4G Network for Air-Ground Data Transmission: A Drone based Experiment

Liqi Chen, Zheng Huang, Zhenbang Liu, and Dawei Liu
Xi'an Jiaotong-Liverpool University, Suzhou, China
{liqi.chen15, zheng.huang15, zhenbang.liu15}@student.xjtlu.edu.cn, dawei.liu@xjtlu.edu.cn

***Abstract*—Today's commercially available drones commonly make use of the 2.4 GHz channel for remote communication. A drawback is the short communication range. To remedy the drawback, we explore the use of 4G network as an alternative. A drone-based experiment platform is developed to evaluate 4G network for air-ground data transmission. Our field experiment shows that 4G network is capable of supporting low-altitude air-ground communication with good connectivity and low packet loss although the packet loss would increase substantially when the signal strength decreases.**

***Index Terms*—Cellular Network, Drone, Packet Loss Rate, TCP, 4G, 5G, IoT**

I. Introduction

The deployment of reliable air-ground communication link would be an essential element for future drone technology. Today's civilian drones commonly use the point-to-point 2.4GHz channel for air-ground communication [1]. A significant drawback is the short link range due to limited radio coverage of remote controllers. Under such circumstances, the location of the controller would significantly confine the activity of drone. To exploit drone's tremendous potential, cellular networks are regarded as an excellent candidate to construct the air-ground data bridge. By cyberizing drones, cellular networks could open the barrier of long-distance air-ground communication, allowing controller controlling drones anywhere with the internet.

Cellular networks like fourth-generation wireless (4G) network was originally designed for ground users, their performance on air-ground communication was rarely discussed. Some previous studies like [2] focuses on drone-cell radio propagation, suggesting a path-loss model to predict signal strength. However, few works on actual air-ground data transmission performance were found. Different from those authors only concerning about radio propagation, we focus on packet loss, which is considered as an essential factor to influence the data transmission performance.

In this paper, air-ground data transmission performance of 4G network was explored by measuring and analyzing the air-ground packet loss rate (PLR) in 4G network over Transmission Control Protocol (TCP). Our research is based on extensive field experiments in a typical urban environment. In our research, the air-ground PLR was found to have a strong negative dependency on the 4G signal strength in term of the reference signal received power (RSRP). The relationship between the RSRP and the PLR is quantitatively analyzed.

II. System Setup

In consideration of economy and drone's expandability, we chose to build a quad-rotor drone from scratch with an open-source autopilot platform ArduPilot. This autopilot is stable and robust, capable of controlling the drone fly fully-automatically over preset airlines. Meanwhile, a 4G-only mobile phone was carried by the drone as shown in Fig. 1.

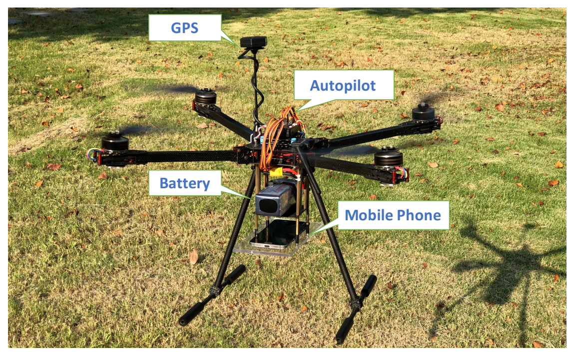


Fig. 1. Overview of Drone

An Android application is specially developed and run on the mobile phone for measuring latitudes, longitudes, heights of the drone and the RSRP of 4G network. The measured data are packed and sent in a frequency of 200Hz to our server with TCP socket. A Python script is running in the server, storing the received data in the MongoDB database. Besides, the mobile phone is saving the data in local storage simultaneously when sending the data. As a result, we can obtain the PLR by comparing the local-saved data and the data collected by our server.

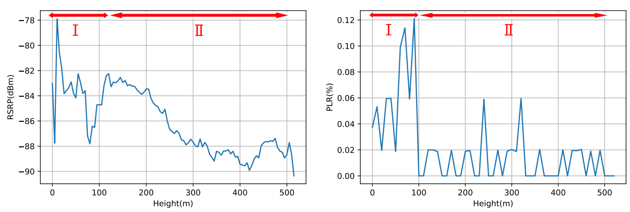
We have tested the stability of the measuring system. The drone was hovering at an altitude of 2 meters for 15 minutes and repeated for three times. There were only 7 lost over 557,693 packets, indicating that the measuring system was stable and would not cause packet loss in system level.

The measurements were carried out in Xi'an Jiaotong-Liverpool University campus. The campus could be considered as a typical urban environment in Suzhou, China. The location of 4G base station is not considered due to the extremely high density of the base station in the urban environment. During experiments, we let the drone fly fully-automatically through preset airlines at vertical and horizontal directions separately to explore the behavior of the PLR and RSRP in three-dimensional space.

