

# Performance Assessment of Off-the-Shelf mmWave Radios for Drone Communications

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**Abstract**—This paper presents experiments to assess and understand the feasibility of millimeter-wave (mmWave) radios for aerial links at low altitude, namely drone communications. In this preliminary study, a Commercial Off-The-Shelf (COTS) mmWave radio is attached to a DJI Matrice 600 Pro drone. The measurement campaign reveals that while the technology is promising, the range is extremely limited, i.e., approximately 30m. Our analysis shows that the poor range is likely due to low-directionality of today’s COTS devices as well as poor rate adaptation in mobile environments. More antennas at both the transmitter and the receiver, along with better 3D beamforming, will be essential to boosting the communication range and thus making this a viable technology for use cases such as high definition real-time monitoring in disaster response scenarios or rapid deployment of multi-Gbps aerial links to expand connectivity in underserved areas.

**Index Terms**—Drone communications, 60GHz Networks, 802.11ad, millimeter-wave.

## I. INTRODUCTION

While there has been considerable work in the millimeter-wave (mmWave) bands for cellular and wireless LAN applications [1], [2], there is now a growing interest in the use of these frequencies for aerial to ground communication. mmWave links to drones can, for example, be valuable for disaster recovery as well as environmental 3D and other high-data rate mapping uses [3]–[5].

The use of the mmWave for aerial communication presents two key technical challenges: (1) **high isotropic pathloss**, which is compensated by collectively using multiple antenna elements to achieve longer directional ranges, also known as *beamforming*, and (2) **susceptibility to blockage**, which is addressed by implementing sophisticated electronical steering techniques, namely *beamtracking*. While directionality and blockage are also issues in cellular and LAN applications [6], the problems are more pronounced in the aerial case due to the high motion, large angular area to cover and the power and payload limitations on the drone.

In this paper, we conduct a series of experiments to obtain some early insights into the feasibility of ground-to-air communication based on Commercial Off-The-Shelf (COTS) devices. More specifically, we perform measurements with two IEEE 802.11ad laptops, with one laptop on the ground and one mounted on a drone. We create a TCP connection between



Fig. 1. Testbed: ground station (client) with the display lid at 45° inclination, and a flying station (AP) attached to the DJI MATRICE 600 PRO drone.

the devices and analyze the achievable bitrate, as well as the chosen beampattern and Modulation Coding Scheme (MCS). To the best of our knowledge, this is the first practical measurement study with drones using COTS mmWave devices.

Our interest in COTS devices is that they can provide low-cost, mass produced radio hardware for consumer drones. In addition, due to the production volumes, the devices benefit from much smaller form factors and payload. Private companies have deployed their own trials such as Google’s Loon (Stratospheric balloons to expand the Internet connectivity [7]), or Facebook’s Aquila (a high altitude platform station with the same goal [8]). However, these initiatives have used custom, special purpose hardware.

## II. EQUIPMENT

The following equipment has been used for our mmWave aerial measurement campaign:

- **DJI MATRICE 600 PRO:** This drone is used to fly the COTS mmWave radios. It provides all the GPS and IMU data of the flights for control of the experimental setup.
- **Acer Travelmate P446-M:** To create the 60GHz mmWave link, we use two such laptops, which are equipped with the client-version of the Qualcomm QCA9008-TBD1 chipset, which is connected to a 32 element phased-antenna array. Furthermore, we use the open source wil6210 wireless driver [9], which provides access to lower layer parameters of the chipset.
- **Server:** We use a DELL LATITUDE E7440 laptop as an auxiliary server to control the experiments and process the data. First, we start a 2.4 GHz hotspot so the mmWave

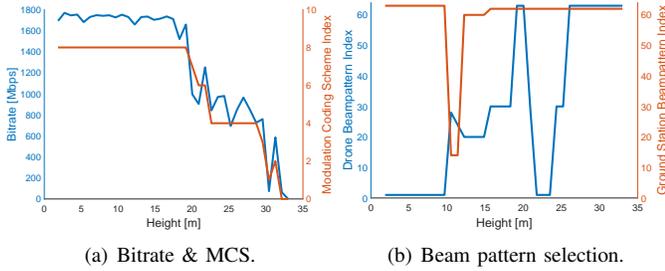


Fig. 2. Vertical study analysis.

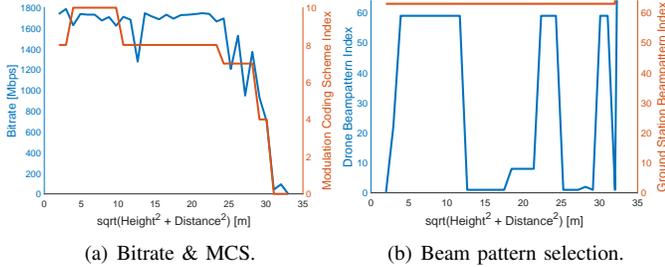


Fig. 3. 45° elevation study analysis.

laptops can connect and have every device in a common network. This way we can access them through an SSH connection to automate the measurement process and gather the required data in a synchronized way.

