Radio Propagation Models for UAVs: what is missing?

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ABSTRACT

In this work, we discuss the two-ray radio propagation model when an UAV acts as a mobile node belonging to a ground wireless sensor network. Currently, UAVs are attracting attention in the market and in the research field, thus more accurate radio propagation models are needed to properly estimate the effectiveness and the feasibility of the use of UAVs in several contexts. The main contribution of this work is in highlighting how the classical two-ray path loss model must be tuned because of aerial mobility.

Keywords

UAV, WSN, ZigBee, two-ray path loss

1. INTRODUCTION

The use of UAVs (Unmanned Aerial Vehicles) is increasing in industry and research fields. They are the perfect candidates for a very large number of scenarios, thanks to their versatility, joint to the chance of easily reaching even impervious areas. Yet, planning a flight path in a full automatic manner makes UAVs well suited for several scenarios. Currently, UAVs are relatively cheap, making easier to buy or build a drone and to use it for several different tasks. Hence, their employment in the WSN (Wireless Sensor Network) context is a promising and fascinating field. An UAV can act as a mobile node in a WSN, when equipped with a wireless communication system, allowing it to collect data as a sink node, communicate with and control the other nodes.

2. REFERENCE MODELS

In [1], an UAV acts as a sink node, collecting data from ground sensors. Different communication technologies are discussed, where each technology has its distinguishing features; the attention is focused on the power consumption to increase the lifetime of the sensors and no attention is paid with regards to communication issues. Differently, this work focuses on specific wireless communication issues with an UAV: it starts from a simple propagation model, unable to fully characterize the performance figures of a communication link from the ground to a flying object. In fact, propagation models in the literature mainly refer to the case of static source-destination pair; only a few works take into account speed [2], antennas orientation [3], aerial RSSI (Received Signal Strength Indicator) measurements [4], but no one has been identified proposing a propagation model that takes into account, at the same time, the effects of speed, height variation, pitch and roll angles variation. This modeling or, at least, the identification of the correction factors is urgent, given the rapid spread of UAVs. Our analysis deepens specific characteristics of the UAV flight, not identified in other works, and shows that they cannot be considered negligible with respect to the traditional radio propagation models. The two-ray path loss model is assumed as a reference, since it takes into account only the ground effect, i.e., the reflected ray due to the presence of the ground, as in our open field testbed scenario. Such a model can be approximated by the *Log Distance* path loss model, $PL \approx 40\log(d) - 10\log(Gh_t^2h_r^2)$, being P_t and P_r the power available at transmitting and receiving antennas, respectively; h_t and h_r the heights of the antennas; G the gain of the two antennas; λ the wavelength; d the distance between transmitter and receiver antenna that must be greater than the critical distance $d_c \approx \frac{4h_th_r}{\lambda}$, where the power drops proportional to inverse fourth power of d. Yet, the angle ϕ between the two polarized antennas involved in the communication introduces the Polarization Loss Factor $PLF = \cos^2\phi$ and ranges from a maximum value, when the antennas have the same polarization ($PLF = 1$), to a value close to zero, when the antennas have an orthogonal polarization ($PLF = 0$).

3. THE TESTBED

One hundred flights have been performed to gather a significant dataset. The communication protocol used in the testbed is ZigBee [5], a protocol suited for indoor WSNs, working at 2.4GHz. The selected ZigBee chipsets, namely Waveshare Electronics Open2530[1], are very cheap; they belong to the well-known Texas Instruments CC253x family. The ground antenna is installed on top of a pole to a height of $h_r = 3.9m$; the other one, installed on the UAV, flies at a mean height of $h_t = 3m$. The UAV uses a barometer to maintain a given height. The ground board is configured as a PAN (Personal Area Network) coordinator, while the mobile one is configured as a router. The collected data, also

[1] The transmission power is 4.5dBm, the transmitting and receiving antennas gain is 2dB.

