5G SA Core deployed as a testbed from the same Belgian network operator. For the 5G network, we used a static private NS for UAVs.

We benchmarked 5G and 4G networks using iPerf3[4] with Transport Control Protocol (TCP) traffic on downlink and uplink. An RTT experiment also was done in both technologies with Internet Control Message Protocol (ICMP). All the experiments were executed for 500 seconds with a data collection interval of 1 second, resulting in 500 data points for every experiment.

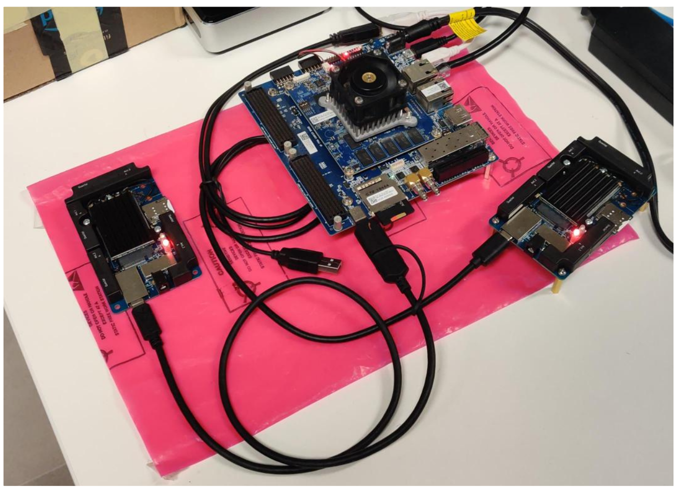

Figure 1: iWave board connected with two Quectel RMU500-EK + two Quectel RM500Q-GL

V. Preliminary Results

A. 5G network

As shown in Figure 2, the RTT varied from a minimum of 18.2 ms to a maximum of 104 ms. The RTT average was 47.28 ms with a standard deviation of 22.81 ms. In Table I, we present the latency requirements per service for UAV operations. The maximum latency possible for UAV operation is around 100 ms one-way latency. This one-way latency is regarding the reaction time for a pilot to control the UAV manually. Based on the initial RTT measurements, we see that even with an average of -91 RSRP, the network can still provide the necessary latency for the UAV operation.

During the execution of the TCP downlink experiment, the RSRP maintained an average of -91.75, with a variance between -96 and -89. The TCP downlink traffic stayed on an average of 66.53 Mbps and a standard deviation of 1.59 Mbps with a minimum of 58 Mbps and a maximum of 74 Mbps. The RSRQ maintained stability on the average of -12 with a minimum of -13 and a maximum of -11. As shown in Figure 2 (b), the throughput is not directly affected by the minor variation on the RSRP during our experiment.

In Figure 2 (c), the TCP uplink traffic behavior demonstrates that it always hit around the 59.7 Mbps bitrate mark, and then it drops to around 31.5 Mbps. On average, the TCP uplink traffic was 45.42 Mbps with a standard deviation of 5.39 Mbps. The RSRP was on average of -93 with a standard deviation of 1.27. The minimum RSRP was -96, and the maximum of -88 RSRP. The RSRQ maintained -12 on average with a maximum of -11 and a minimum of -12. The results of the TCP uplink experiment show that the throughput available on the 5G network, even with RSRPs values around -90, is enough to support the UAV services.

B. 4G Network

Figure 2 (d) shows that the RTT from UAV to C2C was 70.7 on average, with a variance between 39.9 ms and 165 ms. The standard deviation was 25.0 ms. The RTT pattern was not influenced directly by the drops on the RSRP quality from -95 to -96. The average RSRP measurements during the network latency experiment were -95.07 with a maximum of -95 and a minimum of -96. The RTT experiments show that the 4G network with an RSRP average of around -90 increases 49,47% on the RTT average compared to the 5G network experiment. Moreover, it is impossible to confirm that the 4G network can provide the desired latency for UAV operations since the maximum RTT reached 165 ms. The RTT includes downlink latency, uplink latency, and packet processing time on the target host. Therefore, we validate by our measurements that with a -95 RSRP average that the 4G network cannot guarantee the one-way latency of 100 ms requirement for UAV operations.

The TCP downlink on the 4G network could reach a maximum of 70.6 Mbps, minimum of 1.16 Mbps, and an average of 45.8 Mbps. The RSRP was on average of -96 with a minimum of -96 and a maximum of -94. The downlink throughput of 4G networks provides the requirements for UAV operations of 1 Mbps, and the results meet the expectations even with RSRP in the order of -90.

The TCP uplink experiment on 4G networks shows that we could achieve an average of 19.6 Mbps, with a minimum of 8.79 Mbps and a maximum of 32.1 Mbps. RSRP was -95 on average with a minimum of -99 and a maximum of -94. Even with a not ideal RSRP, the 4G network could deliver the necessary TCP uplink throughput for the UAV service of FPV.