The aerial node is set to Access Point (AP) mode and the ground station to client mode. The transmission is downlink, where the aerial node sends TCP traffic to the ground node. In order to configure the mode in each laptop we use the *wpa\_supplicant* service, and to generate the TCP traffic we use *iperf*. In our analysis, we track the throughput of the link, as well as the MCS and the selected beam pattern indexes.

The laptop on the ground was left at 45 degrees inclination to maximize the communication range of the antenna array into the field. The laptop mounted on the drone was left closed, with the antenna array pointing downwards, parallel to the ground, in order to maximize the coverage area. Figure 1 shows how the equipment was placed.

### III. CHARACTERIZATION OF THE MOBILE LINK

#### A. Testbed Setup

To characterize the drone-to-ground communication and see what link ranges can be achieved with mmWave COTS radios, we carry out the following measurement campaigns:

- **Vertical:** In this test, we study the vertical limit of a mmWave aerial link flying directly over a ground AP.
- **45° elevation:** In our setup, to expand the communication range, the aerial relay should be placed at a 45° elevation angle with respect to the ground station. This 45° elevation angle represents the maximum steering angle from the flying station, corresponding to the 90° cone that a phased antenna array can cover with the most effective beampatterns, as it is placed parallel to the ground.

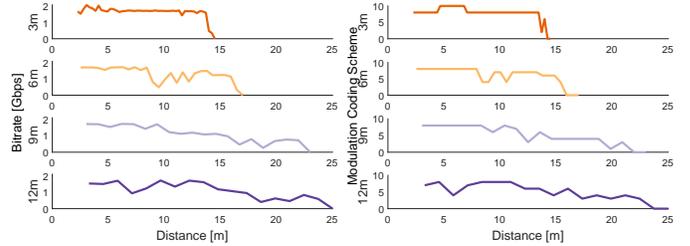


Fig. 4. 3D distance study.

- **3D distance:** We measure the signal quality against the effective 3D distance for a horizontal flight path at vertical heights of 3, 6, 9 and 12 meters.
- **Wind:** We emulate wind by displacing the drone for small distances in different directions at different speeds. For the first three scenarios, the drone is flown with a constant speed of 3 meters per second until the link breaks.

#### B. Results

The results from the vertical study are reported in Figure 2. We observe that the maximum link height is around 31 m. For the first 20 m, the communication throughput is mostly stable with rates of 1700 Mbps. Beyond this distance, the bitrate decreases until reaching zero at 33 m vertical distance. As the traffic is downlink, it can be seen how the drone varies from different beam patterns more often, while the ground station, which only needs to transmit acknowledgement frames, only changes its beam pattern three times. As the acknowledgement transmission uses a lower MCS than the data transmission, lower Signal-to-Noise Ratio (SNR) values are needed, making the beampatterns to be valid for longer times.

The results of the 45° elevation study are depicted in Figure 3. The maximum link distance achieved for this scenario is also 31 m. The communication rate is stable up to the distance of 25 m, where the utilized MCS index is 8, going up to 10 for the distances of 4 to 10 m. When the drone flies beyond 25 m, the rate and the MCS index go down rather abruptly. The drone performs several beam pattern changes during the measurement even though the relative angle among both stations is fixed, oscillating between two main patterns due to a poor beam pattern selection mechanism and slight misalignments during the drone trajectory. In contrast, the ground station does not change its beam pattern.

Results from the 3D distance study are reported in Figures 4 and 5. As expected, the drone achieves longer link distances when it flies higher, as it can serve wider areas with the use of the same beam patterns, due to the directional behavior of the antenna array, which is placed horizontally. Additionally, it can be seen that for higher drone positions, the link rate varies more, as the link quality decreases. The maximum link distances depicted in these tests are equal to 14, 16.5, 22 and 24 m for heights equal to 3, 6, 9 and 12 m, respectively. We note that the ground station uses a set of very few beam patterns for all heights, while the beam configuration on the drone varies a lot. Again we conjecture that these beam pattern

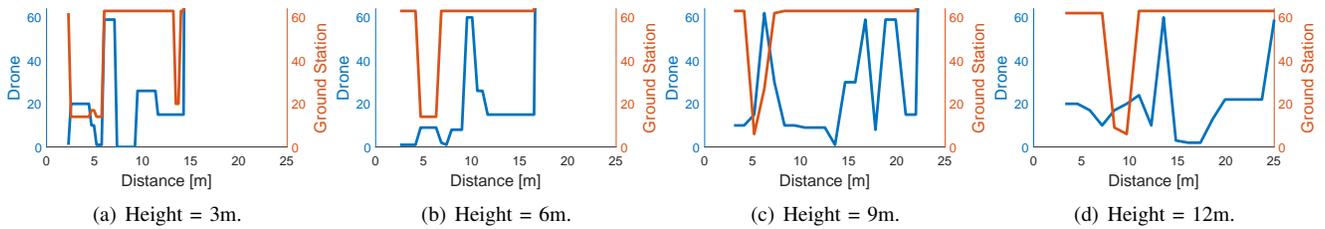


Fig. 5. 3D distance study analysis. Beam pattern selection.

