LTE Mobile Network Technical Feasibility for Unmanned Aerial Vehicle BVLOS operations in a Rural Test Area

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***Abstract*— The Long Term Evolution (LTE) technology for the terrestrial area allows command and control and payload communications between drone and ground station in real-time and beyond visual line of sight (BVLOS) conditions. However, aerial coverage, interference elimination, and network latency require further study, because mobile networks for Command and Control (C2) links are not yet generally accepted in drone operations by Civil Aviation Authorities (CAAs). This study focused on one rural test area in South-Eastern Finland. Commercial cellular operators were used, from which LTE network coverage maps of one operator in the area were used as the basis for the study. Several Unmanned Aerial Vehicle UAV flights were made, and LTE connection measurement results were obtained using the operator's systems and own testing equipment and systems. Nothing unusual occurred in the test flights, which were made in a strong LTE field, and the Command and Control (C2) connection worked well. However, the terminal could have performed better in an area with poor LTE field strength when only one LTE User Equipment (UE) was used. But the data transfer worked very reliably when using a connection with several parallel cellular network connections on at the same time at the poor coverage area. This article shows that it is possible for any BVLOS operation to use the cellular network for the low-capacity Command and Control (C2) link if the operation area is covered by several LTE network operators and the terminal equipment allows the use of parallel connections.**

Keywords: LTE; BVLOS; drone field test measurement; RSRP; RSRQ; Command and Control; C2

I. INTRODUCTION

When operating with drones beyond line of sight (BVLOS) in Europe, the operation must occur under a special category license issued by the aviation authority, and not in the open category, where most drone operations currently operate. In Finland, a license issued by the operator is also required for using a mobile phone network, if the drones use the network for data transmission.

From the beginning of 2022, you can apply for a special category operating license from the aviation authority based on either the Predefined Risk Assessment (PDRA) published by the European Union Aviation Safety Agency (EASA) or the operator's own SORA - Specific Operation Risk Assessment. The operating license, according to PDRA, does not currently allow that flight control at the ground station can take place over a mobile phone network but requires the primary connection from the ground station to the drone must use a direct communication link via a ground transmitter to the drone [1]. According to EASA, this may change, when more experience has been gained using cellular networks [1]. This study aims to increase the understanding and experience of the suitability of mobile phone networks in UAV operations. This study also aims to propose that commercial cellular networks will be accepted for the low-capacity C2 link if certain requirements are met.

This article presents the operation of a commercial cellular network in terms of the operation of a single UAV Command and Control (C2) link in a sparsely populated test area located in South-Eastern Finland. The C2 link was a low-capacity Command and Non-Payload Communication (CNPC) telemetry link used by Ardupilot-based autopilot. There are three major cellular network operators in Finland. In the studied area, all three operators mostly use the same 4G base station masts, where the antennas point in the same direction. The performance difference between the operators is not necessarily high. Of course, there can be differences between operators' base stations in transmission power, receiver sensitivities, and other configurable parameters. If the C2 link is based on subscriptions of several cellular network operators, it is unlikely that there will be interference in all connections simultaneously. There are many proposals that a dual-operator hybrid access system could improve latency and reliability [2]-[5].

The key contributions of this study are summarized as follows:

1) The measured signal level in the air is naturally higher than ground level. As the measurement locations were reasonably far from the base stations, the measured signal levels and qualities did not differ significantly at various altitudes.

2) The LTE network is well suited for implementing a low-capacity C2 link, especially if it is known based on measurements or simulations that sufficient field strength is available.

3) When measurements were made with a single terminal in an area where the strength of the LTE network was weak, this specific modem still endeavoured to keep the connection to the LTE 1800 Mhz network, even though a good quality 3G or 800 MHz network service was available. However, 3G network is no longer important, as the 3G networks will be dismantled soon.

4) When measurements were made in the same weak field area with a unit supporting several simultaneous network connections the C2 link performed very well.

5) When a single terminal was used and interferences in the connection were observed, the C2 link recovered in all situations, although there could be a break in data transmission for several tens of seconds in a weak field.

