Small UAV Radiocommunication Channel Characterization

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***Abstract*— Small Unmanned Aerial Vehicles (UAV) are finding different applications as platforms to carry observation payloads. The need to establish reliable high data rate channels requires to characterize the radiocommunication channel between the UAV and the ground station. In this communication an experimental set-up and some results for the characterization of a radio channel at 5.8 GHz are presented.**

I. INTRODUCTION

Small light weight UAV's (Unmanned Aircraft Vehicles) have recently proved to be a useful platform to carry remote sensing devices such as radiometers and Synthetic Aperture Radars [1][2][3]. These remote sensing applications require to have a reliable high capacity radiocommunication downlink to transmit the high data flow from the UAV to the ground station. The alternative to store the data on-board increases the weight of the payload, it is not so reliable, it may limit the observation time and it does not allow real-time data processing.

On the other hand, the radio channel is subject to deep fading variations due to the small grazing angle between transmitter and receiver that causes strong multipath interference. Also when the UAV is manoeuvring the antenna orientation changes and it can even be occluded by the UAV structure. In this case deep signal losses may also occur. Since the last decade, multiantenna wireless communications systems have gained a strong interest in both the academic and industrial sectors. Also known in the literature as multiple-input multiple-output (MIMO) transmitter and/or receiver to increase the transmission rate and the strength of received signal, as compared with traditional single-input single-output systems, which use one transmit antenna and one receive antenna. Most importantly, these gains come with no additional increase in bandwidth or transmission power, which are scarce resources; rather, they come at cost of system complexity [4] [5][6].

The use of the unlicensed 2.45 GHz and 5.8 GHz bands offers to possibility to place multiple antenna systems spaced a few wavelength even in small remote controlled airplanes. The optimum configuration of antenna placement, radiation pattern and polarization must be experimentally assessed in order to optimize the channel capacity.

II. MEASUREMENT SET-UP

In order to characterize the influence of the antenna type and location on a small UAV, a 2 by 2 antenna system operating at the unlicensed 5.8 GHz band has been designed. The main characteristics of the system are their lightweight and simplicity to perform field measurements. Still complete channel matrix acquisitions can be made.

The system is divided into the UAV payload and the ground segment. The UAV payload includes two transmitters operating at slightly different frequencies. The frequency difference is 100 KHz with allows to identify the pilot signal transmitted by each antenna, but both pilot frequencies are close enough to assume that the channel is frequency invariant. The payload includes also a GPS receiver for synchronization purposes and for retrieval of the flight path. Figure 1 shows a block diagram of the system.

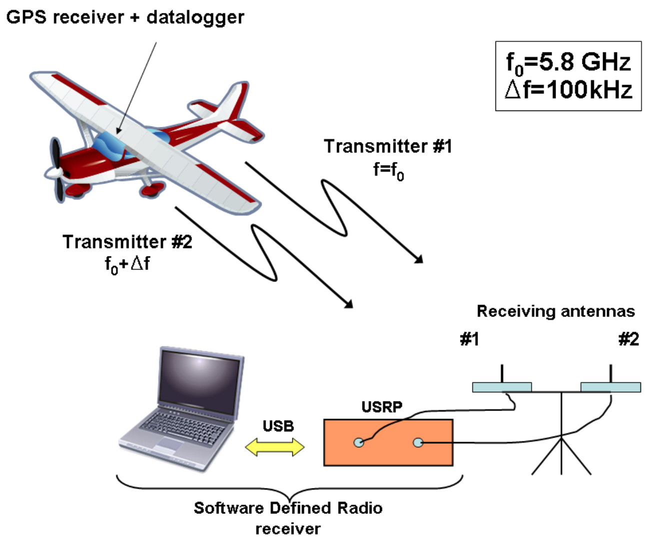

Fig. 1 Block diagram of the measurement system.

In Fig. 2 a picture of the small UAV carrying the payload is shown. It is an electrically driven RC airplane able to carry a payload of 1.5 kg. It allows testing different positions of the antennas on the plane fuselage and the range is 2 km and the maximum flying altitude 500 m.

III. RESULTS

A. 2 x 1 Measurement campaign

In order to test the system and validate its performance a simplified test campaign with one transmitter antenna at the UAV and two receiver antennas on the ground station was performed. In addition to the system validation, this measurement campaign had also as objective to assess the performance of the link with different antennas on the ground segment.

Specifically measurements were done using 2 monopoles as an example of non directive antennas and a combination of a monopole and horn antenna to assess the effect of a directive antenna on the received signal. The antenna spacing on the ground segment was 60 cm, that is more than 10 wavelengths apart.

Fig. 2 Small UAV carrying the payload.