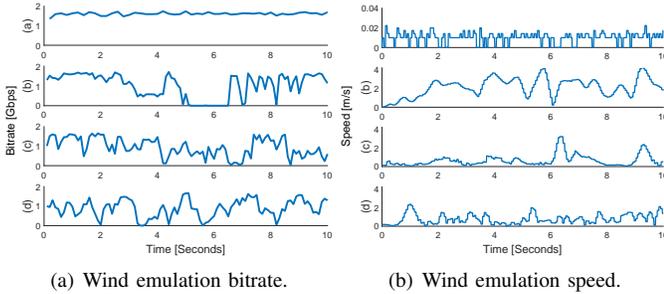


Fig. 6. Wind emulation.

variations are due to slight drone misalignments together with a sub-optimal beam pattern selection mechanism.

As the mmWave radios that we are using for this evaluation are regular laptops, their codebook is not optimized for 3D beamsteering or large link distances. Better codebooks would significantly enlarge the communication range and we would see how for different angles the stations would choose different beampatterns, differently to our measurements, where stations jump between several beampatterns for non-related angles.

Figure 6 shows how in the wind emulation measurements the measured bitrate varies with the drone speed. First, in subplot (a), we provide an example of standard wind characterization where the drone is flying in a static point. With normal wind conditions, the drone is shaking with an average speed of 0.01 meters per second. With this steadiness, the link is able to provide a constant flow of data with small variability: an average bitrate of 1600 Mbps and standard deviation of 70 Mbps is measured in that specific location. Subplots (b), (c) and (d) show three different examples of high wind emulation, where we shake the drone with average speeds of 1.75, 0.81, and 0.50 meters per second, respectively, having peak movements up to 4.15, 3.19 and 2.34 meters per second. We determine the effect of the vibrations on the beam misalignment and the resulting rate degradation. Nevertheless, even though the standard deviation is high (595, 467 and 443 Mbps) for each of the cases, the system still achieves a good average throughput of 1000, 933 and 884 Mbps, respectively. On average, the wind emulation reduces the throughput of the link by 40%, which means that the link is still capable of transmitting high speed data despite its high variability.

#### IV. CONCLUSIONS

In this paper, we show the performance of mmWave drone communications with IEEE 802.11ad COTS radios. The resulting links achieve the multi-Gbps rates typical for mmWave

bands, but the communication range is limited, primarily due to poor beamforming codebooks (not designed for such three-dimensional communication scenarios), the inexpensive design of the COTS radios, and a comparatively low number of antenna elements. We carried out measurements at different distances to determine the maximum range that can be achieved with a mmWave aerial link. We observed that these radios can be pushed to a vertical distance of 31 meters and to a 3D distance of 24 meters when the mobile mmWave link is moving on the horizontal plane at a height of 12 meters.

We have also shown how these links behave in windy scenarios. While the data rate is still sufficient for many use cases, it decreases by up to 40% and the link experiences high throughput variability which would cause large jitter to the users. This variance may jeopardize specific use cases such as real-time high resolution video streaming, but it would still be useful for less latency sensitive applications such as providing Internet access or for file sharing.

#### ACKS

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#### REFERENCES

- [1] T. Rappaport *et al.*, "Millimeter wave mobile communications for 5g cellular: It will work!" *IEEE access*, vol. 1, pp. 335–349, 2013.
- [2] S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter-wave cellular wireless networks: Potentials and challenges," *Proceedings of the IEEE*, vol. 102, no. 3, pp. 366–385, 2014.
- [3] M. Mezzavilla *et al.*, "Public safety communications above 6 ghz: Challenges and opportunities," *IEEE Access*, vol. 6, pp. 316–329, 2018.
- [4] E. Arribas, V. Mancuso, and V. Cholvi, "Fair cellular throughput optimization with the aid of coordinated drones," *Proc. MiSARN 2019*.
- [5] I. Guvenc *et al.*, "Wireless communications, networking, and positioning with unmanned aerial vehicles [guest editorial]," *IEEE Communications Magazine*, vol. 54, no. 5, pp. 24–25, 2016.
- [6] G. Bielsa *et al.*, "60 GHz Networking: Mobility, Beamforming, and Frame Level Operation From Theory to Practice," *IEEE Transactions on Mobile Computing*, 2018.
- [7] G. X. Company. Loon: internet baloon. [Online]. Available: <https://loon.co/>
- [8] Facebook. Aquila: Whats next for high-altitude connectivity? [Online]. Available: <https://code.fb.com/connectivity/aquila-what-s-next-for-high-altitude-connectivity/>
- [9] Qualcomm Atheros. (2016). [Online]. Available: <https://wireless.wiki.kernel.org/en/users/drivers/wil6210>