There are many advantages when using commercial cellular networks: the connection is inexpensive, and operationally reliable due to, e.g. error correction on the radio path, and the fact that handovers between base stations occur automatically, etc. The problem, however, is that the cellular network is not designed for unmanned aviation. The following section discusses the challenges of using a cellular network in unmanned aviation and the proposed solutions.

II. The Impact of UAVs on the Cellular Network

In LTE systems, a power control mechanism is used to maximize the energy efficiency of the UE transmission, whilst minimizing the overall system interference [7]. Aerial UEs, such as UAVs, differ from classic LTE scenarios with terrestrial UEs. They are likelier to experience line-of-sight (LOS) to their respective serving cells than a terrestrial UE, particularly in urban areas [7]. Consequently, they tend to require a transmit power smaller than their terrestrial counterparts in most cases. At the same time, the interference received by non-serving cells is significantly higher than for the same user on the ground, especially when UAVs use a significant amount of network resources [7]. This will cause the uplink throughputs of other users in those cells, including the terrestrial users, to be negatively affected.

During the UAV operations of this study, only the telemetry channel was used. The speed of the channel, which represents critical and necessary data transfer, was relatively low: less than 4 kbytes/s of payload data on average [8]. Based on previous studies [9], it can be assumed that such a low use of network resources will similarly not disturb the terminals on the ground. Interferences caused using the telemetry data transmission channel were left out of this study and the focus was on the reliability of the data transmission channel.

Newer 3GPP releases (starting from rel. 15) support LTE Aerial enhancements. There are, e.g. new features supporting:

1) Power control by using UE-specific parameters to adjust the power control settings

2) Height reporting indicate whether the terminal is in the air or on the ground

3) Limitations on the measurement reports of aerial UEs to avoid excessive load on physical resources by introducing a new parameter

4) The possibility for the network to ask for the location and the intended flight route of the UAVs.[7], [10]

It is unknown how the operator utilizes these newer features or whether any mobile network manufacturer has actually implemented these functions in their commercial products.

III. Measurement Equipment and Methodology

In October 2022, the Aerial Connectivity Joint Activity – Work Task #2 published a Reference Method for assessing Cellular C2 Link Performance and RF Environment Characterization for UAS [11], which could have been a good reference document. In this study most measurements were made before the paper was published; thus, the recommendations have not been considered. In hindsight, however, it appears that most of the topics were covered in the measurements.

Measurements were made at various heights and beyond line of sight in reserved danger areas - so called Tempo-D areas - in the airspace.

Additional measurements were made during the spring of 2023, but they only focused on how a terminal that supports multiple parallel LTE connections at the same time can improve the quality of the connection in the area of the weak field found.

A. Devices

The LTE connection was tested with a Fixed Wing VTOL drone (Foxtech Loong 2160) equipped with a Raspberry companion computer and Huawei E7732 modem. The modem had external omnidirectional 4G router antennas from Huawei. The arrangement was similar to the article “Mobile Network Performance and Technical Feasibility of LTE-Powered Unmanned Aerial Vehicle”, where a cloud-based operational system was implemented and a cloud server service from UAVmatrix, known as UAVcast [12], was used [13].

A SONY Xperia mobile phone monitored the network with the Gmon application. This device was used when LTE network performance was studied at various altitudes and when doing a longer BVLOS flight.

During the BVLOS flight, both connections from Huawei modem and SONY Xperia terminal were monitored on the network operator side as described later.

The Huawei antennas (Freq. range: 700 – 2600 MHz, Gain: 5 dBi, Vertical polarization) were placed longitudinally on the top and back of the drone as presented in Fig. 1. The placement is not optimal in terms of the radiation field, but this way the effect of the antennas on the aerodynamics of the drone is not great.

To improve connection reliability, Huawei's E7732 modem was changed to Elsight's Halo OEM Platform, which supports four parallel LTE connections. Three simultaneous LTE connections with three SIM cards from various network operators. The additional four antennas were installed on the legs of the landing gears as shown in Fig. 1.

