Verizon/FAA Memorandum of Agreement Cellular Technologies to Support UAS Activities Report

Program Parameters

Pursuant to a Memorandum of Agreement dated April 29, 2021 between Verizon and the Federal Aviation Administration (FAA) (referred to as "the MOA"), Verizon conducted four flight campaigns with the intent to measure the impact of the RF environment and performance of available cellular connectivity for command and control (C2) of uncrewed aircraft (UA) in flight. Between November 2020 and January 2022, Verizon completed 414 flights, totaling 332.3 hours, using three different makes and models (OEM) of fixed-wing UA at multiple locations in California, Florida, Missouri, Mississippi, Oregon, and Washington. Flights were conducted using Verizon LTE Bands 13, 4 and 2 in urban and rural areas, as defined by the Census Bureau. Operating altitudes ranged from 39 to 140 meters (128 to 459 feet) with an average operating altitude of 77 meters (252 feet). An automatic flight control mode was used 96.196% of the time with the remaining 3.804% in a semi-manual flight mode.

Limitations of the Airborne LTE Operations (ALO) Module

Certain characteristics, set up, and limitations of the ALO Module may have been factors in the outcome in the data produced pursuant to the MOA UAS campaigns and are therefore noted below:

Reference Signal Receive Power (RSRP)[1] and Reference Signal Receive Quality (RSRQ)[2] charts were not separated by band. Reported RSRP values may range from -44 to -140 dBm and reported RSRQ values may range from -3 to -19.5 dB as defined by 3GPP.

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[1] RSRP is the average received power per resource element across specified spectrum bands. Put basically, RSRP is a measure of signal strength.

[2] RSRQ is the ratio of RSRP to all downlink received power (i.e., from other cells or external interference, thermal noise, and traffic load). Also put in basic terms, RSRQ measures signal quality.

RSRP values recorded during execution of the MOA commonly ranged between -60 to -90 dBm. The highest concentration of RSRP values ranged between -70 to -80dBm. The lowest RSRP value reported was -140dBm. RSRQ values commonly ranged between -13 to -20 dB. The highest concentration of RSRQ values occurred between -15 to -17dB. The lowest RSRQ value reported was -20dB.

The Verizon ALO module limited uplink throughput to 4 Mbps to minimize the impact of interference to terrestrial users on the network.

The frequency bands used during these campaigns do not include bands with aeronautical restrictions, including Band 5.

Interference

Local Verizon Network Performance team members were notified of flight operations prior to and during the flight campaigns referenced in this report. The Network team members were instructed to provide reporting on any observed abnormalities, such as interference Key Performance Indicators (KPIs) in the area of flight operations. There were no reports of such abnormalities presented during the flight campaigns referenced in this report. There were no remote pilot in command (RPIC) reports of interruptions to the C2 link caused by interference.

General Disclaimer

In all campaigns included in this report, SINR or SNR was recorded but not analyzed. Signal to Interference plus Noise Ratio (SINR) and Signal to Noise Ratio (SNR) are not standardized 3GPP parameters and measurement and logging can vary between OEMs. In order to accurately present a comparison of different UA configurations, SINR and SNR are not analyzed.

For statistical reporting, not all logs were used. Only those logs corresponding to aircraft altitude greater than 5 meters (16 feet) are considered in order to filter out ground-based logs.

Total quantity of flight hours includes all logged time corresponding to records where barometric height is greater than 5 meters (16 feet).

Summary of Main Takeaways

1. Verizon's existing network is sufficient to support the cellular Command and Control (C2) mission within the tested altitudes. In order to accurately represent data, the concept of full connectivity is measured as Cellular C2 Link Connection (CLC).

1.1. Percentage of time with full CLC: This is defined as the amount of time the UA is connected to the cellular network for C2 as measured by successful heartbeat messages logged at the same frequency as modem parameters, divided by the total amount of time that the UA is in flight and using LTE for the C2 link.

Percentage of time with full CLC: 99.008% (out of 332.3 hours)

Campaign	Dates	Flights/Hours	CLC
1	NOV 2020 - MAY 2021	105 / 120	99.987%
2	AUG 2021 - AUG 2021	12 / 10.3	99.961%
3	OCT 2021 - DEC 2021	53 / 37	99.086%
4	DEC 2021 - JAN 2022	244 / 165	98.220%

2. Performing the cellular C2 mission on Verizon's wireless network connected drones on a network separate from traditional aviation spectrum. The UAs used spectrum Bands 13, 2, and 4, all of which are licensed to Verizon in the geographic areas in which the MOA flight campaigns were performed. In effect, Verizon's efforts demonstrated that it is possible to connect drones for C2 functions as part of an existing commercial wireless network, independent of current aviation frequencies. Of the three bands used in the testing, Band 13 was utilized most often followed by Bands 4 and 2 respectively.

3. Performing the cellular C2 mission on Verizon's cellular network does not affect ground users. It can be inferred that ground users are not impacted, since no adverse effects on the network KPIs were reported by Network team members during the test period. No adverse KPIs were noted on the serving network nodes.