In fig. 3 it is shown the UAV flight path during the measurements. The horizontal distance is the distance between the UAV and the receiving antennas measured on a flat earth. Height and distance were both determined with the on board GPS. Since the interest was to study the effect of low grazing angles in the propagation, the height was limited to 150 m and the maximum distance to 500 m.

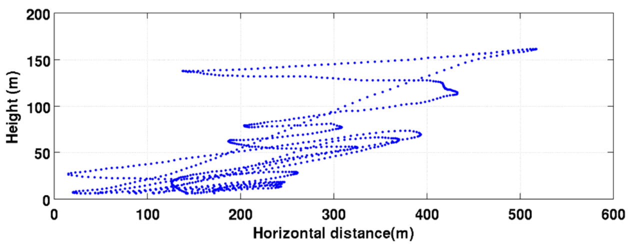

Fig. 3 Flight path by the UAV.

Fig. 4 shows the results of the received power as a function of the distance. For comparison purposes the case in which a directive antenna and a monopole are used are shown. Also for reference purposes the free-space expected received power is also shown. The results show, as expected, that the received power by the directive antenna is larger than with the monopole. Slow signal fluctuations can be attributed to the UAV attitude changes, while fast signal changes can be attributed to multipath interference of direct and reflected signals.

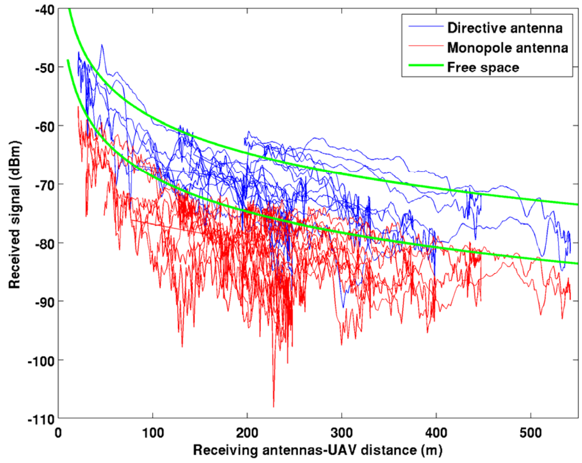

Fig. 4 Received signal by a monopole and a directive antenna.

Figure 5 (top) shows the normalized received signal by the monopole and the directive antenna when the UAV was taking-off, the UAV trajectory is shown in fig. 5 (bottom). The normalization has been done subtracting the free-space propagation losses and the antenna directivities. It is shown that as the UAV is gaining altitude (yellow path) the signal received by the monopole exhibits a +/- 3 dB ripple, while the signal received by the directive antenna is almost constant. This result is consistent with the previous ones and it is explained by the interference of the direct and ground reflected signals on the monopole. On the other hand, the directive antenna is able to reject the reflected signal giving a much more constant received level.

When the UAV is turning around (green path), the signal received by both antennas presents strong and similar fluctuations. This is due to the changes of orientation of the antenna placed on the UAV. The antenna was in this case a monopole placed at the bottom of the fuselage. It is clear that a thorough study of the placement of multiple antenna systems on the UAV fuselage can minimize the fading on the received signal when the UAV is manoeuvring.

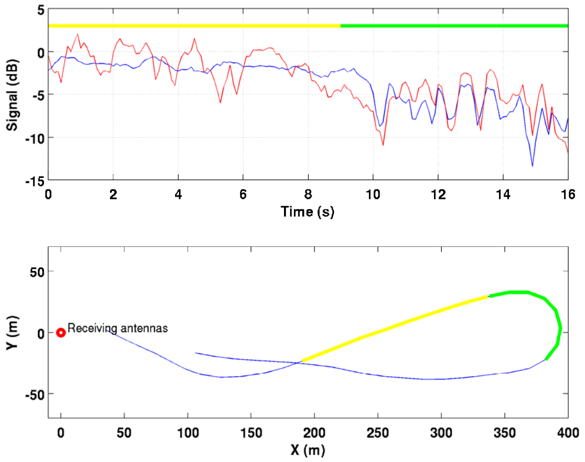

Fig. 5 Normalized received signal by a monopole (red) and a directive antenna (blue) (top) on a given trajectory (bottom).

Finally the effect of combining the two received signals has been studied. In this case the two receiving antennas are monopoles. Fig. 6 shows the cumulative probability distribution function (CDF) of the normalized received power by each antenna. The normalization has been done subtracting the free space propagation losses and adjusting the received power to 0 dB for a 50% cumulative probability. Also the CDF after applying and Maximum Selection Combining (MSC) scheme is shown. In this case a moderate diversity gain of approximately 1 dB is observed.