Fig. 2 presents Elsight's OEM Halo platform based on four Telit LTE modules and four SIM card slots. On the ground station side, the same type of platform was also used to establish a reliable connection from the ground station to the Internet.

The Halo platform was able to collect a log of the drone's location data and the main parameters of the connections. In addition, the Wireshark program was used to record all transmitted and received packets.

Figure 1. Loong 2160 drone with the antennas placed on the front top, rear bottom and legs of the landing gear.

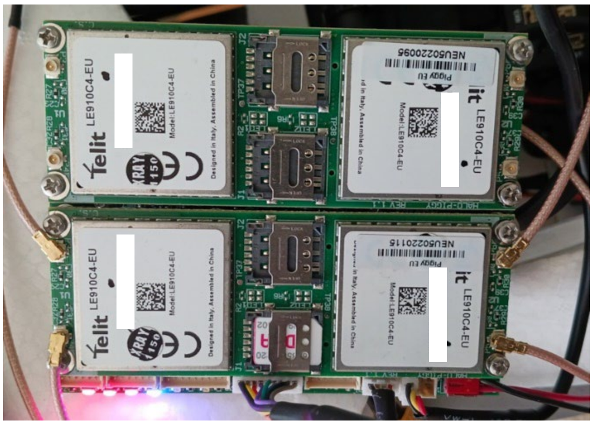

Figure 2. Elsight's Halo OEM Platform supporting four simultaneous LTE connections

B. Test Area and LTE Network Coverage Simulations

The starting point of the research was the network coverage simulation results for different systems from the operator. In the simulations, it was assumed that the terminal is located at the height of 100 meters. There were no 5G, LTE 2600 and LTE 2100 network coverage in the test area but, LTE 1800, LTE 800, 3G, and 2G coverage was good on average.

Figures 1 & 2 present the simulated signal power level for both the LTE 800 and LTE 1800 systems. The main test area is located between eNB1 and eNB2. The measurements were performed with a test phone in the locations P1, P2 and P3 at three invidual heights: 100m, 200m and 300m. The measured parameters were **Reference Signal Received Power (RSRP)** and **Reference Signal Received Quality (RSRQ)** from the known eNBs. A BVLOS flight was performed between eNB1 and eNB2, where the signal level is good according to the simulations, and other VLOS flights were performed in location P4 where the signal is weakest. In addition to the locally performed measurements, log reports from the test phone and telemetry from the terminal used in the connection were available from the operator. In the images the track between eNB1 and P4 are the measurements on the ground.

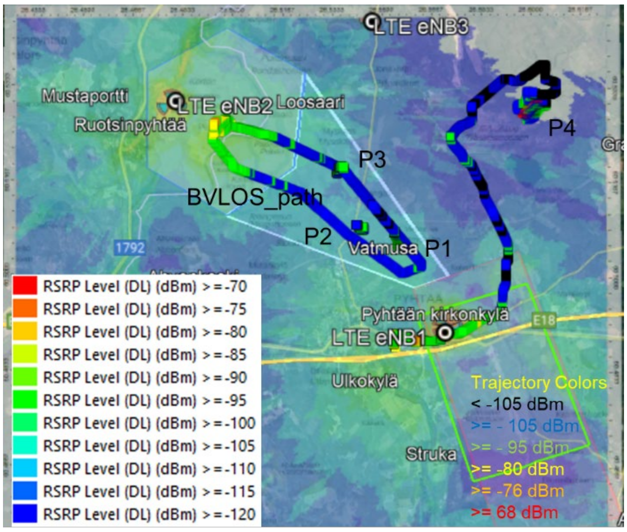

Figure 3. RSRP according to simulations at a height of 100m on the LTE 1800 MHz network.

