Towards a Simulation Framework for Paraglider Networks

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ABSTRACT

In this paper we show how applications and protocols for paraglider ad-hoc networks can be evaluated by means of simulation. We present our approach from the first field operational test to the working simulation model. A special focus was put on the physical layer as we believe this to be one of the most critical parts of the simulation model. In particular, we extend our previous model with a non-deterministic component to also account for multi-path fading effects. All recorded data and the source code for all models are made publicly available.

Categories and Subject Descriptors

I.6.5 [**Simulation and Modeling**]: Model Development; C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design - Wireless Communication

Keywords

Flying ad-hoc networks, Paraglider, Simulation

1. INTRODUCTION

Paragliding is a popular sport that can benefit massively from better communication between pilots. Here, the only way for pilots to gain altitude with their foot-launched glider aircraft (see Figure 1) is to find *lifts*: Soaring in updrafts or circling in thermals, that is, in rising columns (or, more commonly, bubbles) of air, they can reclaim lost height and prolong their flight. Thermals, however, are not directly visible, very local, and often short lived, requiring skill and also luck to find them. Even more demanding is the coordination of search and rescue operations which are unplanned and often time critical. Market ready systems for position reporting and proximity warning exist, but they are only single hop [2] (and thus are infeasible for wide area data exchange) or they require satellite or cellular data connections [9] (which can incur massive costs while abroad).

Figure 1: Paraglider

These problems have therefore triggered research into *Flying Ad Hoc Networks*, using multi hop communication over short range radios as a way to exchange locally available information such as thermals and/or to dynamically reserve air corridors to support search and rescue operations in real-time [4]. Investigating these and other applications, however, requires numerous experiments. Naturally, these could be conducted in the form of field trials (and they have been [5]), but, as always, field trials are very time and cost intensive, the reconstruction of dangerous situations is infeasible because of safety concerns, and precise environment conditions are impossible to reproduce. Conversely, simulative performance evaluation of ad hoc networks has proven to be a powerful tool [7] in the past and many core building blocks are already in place. Still missing, however, is an implementation of the required highly specific radio propagation model.

In previous work [5], we have presented an approach to capturing systematic path loss effects in a mathematical model. In this paper, we present the complete steps from early prototyping and field tests to the next logical steps: integrating the deterministic model from [5] with a component to capture non-deterministic effects, and then putting the system into a complete simulation model for inter-paraglider communication. We are sharing the full trace data and complete source code of the model for download and use under an Open Source license.[1]

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[1] `http://www7.cs.fau.de/skynet/`

(a) Skytraxx variometer (b) Communication dongle

Figure 2: Current hardware setup

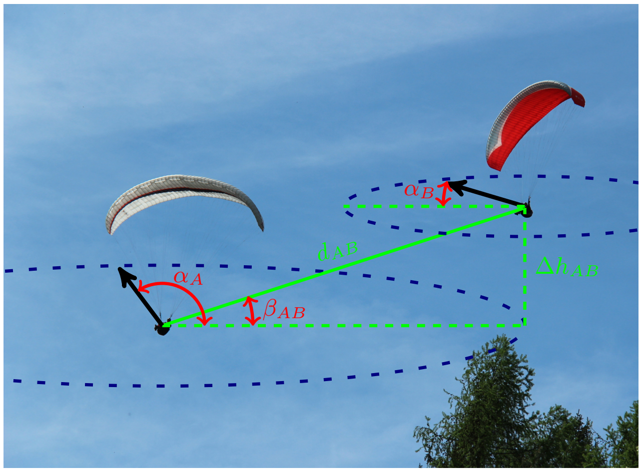

Figure 3: Paraglider alignment

2. PROTOTYPING AND FIELD TESTS

Variometers, pictured in Figure 2(a), are devices carried by every pilot. They are small and light-weight computers that show the current rate of climb or descent. It is critical that our equipment is also compliant with the specific size and weight requirements that come with paragliding. We therefore designed our prototype to be an extension for an existing (Skytraxx) variometer, which we connected to a custom-built dongle, pictured in Figure 2(b), that communicates over an Si4463 transceiver with a transmission power of up to 20 dBm at 868 MHz or 915 MHz. For the tests presented in this paper, we programmed the devices to use a Time Division Multiple Access (TDMA) medium access scheme on top of an IEEE 802.15.4g-2012 physical layer [1] to avoid packet collisions. The modulation was set to filtered BFSK with a binary symbol rate of 50 ksymbol/s yielding a bit rate of 50 kbit/s. We used a half-wave dipole antenna that we mounted vertically on the harness (or cockpit, if available) in front of the pilot.