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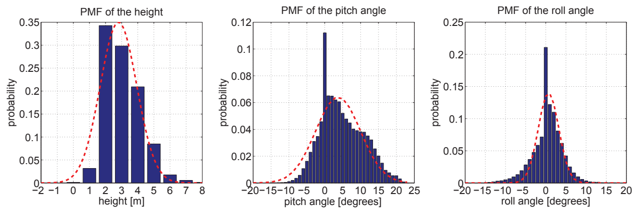

Figure 1: Probability Mass Functions of the height h_t, pitch angle θ and roll angle γ of the UAV during the trials; the red dotted line represents the Gaussian fitting of the collected data, in blue.

including continuously GPS readings, are logged by using a laptop. Ten 50-byte packets are sent every second from the router to the coordinator, resulting in a continuous packets flow. During the tests, two different flight paths were used: around a field or through the field, thus having, respectively, a circular or a linear path.

Each packet is sent in broadcast. It means that every node in the communication range of the UAV will receive the broadcast, and any broadcast storm is avoided by setting the radius to zero. In this way, it is possible to estimate when speed and distance between the UAV and a ground sensor can interfere with a correct packet decoding, excluding the need of control traffic to update neighbors and routing tables.

Three different target speeds have been set on the UAV for our testbed: 10km/h, 20km/h and 30km/h; recall that, using our UAV in automatic flight mode, the maximum speed is 40km/h. The antennas of the two nodes are initially aligned, having a $PLF = 1$, but the antenna of the on-board node oscillates during the flight, thus pitch and roll angles should be taken into account, together with the height of the UAV with respect to the ground.

In Figure 1, the Probability Mass Function (PMF) of the height, the pitch angle, and the roll angle of UAV, collected during the testbed, are shown. The first plot in Figure 1 shows the measurements and the best Gaussian fitting, ($\mu = 2.8m$, $\sigma = 1.6m$); the second plot shows the pitch angle θ and the Gaussian fitting ($\mu = 3.7°$, $\sigma = 8.8°$); the last plot shows the roll angle γ and the Gaussian fitting ($\mu = 0.69°$, $\sigma = 3.59°$). At low speeds, as in the testbed, the pitch and the roll angles can be considered negligible but, as the speed increases, the angle between the antennas varies consequently. This must be taken into account because the PLF changes its value.

Figure 2 shows how empirical data fit the original (left) and the proposed two-ray path loss model (right). The modified propagation model is averaged according to heights and angles distribution. The modified Path Loss expression $\tilde{PL}$ depends on $PL(\cdot, h_r, h_t)$ and $PLF(\phi) = PLF(\theta, \gamma)$ such that $\tilde{PL} = PL(\cdot, h_r, h_t) + PLF(\phi)$ [dBm]. Each measure has two error bars: one horizontal, stating the confidence interval of the GPS readings, and one vertical, stating the confidence interval of the RSS readings. Both of them represent the 0.05, the 0.50, and the 0.95 quantiles of observed values, respectively. The main contribution of the left plot in Figure 2 is to state the failure of the two-ray path loss model to fit the empirical values. Instead, the right plot shows a better fit. The standard deviation between expected RSS values,

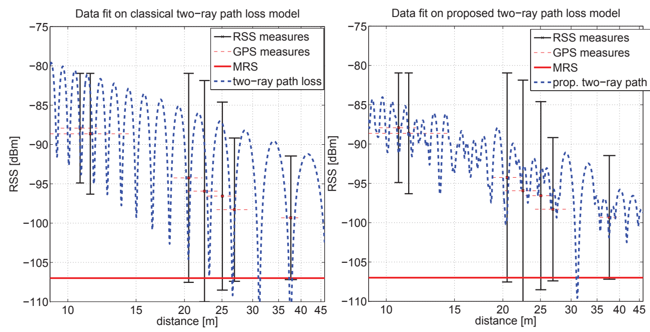

Figure 2: Empirical data fit on two-ray path loss model (left plot) and on the proposed one, $\tilde{PL}$ (right plot).

according to the model, and the 0.50 quantile of readings is assumed as a reference metric: the first plot exhibits a standard deviation value greater than 8.9, which is three-fold the value of the second plot, ≈ 3.1, which takes into account the proposed correction factors.

4. CONCLUSIONS

A measurement campaign has been conducted in order to assess if the two-ray propagation model well fits when an UAV communicates with a ground WSN. The effects of height, pitch and roll angles of the UAV during the flight are discussed. Since the classical path loss model does not properly fit the collected dataset, some correcting factors, taking into account the flights dynamics, have been successfully applied. As far as we can tell, this is the first time that experimental data are used to assess such a propagation model in a similar scenario.

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