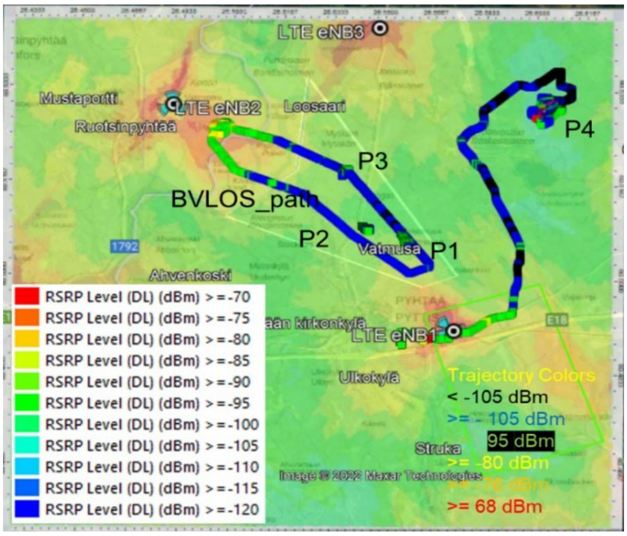

Figure 4. RSRP according to simulations at a height of 100m on the LTE 800 MHz network.

C. *Measurements on the Operator Side*

A longer BVLOS flight and a flight in a weak LTE field area (P4) were monitored also by the operator with two various systems.

The first system of the operator measured the events of the packet-switched network, e.g. with the following parameters:

- Cell id;
- PS event type and the reason for the event;
- IP-address;
- Total data volume.

The system was also able to measure Key Performance Indicators (KPIs) such as

- Application throughput (UL/DL);
- Peak application throughput (UL/DL);
- Session data volume (UL/DL).

The second system of the operator collected a log of the traffic and signaling events.

- RSRP and RSRQ of the used and neighboring cells;
- SRB Signaling radio bearer in/out events;
- UE UL SINR;
- S1AP out events and cause;
- Connection setup time.

Measurements and events were recorded during the five-minute flights at dozens of moments in time, which gave a comprehensive picture of the network's functionality.

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IV. RESULTS

A. *Measurements with a test phone in various heights*

The purpose of the first measurements at various heights was to find out what kind of phenomena there are in network connections when the terminal is clearly above the ground and vegetation.

Tables 1. – 3. present RSRP and RSRQ values at three various heights (100m, 200m, 300m) and locations. Due to the handovers, one table consists of two or three sub tables. The measurements occurred once per second when the UAV moved at 5 m/s. In practice, more than 100 measurements were made at one height. All measurements were made with a monitoring test phone (Sony Xperia).

In all locations, as expected, the RSRP is lower and the RSRQ is better at ground level. However, there are no significant changes in the measured values at various heights. In each location (P1, P2, P3), handovers took place between various base stations (eNB1, eNB2 and eNB3), and therefore there are several sub tables per location.

TABLE I. MEASURED RSRP AND RSRQ VALUES IN P1

eNB1 1800MHz (d=1,8 km)

P1	P1 (RSRP)	Std. Dev.	P1 (RSRQ)	Std. Dev.
GND	-106,0		-13,0	
100	-91,0	2,4	-15,0	1,2
200	-91,0	2,4	-15,1	1,4
300	-92,0	2,6	-14,2	1,4

eNB2 1800 MHz (d=5 km)

P1	P1 (RSRP)	Std. Dev.	P1 (RSRQ)	Std. Dev.
GND				
100				
200	-96,2	1,2	-18,2	1,2
300				

MEASURED RSRP AND RSRQ VALUES IN P2

eNB1 1800MHz (d=2,5 km)

P2	P2 (RSRP)	Std. Dev.	P2 (RSRQ)	Std. Dev.
GND	-101,0		-10,0	
100	-92,5	1,1	-14,0	1,9
200	-95,7	1,4	-14,0	2,3
300				

eNB2 1800MHz (d=4,2 km)

P2	P2 (RSRP)	Std. Dev.	P2 (RSRQ)	Std. Dev.
GND				
100	-95,0	5,7	-16,0	2,8
200	-93,5	2,0	-15,0	1,5
300	-92,5	3,5	-12,5	2,1

TABLE II. MEASURED RSRP AND RSRQ VALUES IN P3

eNB2 1800MHz (d=3,4 km)