The main goal of the field tests was to collect enough data to derive accurate simulation models. We therefore logged a multitude of parameters that might correlate with systematic changes in the Received Signal Strength (RSS). Unfortunately, not all potential influences could be captured.

First, the positioning of the antenna is problematic. The cockpit, that is, a small 'table' in front of the pilot, is attached rather loosely and will continuously change its alignment mid-flight. Also, as can be seen in Figure 1, a paraglider has no rigid primary structure, making a fixed angular alignment almost impossible. Further, during the complex and potentially rough take-offs the antenna can get displaced.

Second, situations cannot be paused or repeated. It is obvious that paragliders cannot stop mid-air and wait for a certain amount of packets to be transferred. The recreation of a certain situation is also very difficult as it would involve two or more paragliders to maintain a certain position and orientation in a very dynamic 3D space.

Our field tests consisted of five paragliders equipped with our test hardware. We conducted experiments over a period of three weeks and collected data for over 100 000 packet transmissions. Each device was set to periodically broadcast packets and also log transmit/receive power (five different transmit power settings were used) for each packet. Furthermore, we logged the traces of each pilot consisting of their GPS position and their orientation. Our hardware did not allow us to directly record information about lost packets, however, using unique sequence numbers and the positions of the pilots, we were able to derive which packets could not be decoded. In total, we recorded more than 200 h of flight data.

3. MODELING THE PHYSICAL LAYER

Capturing the characteristics of the wireless medium in the simulation model is crucial for the evaluation of higher layer protocols and applications, as their performance can be heavily influenced by effects of the physical channel such as packet loss, latency, or interference.

3.1 Signal Attenuation

Computing the RSS P_r at a node can be done using a model

$$P_r[\mathrm{dBm}] = P_t[\mathrm{dBm}] + G_t[\mathrm{dB}] + G_r[\mathrm{dB}] - \sum L_i[\mathrm{dB}], \quad (1)$$

which takes into account the antenna gains G of both sender and receiver, the transmission power P_t and a sum of path loss components L that model, e.g., the attenuation over the distance between sender and receiver.

For a network composed of paragliders, that is, sparsely populated nodes in a 3D space with seemingly perfect Line of Sight (LOS) conditions, it seems to be a straightforward choice to model signal attenuation over distance as free-space path loss

$$L_{fs}(d)[\mathrm{dB}] = 10\log_{10}\left(\frac{16\pi^2 d^2}{\lambda^2}\right). \quad (2)$$

However, we found that this model does not accurately reproduce the signal strengths recorded during our field tests, but overestimated them by approximately 10 dB [4].

Looking at our measurements we found a strong correlation between the RSS and the horizontal angle $\alpha_{AB} = \alpha_A + \alpha_B$ (or relative bearing) and vertical angle β_{AB} between sender and receiver [5]. These angles, as illustrated in Figure 3, could be

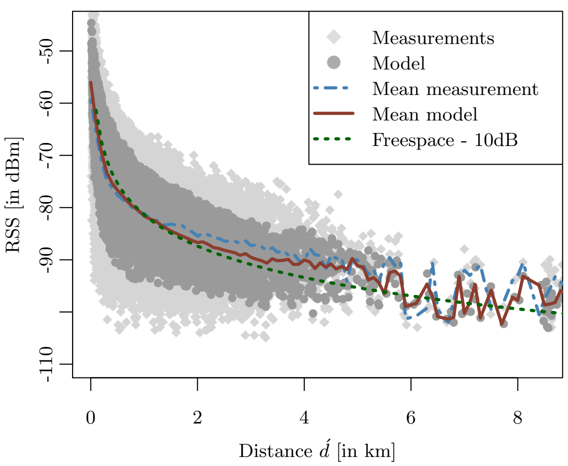

Figure 4: Comparison of measurements and models based on results from [5]

shown to have a linear influence on the signal strength and can therefore be modeled using two attenuation components

$$L_{hor}(\alpha_{AB})[\text{dB}] = -\kappa\,\alpha_{AB}, \tag{3}$$

$$L_{vert}(\beta_{AB})[\text{dB}] = -\zeta\,\beta_{AB}. \tag{4}$$

The coefficients κ and ζ were determined empirically by fitting our measurements, however, they were almost identical for two different field operational tests at different test locations. (The values found were $\kappa = -0.042\,83\,\text{dB}/^\circ$, and $\zeta = -0.1391\,\text{dB}/^\circ$).