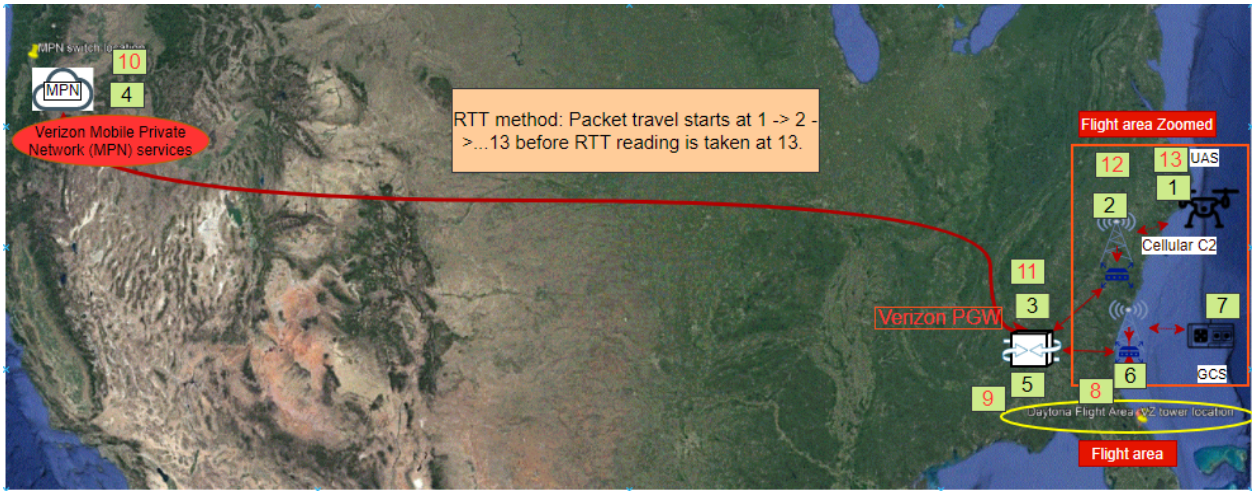
3.1. Cellular handover behavior. There were 75,935 combined handovers during the campaigns. In cellular network systems, a handover is defined as the process of transferring a data session from one cell to another cell. Handover logic may consider signal strength, channel utilization, channel capacity, cell density and other parameters when determining which channel to transfer the session. The objective of the handover logic is to prevent interruptions to the session that could result in termination of the connection. Due to the complex nature of handover trigger settings and cell selection algorithms, as well as the varying cell site design possibilities, it is not valid to compare the quantity of handovers per mile of flight between different locations or UAs. While handover failures may occur due to signal interference, cell availability and other causes, the user equipment (UE) is unable to record instances of unsuccessful handover attempts in the UAs operating on the network during these tests due to limitations of device logging capabilities.

4. Aircraft equipment manufacturers could benefit from optimizing RF antenna design for cellular C2 missions. Analysis of the collected data shows that in some cases there is a correlation between changes in UA roll, pitch and yaw, handovers between cells, and the loss of C2 link. It is suspected that a change in roll, pitch and yaw of the UA could result in simultaneous degradation of the serving cell signal and improvement of the neighbor signal strength, triggering a handover attempt. Frequent handovers, both inter- and intra- band, could have a detrimental impact on the LTE C2 link performance. UA design decisions, such as the location and orientation of the cellular modem antennas, could impact the frequency or severity of occurrences of loss of C2 link due to change in aircraft orientation relative to the serving and neighbor cells. Notably, the three UAs flown in the campaigns for this report have dissimilar antenna configurations, including different combinations of antenna make/model, RF characteristics, quantity of onboard antennas installed (such as main and diversity antennas) and antenna orientation relative to the body of the aircraft.

Explanation of Cellular C2 Network Traffic

The duration of C2 latency varied across all UA. Normal values ranged between 48-670 ms with an average C2 latency of 350 ms. C2 network architecture provides the communication from ground user to network (tower), to UA. Round trip latency is measured

from the UA, to the network nodes, and then back to the UA.[3] Regardless of location of flight, all C2 data traffic went through the Verizon core network site in Washington State.



[3] UA > Verizon Network (local P-GW > MPN-GW in PNW) > Control Station > Verizon Network (local P-GW > MPN-GW in PNW) > UA.

Lessons Learned

A. The typical ranges for existing network density, tower proximity and height, tower line-of-sight and antenna downtilt were sufficient to support the C2 missions within the altitudes tested.

B. Lost C2 / return to land (RTL) occurrences were analyzed in four geographic areas with varying RF conditions. There appears to be correlation between changes in UA roll, pitch and yaw, handovers and the loss of C2 link. Based on the analysis of data it appears that the major contributing factor to the reported occurrence of RTL was RF receptivity degraded by specific UA movement.

C. RSRQ observed by UA while flying appears to degrade as the flight altitude increases.

D. At higher altitudes and if the UA encounters weaker RSRP (less than -80dBm), there is a 20 percent chance that the value of RSRQ degrades to less than -18dB. That is, when signal strength degrades to mid-cell level coverage, there is a 20 percent chance that signal quality degrades to cell edge level coverage.

E. All of the challenges encountered can be mitigated through practical UA and network optimization techniques.