P3	P3 (RSRP)	Std. Dev.	P3 (RSRQ)	Std. Dev.
GND	-108,0		-12,0	
100				
200	-92,0	9,9	-13,0	2,8
300	-97,5	2,3	-18,0	1,4

eNB2 800MHz (d=3,4 km)

P3	P3 (RSRP)	Std. Dev.	P3 (RSRQ)	Std. Dev.
GND	-115,0		-11,0	
100	-91,5	2,1	-16,0	2,8
200				

eNB3 800MHz (d=2,8 km)

P3	P3 (RSRP)	Std. Dev.	P3 (RSRQ)	Std. Dev.
GND	-110,0		-13,0	
100	-90,5	3,5	-15,5	2,0

In [14] was measured RSRP and SINR at five various heights (20m, 40m, 60m, 80m, and 100m). No significant differences were identified in the median RSRP received from the serving cell. However, height-related degradation on signal-to-interference levels were observed.

In our measurements, similar behavior was observed regarding signal-to-interference levels under 100m heights. However, there were no significant differences in the average SNR measures at various measurement heights.

The average of the SNR values measured at location P1 for heights of 100m, 200m and 300m were -3.8; -0.6 and -6.3 dB. At location P2 the values were 0.4; -4.2 and -0.3 dB. At location P3 the values were -3.5; -1.9 and -6.4 dB.

B. Measurements in the BVLOS flight in the region of a strong LTE-field

The BVLOS flight route in Fig. 3. and 4. was over 10 kilometers and the flight path happened to be between two base stations. The drone was equipped with Huawei modem and Sony Xperia test phone.

The flight in the test area between eNB1 and eNB2 occurred without any connection problems. When the drone was at the far end of the flight path near eNB2, handover occurred six times between base stations, but there were no interruptions in data transmission. Five TAUs (Tracking Area Updates) were recorded by the operator system.

C. Measurements in flight in the region (P4) of a weak LTE-field with Huawei E7723 modem

Since the cellular network connection worked perfectly for the Huawei E7723 modem during the flight in a good LTE field, we started to make flights in a weak field in accordance with the operator's simulations. The test area was in Fig. 3 and 4. at the point P4 where VLOS-flights were made.

The following events occurred when the drone flew at the height of 100m for 5 minutes in a weak LTE-field:

- One Drop call, Paging event

- Six times UE context releases

- Tens of seconds break in payload transmission

- Handover to an LTE 1800 base station (marked as eNBb in table IV) located 20 km away, even though there was a UMTS, HSPA base station available with good signal strength

- The transmission of the telemetry data link recovered after all events.

Table 4. summarizes the events and handovers between base stations as a function of time. LTE 1800 base stations were eNB1, eNBb and LTE 800 base stations were eNB3 and sNBd.

Based on the KPI-logs, the uplink capacity required by the C2 link was on average less than 10 kB/s. One momentary transfer burst exceeding 1 MB/s was observed. The longest C2 transmission outage occurred after the first minute of takeoff. The outage lasted up to one minute.

TABLE III. EVENTS DURING THE FLIGHT (WEAK LTE FIELD AREA)

(s)	Event type	Cell
7	AggData Activity	eNB1
15	AggData Activity	eNBb
23	UE context release	
33	Paging	Failed HO
53	AggData Activity	eNBb
61	Service req & UE context release	
63	TAU	eNB3
75	Service req & UE context release	
75	AggData Activity	
93	TAU & UE context release	eNBb
108	AggData Activity	
160	AggData Activity	
163	Service req & UE context release	
184	AggData Activity	
215	AggData Activity	eNBd
	….	
285	AggData Activity	

D. Measurements in flight in the region (P4) of a weak LTE-field with Elsight's Halo platform

The Elsight's Halo OEM platform supports four simultaneous connections It combines LTE communication links with bonding algorithms that make the connection work through alternative channels.

There were made 4 flights in two different days as follows:

1) *Three SIM cards from three various operators (day 1)*
2) *One SIM card with 3G connection (day 1)*
3) *Three SIM cards from three various operators (day 2)*
4) *One SIM card (day 2)*

The platform was able to record the following general parameters during the flight: time, longitude, latitude, altitude, satellites, velocity, and direction. Per one SIM card the recorded parameters were: cellular generation, Rx level, signal to noise level, band number, band frequency, arfcn original, cell id and RSSI.