III. Experiments and Analysis

A. Vertical Direction

To begin with, we have explored the behavior of the RSRP and PLR in the vertical direction. In this experiment, 3 times of government-approved high-altitude flight were done with drone keeping at a fixed point and slowly rising to 500m. We calculated the average RSRP and PLR with splitting the height to 50 intervals, the result is shown in Fig. 2 with two stages labeled. Irregular oscillation of both the RSRP and PLR is observed in stage I because of the signal interference near the ground. Although the RSRP tends to decay in stage II due to increments in the three-dimensional drone-cell distance, the PLR does not change much. Furthermore, the decaying of RSRP is only about 2dBm per 100m on average. Therefore, It is possible to infer that the PLR is insensitive to the height because the RSRP would not change significantly in the vertical direction.

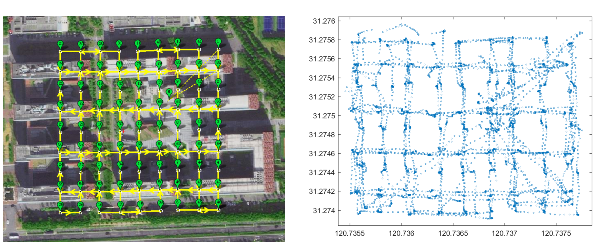


(a) Height-RSRP (b) Height-PLR

Fig. 2. RSRP and PLR in Vertical Direction

B. Horizontal Direction

We also have done several airline flights to investigate the effect of horizontal displacement on the RSRP and PLR. Fig. 3 shows both preset airline and actual flight path in this experiment. The coverage of preset airline is a square with a side length of 200m, and the drone would hover for 10s every 25m along the airline. The advantage of this S-shaped path is that at a particular height, this coverage could be easily divided into 9×9 grids, then we could calculate average RSRP and PLR in each grid and analyze the correlation in between.



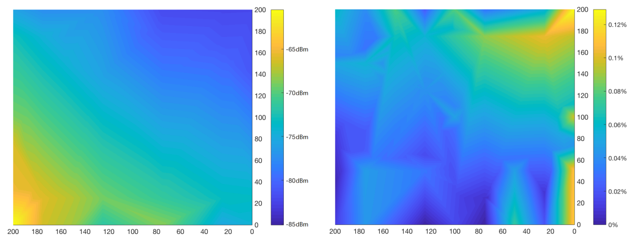
(c) Preset Airline (d) Measured Flight Path

Fig. 3. Preset Airline versus Actual Flight Path

$$\overline{PLR} = \frac{N_s - N_r}{N_s}$$

The equation of the packet loss rate is shown above, where N_s represents the number of packets sent by the mobile phone and N_r denotes the number of packets received by the server.

In the horizontal direction, the RSRP, as well as the PLR, was significantly changing from point to point, and a close relationship between them was found. We took several airline flights at several altitudes under 120m (legal height limitation). However, different altitudes have very similar outcomes which can be explained by the vertical experiment. To demonstrate, the airline experiment at 60m is chosen as an example, and we plot the distributions of the RSRP and PLR as shown in Fig. 4. From this plot, a negative relationship can be observed, as the area with a high RSRP tends to have a low PLR.



(e) Mean RSRP (f) Mean PLR

Fig. 4. RSRP and PLR Distribution at 60m

The PLR measured keeps at a shallow level with a maximum of 0.12%, and it is strongly dependent on RSRP with correlation coefficient calculated to be approximately -0.5. A clearer relationship can be observed in Fig. 5 that the PLR would substantially decrease as the signal strength increases.

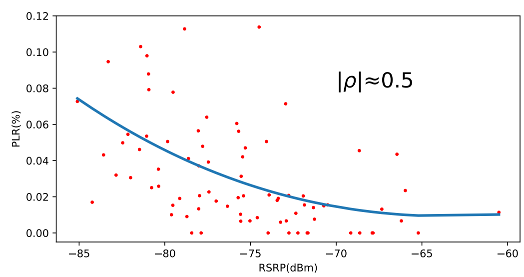


Fig. 5. Polynomial Fit

IV. Conclusion

This paper provided a pioneering observation of air-ground data transmission performance in 4G network by exploring the packet loss rate (PLR). The results show that the PLR has no significant change in vertical direction, but changes in the horizontal direction and dependent on the reference signal received power (RSRP). Moreover, the PLR always keep at a low level with a maximum value of 0.12%, showing that the 4G network is an excellent candidate for low-altitude air-ground data transmission. For the future use of cellular network based drones, our work could be a valuable reference.

References

[1] M.A.Chung and C.F.Yang, "Built-in antenna design for 2.4 ghz ism band and gps operations in a wrist-worn wireless communication device," *IET Microwaves, Antennas Propagation*, vol. 10, no. 12, pp. 1285–1291, 2016.

[2] A. Al-Hourani and K. Gomez, "Modeling cellular-to-uav path-loss for suburban environments," *IEEE Wireless Communications Letters*, vol. 7, no. 1, pp. 82–85, Feb 2018.