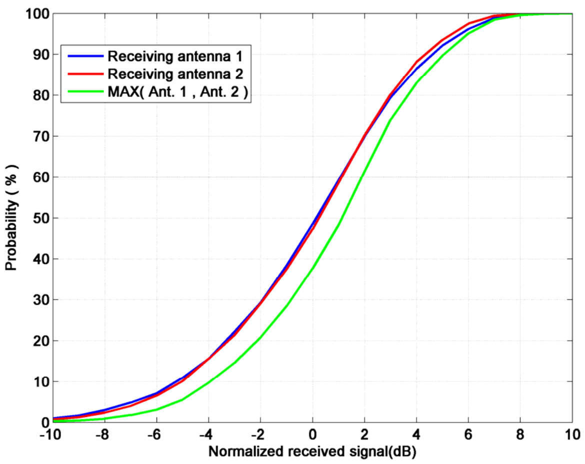

Fig. 6 Cumulative probability distribution function of the normalized received signal by two monopoles and after applying maximum selection combining.

B. *2x2 Measurement campaign*

A second measurement campaign was performed with a 2x2 antenna system. In this case two monopole antennas were placed one at the top and the other at the bottom of the UAV fuselage. The ground segment receiving antennas were two monopoles spaced 60 cm.

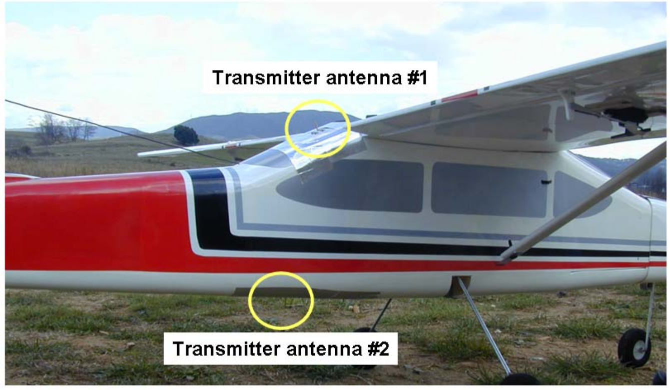

Fig. 7 Placement of the antennas on the UAV. The top and bottom antenna are circled..

Fig. 8 shows the flight path for this measurement campaign. The maximum distance was 425 m and the maximum height 125 m.

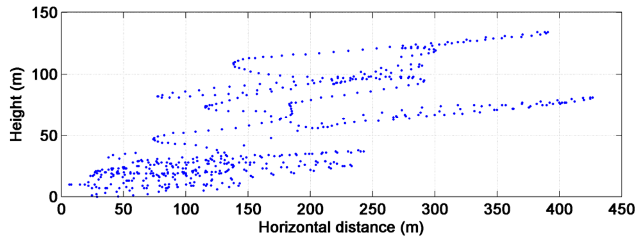

Fig. 8 Flight path for the 2x2 measurements.

Fig. 9 and 10 show the received power by each of the receiving antennas. Specifically fig. 9 shows the received power when the transmitter is the top antenna (T1) and fig. 10 shows the received power when the transmitter is the bottom antenna (T2). For reference purposes the expected received power in free space is also shown. In agreement with the results shown in fig. 4, the received signal shows the effects of fast fading due to the use of non directive antennas.

In order to study the statistical behaviour of the received signal the normalized CDF for the different combinations of the transmitter and receiver antennas are shown in fig. 11. In this case the normalization consists on subtracting the free-space losses. In agreement with the results shown in fig. 6 it is seen that given one transmitter antenna the CDF is the same for the two receiving antennas. On the other hand, the bottom antenna (T2) causes a larger dispersion the received power, result that is consistent with the plots of fig. 9 and 10.

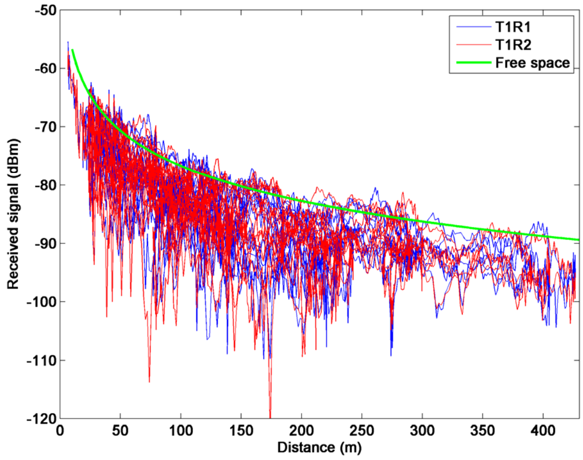

Fig. 9. Received signal. Transmitter is the top antenna.