VI. Conclusion & Future Work

In this paper, we present a work-in-progress of multiple RATs on the UAV prototype. The research aims to manage the RAT avoiding significant drops in the quality of the experienced QoS by the UAV due to the current cellular networks are not

[1]https://www.iwavesystems.com/wp-content/uploads/2020/11/iW-RainboW-G30D-Zynq-Ultrascale-MPSoC-SOM-DevKit-QuickStartGuide-R2.0-REL1.0.pdf

[2]https://www.quectel.com/product/5g-rm500q-gl/

[3]https://www.manualslib.com/products/Quectel-Rmu500-Ek-11303579.html

[4]https://iperf.fr/

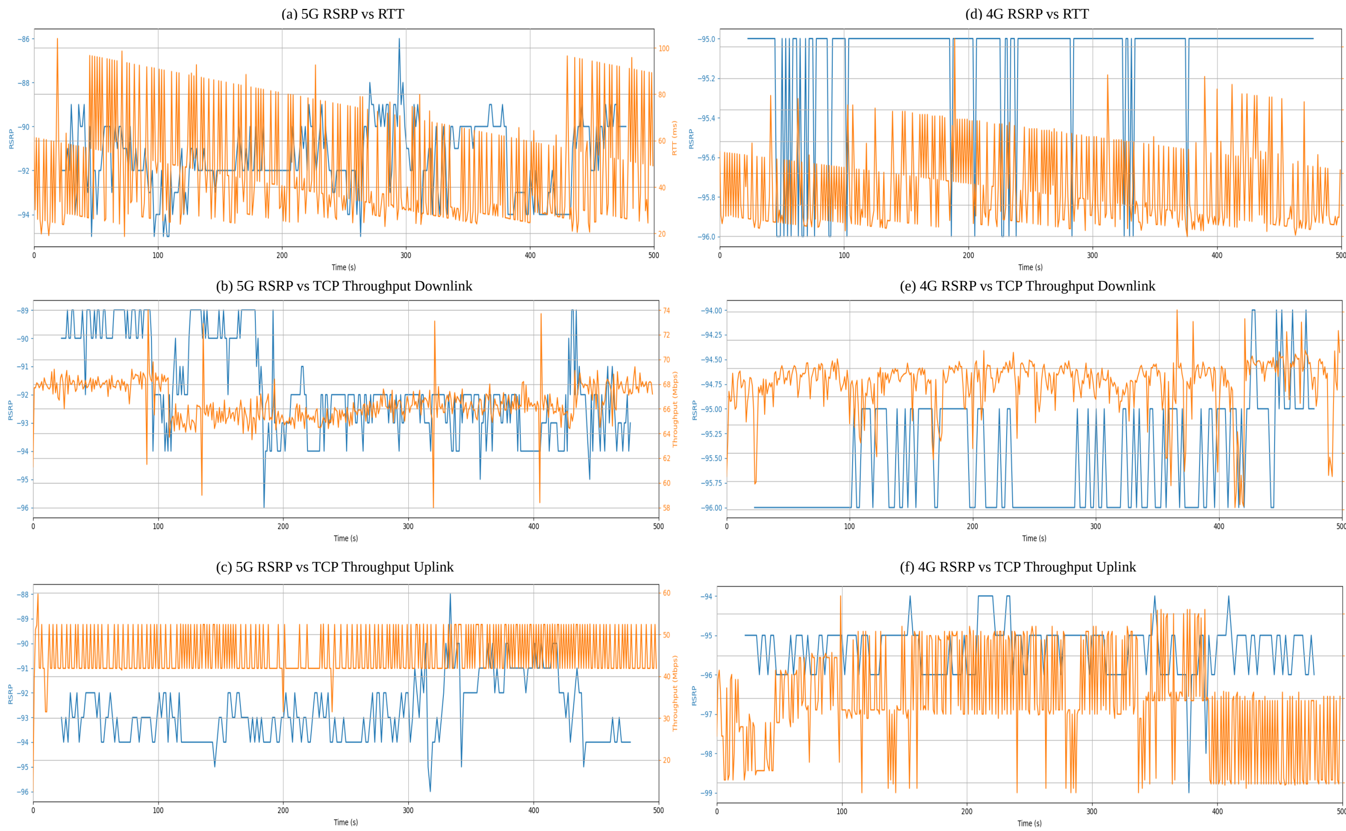

Figure 2: Throughput and latency benchmarking experiments vs RSRP on 5G and 4G networks

optimized for high altitude User Equipment (UE). Therefore, to decide which RAT should be used and when, our solution considers radio Key Performance Indicators (KPIs), *e.g.*, Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ).

In this stage of the experiments, we could collect data from a 5G network testbed and a 4G commercial network with a private APN. Since the UAV application uses TCP for the exchanged messages with the C2C, we measured the TCP downlink and uplink through of 5G and 4G network worst-case scenario with RSRP in the order of -90. Furthermore, we also collected the RTT of ICMP packets from UAV to C2C. Our findings show that the 5G network testbed could attend to the latency and throughput UAV services requirements on ground-level with unideal RSRP.

As future work, we will collect data from the C-band radio as well to confirm that this solution is a reliable radio link when the cellular networks cannot provide the necessary QoS. Moreover, we will do multiple flights experiments to collect mainly 5G and 4G networks data on high altitudes. Collecting the required data of the networks in different scenarios, we will create a Proof of Concept (POC) intelligence to manage the multiple RAT to surpass the non-idealistic cellular infrastructure for serving UAVs.

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