This results in a final model that uses free-space path loss to capture attenuation caused by distance as well as two components for angle dependence, yielding

$$\begin{aligned} P_r[\text{dBm}] &= P_t[\text{dBm}] + G_t[\text{dB}] + G_r[\text{dB}] \\ &\quad - L_{fs}(\acute{d}_{AB}) - L_{hor}(\alpha_{AB}) - L_{vert}(\beta_{AB}). \end{aligned} \tag{5}$$

As can be seen in Figure 4, this simple, deterministic model fits the measurements far better than the free-space path loss (with penalty) model. It shows that a significant part of the variance in the real measurement can be reproduced in a deterministic manner. This can easily be seen in regions were only a few measurement points are available (e.g. from 6 km to 8 km): Our model mean follows the true mean well, whereas the free-space model can not capture the variance introduced by other effects as the pure distance.

3.2 Modeling the Remaining Error

To improve our model to also account for the non-systematic variations in the measured data, we investigated the remaining error, that is, the difference between the RSS of each measured point and the RSS computed by the model. The distribution is shown in Figure 5. If the proposed deterministic component is correct, the remaining error caused by fading (e.g., caused by multi-path propagation) should be log-normally distributed around the deterministic mean [3]. Even at high altitudes, multi-path fading cannot be neglected and, caused by uneven grounds, will have a considerable impact on the RSS [8].

We follow the approach of Johnson [6] to prove that our data is log-normally distributed: A random variable X follows a log-normal distribution if the four parameters of

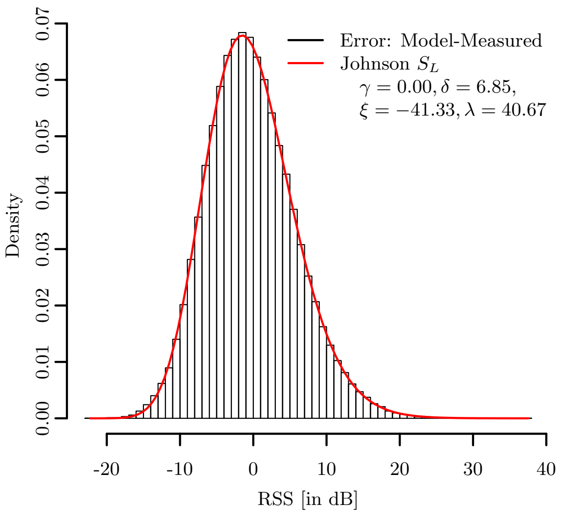

Figure 5: Modeling of remaining error

$$Z = \gamma + \delta \ln\left(\frac{X - \xi}{\lambda}\right), X > \xi \tag{6}$$

can be fitted so that the result Z is a standard normal random variable. In detail, γ and δ are shape parameters, λ is a scale parameter, and ξ is a location parameter.

As can be seen in Figure 5, the Johnson distribution fits our measured errors very well, and gives a strong indication that our deterministic model is correct. We therefore extend the model in Equation (5) by this non-deterministic random variable, that is, the reverse of Equation (6), to account for fast fading caused by multi-path propagation.

3.3 Bit Error Model

After computing the RSS for a received packet, the simulation has to decide whether the packet can be decoded successfully by the receiver. For this, the Signal-to-Noise-plus-Interference Ratio (SNIR) has to be calculated, that is, the ratio of the received power of the received packet and the sum of all other overlapping packets plus the background noise. Once the SNIR has been computed, a bit error model is deployed. According to [10], the bit error probability for Binary Frequency Shift Keying can be computed as:

$$P_{Eb} = \frac{1}{2}\text{erfc}\left(\sqrt{\frac{1}{2}\text{SNIR}}\right) \tag{7}$$

The probability P_{Sp} for a packet of length n bit can then be computing as $P_{Sp} = 1 - (P_{Eb})^n$. The final decision is then made based on whether a random number $r \in [0, 1)$ is smaller or bigger than P_{Sp}.

4. MOBILITY TRACES

Course decisions made by a pilot are based on multiple inputs (like current environment, weather situation, visual clues for rising air, flight paths of other pilots or birds, etc.) in combination with a lot of flight experience. All this information is very challenging to mimic in a simulator. At the current, early development stage the system is only passively logging data, not displaying any additional information. It thus does not interfere with the steering decision procedure. Hence, recorded GPS traces of real flights can be utilized for the mobility in the simulator. As soon as the system offers information, like where to find the next lift, the decision process is biased and a more complex mobility model is required.