All the Mavlink telemetry packets between ground station and autopilot were recorded by Wireshark application.

Fig. 5. presents the data flow when the modem was equipped with 3 SIM cards. One of the SIM cards was configured for using 3G network. During the flight, packet transmission was invariably rather constant at 70 – 80 Mavlink protocol packets per second. The typical packet length was between 50 and 140 bytes and the corresponding bit rate was about 60 kbits/s. No disturbances were observed in the ground station application used for monitoring the flight.

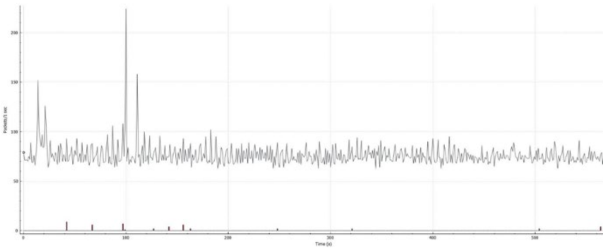

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Figure 5. Packet transmission during the first flight with three SIM cards

Fig. 6. presents the packet transmission when the terminal was configured using the 3G network. The traffic flow was disrupted three times during the flight. Since the system can display 4G base stations, but not 3G base stations, it was unclear whether the disturbances were related to handovers, for instance.

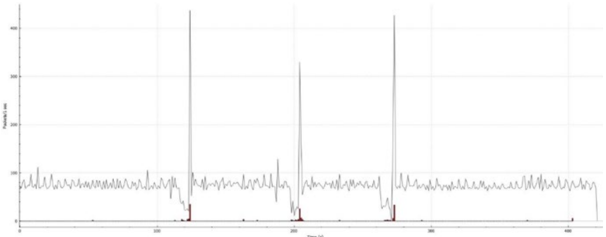

Figure 6. Packet transmission during the second flight with one SIM card using the 3G network.

When three SIM cards from three various operators were used the traffic data flow was very steady. One of the operators was continuously connected to the LTE 800 network. For other operators, the variation was greater in terms of the cellular system used.

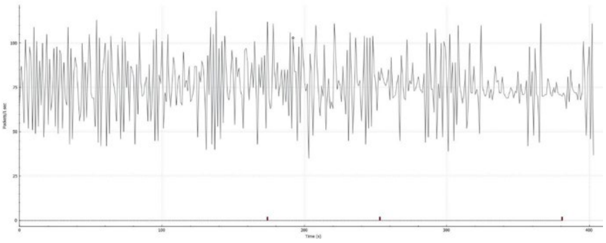

Figure 7. Packet transmission during the third flight with three SIM cards.

Figs. 8., 9. and 10. present the data from the fourth flight using one SIM card and LTE network. From Fig. 8. can be seen the packet transmission is again quite constant even there are many handovers between LTE base stations as presented in Fig. 9. The used base stations are indicated with various colors used in various sections of the flight path. Fig. 10. shows the location of the four nearest base stations in relation to the area P4 where the flights were made. Some of the momentarily used base stations were in excess of ten kilometers away, but most of the time the drone was connected to the nearest base stations. All the connections used 800 MHz frequency.

According to Figs. 9. and 10., the connection direction from the base station is mostly perpendicular to the flight path. This may well be explained by the fact that the antennas were installed along the drone's body in the horizontal plane, in which case the antenna's radiation occurs mostly to the sides. In terms of connections, a better result would probably have been reached if the antennas had been installed vertically, in which case the radiation pattern would have been the same horizontally in all directions. For practical installation reasons, this was just not very easy to do without the installation having an effect on the drone's aerodynamics.

Even though the base stations were relatively far away, the connection worked without interruption throughout the flight despite the antenna's suboptimal installation and numerous handovers.