To study the potential advantages of using a diversity system based on multiple antennas on the UAV and ground segment, the CDF of using Maximum Selection Combining (MSC) scheme are also shown in fig. 11. In one hand the CDF of applying an MSC considering the case of the top antenna in the UAV (T1) and two receiver antennas is analogous to the result of fig. 6, and a consistent result of approximately 1dB diversity gain is obtained. It is relevant to notice the repeatability of these results. It is also shown the case of the MSC applied to the case of considering the two transmitting antennas in the UAV (T1 and T2) and one receiving antenna on the ground segment. In this case, as anticipated by the results of fig. 5, a 2 dB diversity gain is obtained. In this way the hypothesis that two antennas on the UAV provide a more robust radio link during the UAV manoeuvring is confirmed. Finally an almost 4 dB diversity gain is obtained when the MSC is applied to the four possible measurements. All diversity gains are measured at a 50% probability.

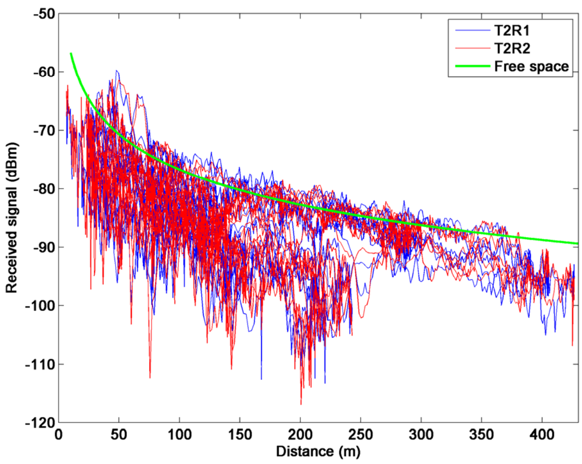

Fig. 10. Received signal. Transmitter is the bottom antenna.

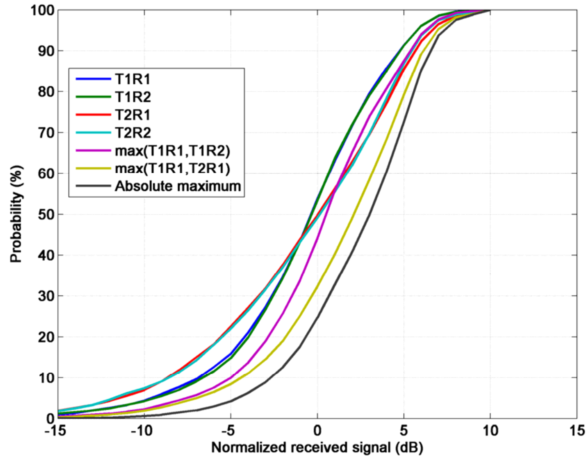

Fig. 11. Cumulative Distribution Function of the 2x2 received signal.

As a final example of the benefits of using two antennas on the UAV, in fig. 12 the normalized received power for a given flight path is shown. Once again it is clear that having two antennas on ground adds very little redundancy, but the two antennas on the UAV provide a way to compensate for signal fading due to the UAV manoeuvring.

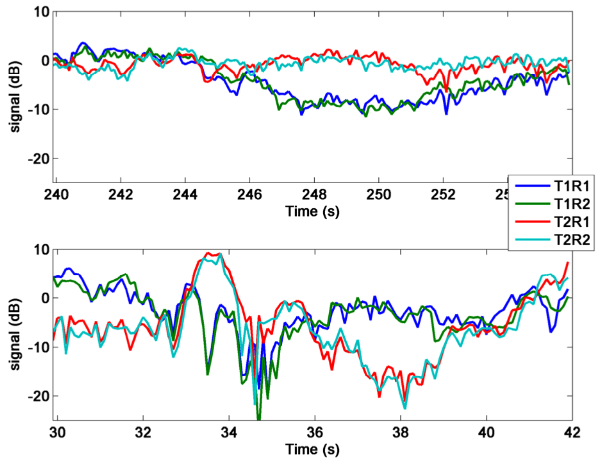

Fig. 12.Example of received signal for a given flight path..

IV. Conclusions

A simple light weight experimental set-up has been developed and tested to assess MIMO wireless channels between an UAV and a ground segment. The system has been proven flexible enough to test different antenna configurations either on the UAV or the ground segment. The main conclusions are that the effect of multipath interference can be alleviated by the use of directive antennas on the ground, and that multiple antennas on the UAV provide a more robust radio channel in front of the antenna changes of orientation when the UAV is maneuvering. Future studies will concentrate on the optimum placement of the antennas on the UAV.

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