During the RSS test flights, we recorded several hundred hours of flight paths which can be utilized for this purpose. An alternative source are freely available online databases like DHV-XC containing hundred of thousands of flights.[2] The flights are stored in the standardized International Gliding Commission (IGC) format using WGS 84 as a reference system. Like we did, these coordinates can be transformed into Cartesian coordinates for the simulation using a straightforward projection approach. In this paper, we opted for Universal Transverse Mercator (UTM), choosing the appropriate zone for our flights to not only have a conformal projection but to also keep distance errors below 0.1 %.

We logged data at intervals of 1 s. Even though other available trace data might use any interval of up to 10 s, the average paraglider has a travel speed in the range of approximately 22 km/h to 55 km/h relative to the wind speed. Linear interpolation between the logged positions is sufficient: as paragliders (aside from acrobatic flights) do not significantly alter their course within the recorded time intervals, this incurs only minimal errors.

No additional 3D map data for the simulations is required. Firstly, the resolution of commonly available maps is by far insufficient to compute multi-path effects. Secondly, due to the altitude of the paragliders Non Line of Sight (NLOS) situations are uncommon or caused by objects of such scale that no reception would be possible anyway.

5. CONCLUSION AND FUTURE WORK

Enabling ad-hoc communication between paragliders allows for the deployment of both innovative safety and non-safety applications [4]. In order to efficiently and thoroughly test these applications or protocols, a simulation model that accurately captures the characteristics of the wireless channel is needed.

Based on extensive field operational tests we showed that the RSS can be deterministically modeled based on the horizontal and vertical angle between the paragliders. Fast fading effects can additionally be captured with a random variable that follows a log-normal (Johnson) distribution. Using a trace-driven approach to account for the distinct mobility patterns of paragliders, is it possible to evaluate the performance of new applications using a simulation model for OMNeT++, which we made publicly available.

Future work focuses on the development of a mobility model for foot-launched gliders to be able to have applications also influence the pilots' behavior in the simulator.

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6. REFERENCES

[1] Physical Layer (PHY) Specifications for Low-Data-Rate, Wireless, Smart Metering Utility Networks. Std 802.15.4g, IEEE, 2012.

[2] T. Baumgartner and U. Maeder. Trajectory Prediction for Low-cost Collision Avoidance Systems. In *IEEE/AIAA 28th Digital Avionics Systems Conference (DASC 2009)*, pages 1.C.5–1–1.C.5–8, Orlando, FL, October 2009.

[3] A. Coulson, A. Williamson, and R. Vaughan. A statistical basis for lognormal shadowing effects in multipath fading channels. *IEEE Transactions on Communications*, 46(4):494–502, April 1998.

[4] J. Eckert, D. Eckhoff, and R. German. Flying Ad-Hoc Network Communication for Detecting Thermals: Feasibility and Insights. In *3rd International Conference on Innovative Computing Technology (INTECH 2013)*, pages 333–338, London, UK, August 2013. IEEE.

[5] J. Eckert, D. Eckhoff, and R. German. A Deterministic Radio Propagation Model for Inter-Paraglider Communication. In *11th IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS 2014)*, Obergurgl, Austria, April 2014. IEEE.

[6] N. L. Johnson. Systems of frequency curves generated by methods of translation. *Biometrika*, pages 149–176, 1949.

[7] M. Korkalainen, M. Sallinen, N. Karkkainen, and P. Tukeva. Survey of wireless sensor networks simulation tools for demanding applications. In *Fifth International Conference on Networking and Services (ICNS 2009)*, pages 102–106, Valencia, Spain, April 2009.

[8] J. Salo, L. Vuokko, and P. Vainikainen. Why is Shadow Fading Lognormal? In *International Symposium on Wireless Personal Multimedia Communications (WPMC 2005)*, Aalborg, Denmark, September 2005.

[9] A. Sarwar, B. Li, and A. Dempster. SPOT in Location Based Emergency Services, LBES Detailed Analysis. In *International Global Navigation Satellite Systems Society Symposium (IGNSS 2009)*, pages 1–15, Qld, Australia, December 2009.

[10] B. Sklar. *Digital Communications: Fundamentals and Applications.* Prentice Hall, 2nd edition, 2001.

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[2] http://www.dhv-xc.de/