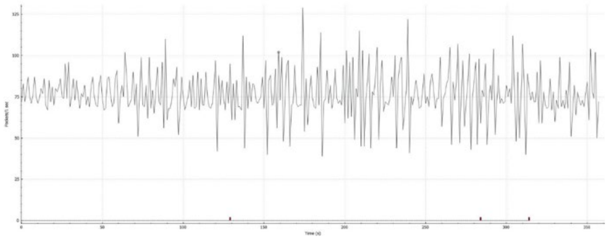

Figure 8. Packet transmission during the fourth flight with one SIM card.

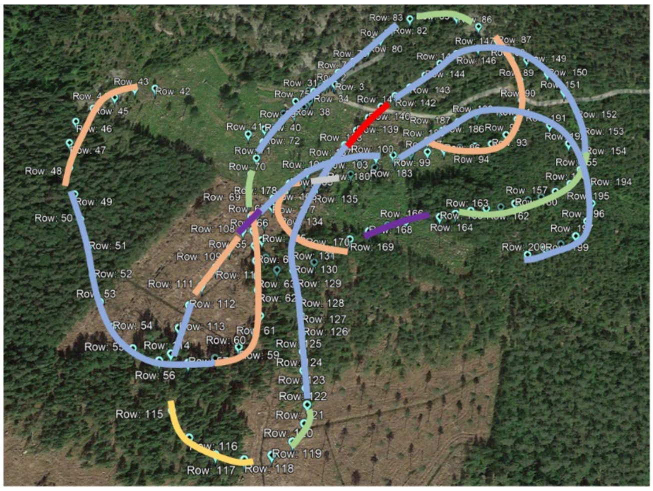

Figure 9. Flight trajectory, coloured with base station connections.

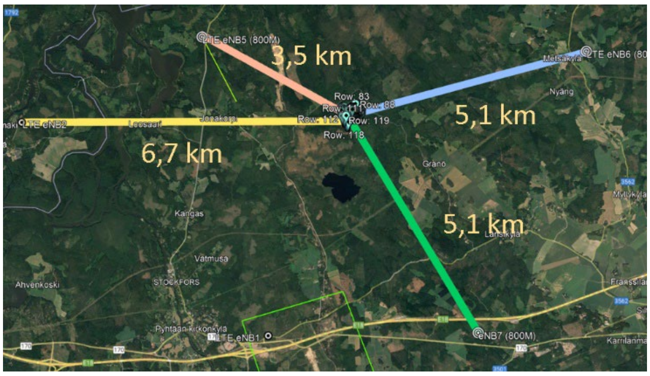

Figure 10. Base Station distances

V. DISCUSSION

To conclude, it was observed that in a strong LTE-field, the C2 link works without any problems even with a very standard LTE modem with external antennas. Thus, significant interference with terrestrial terminals is unlikely when a slow telemetry connection is used for essential and critical data transfer.

When the UAV takes off, RSRP rises after tens of meters, but no major changes were observed after this, particularly above 100 meters.

RSRQ did not decrease significantly with increasing altitude when the use of network resources was low. This was also because the measurement locations were reasonably far from the base stations.

Four kilobytes/s is sufficient for the critical information of the telemetry connection; thus, a 4G LTE connection offers an unnecessarily large capacity for critical data transfer. Despite this, when the network made a handover decision, the Huawei E7732 modem was always connected to the base station with the highest capacity (e.g. LTE 1800 MHz), even if the LTE 800 MHz or 3G system offers substantially better signal quality. As a result, the connection could be lost for several seconds.

In the case of the Halo OEM terminal the LTE 1800 MHz network connection was not used unnecessarily, and the traffic worked without interruptions also when the terminal was equipped with one SIM card. In the first test, the SIM card was limited to the use of only the 3G network, and in the second test with one SIM card, the terminal used the LTE 800 MHz network connection with better coverage than the LTE 1800 MHz network.

As a conclusion, it can be stated: that if the drone operator can ensure that even a weak LTE network coverage is available in the flight area from more than one operator and the LTE terminal supports several simultaneous connections, it is quite unlikely that the connection will be lost during the flight. If these conditions are met, the Civil Aviation Authorities should also begin to accept mobile phone network connections more widely in the implementation of the C2 link.

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