A Low-Cost RSSI Based Localization System Design for Wildlife Tracking

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***Abstract*—We present a low cost localization system for bats tracking. The system is based on an angle-of-arrival estimation using field strength difference measurements of two directional antennas. The receivers are constructed of low-cost commercial broadcast receivers and an embedded processing platform. A concept for an efficient 2-stage differential correlation is shown to address the dynamic range limitations of the low-cost hardware, the processing power limitations and frequency offsets. We show that the dynamic range can be improved by >16dB compared to a power detection method. The full system has been validated in a field trial in the rain forest of Panama.**

I. Introduction

Bats are an important indicator of a healthy natural environment. There are also indications that bats are carriers of deadly diseases, such as Ebola. However, there is little knowledge of their social behavior. Thus, a project funded by the German Science Foundation (DFG) called BATS has been set up to track bats in their natural habitat. For this purpose, the bats are equipped with ultra lightweight transmitters [1] (max. 2 g). We developed a ground network, consisting of multiple receiver stations, that is able to measure the trajectory of the bats with a rate of few Hz. For keeping the system costs at a minimum, the ground network only uses cost effective off-the-shelf commercial components. For proving the functionality of our system, we performed a field trial in Panama.

II. Receiver Hardware / Software

As depicted in Fig. 1, the test systems employed four base-stations (BS), which were connected to a server via Ethernet. The devices were placed in a rectangular shape with a distance of approx. $50 \times 50\,\mathrm{m}$. Our BS receivers are equipped with a low-cost embedded processing platform (RaspberryPi B+) and two software-defined radio capable USB-based terrestrial TV broadcast receivers (D-RX). Furthermore, we developed a special localization antenna. The D-RX provides an IQ data stream in the selected frequency band with 8-bit quantization. These data are streamed to a central server (notebook) that performs all required signal processing for the localization. The processing power limits the sampling frequency to $250\,\mathrm{kSps}$. The ultra-low price of the D-RX (< 10$) clearly leads to further performance limitations, such as limited dynamic range. The use of an automatic gain control (AGC) for increasing the dynamic range is not feasible, due to the short duration of the localization signals. This limited dynamic range is one of the main challenges and will be further addressed in Sec. IV-B.

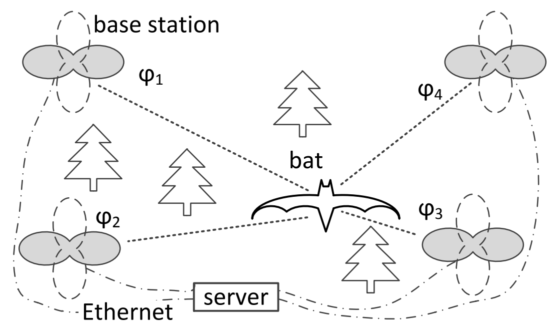


Figure 1: Bats localization system with four base stations connected by Ethernet to a central server

III. RSSI AoA Antenna

For our Received Signal Strength Indicator (RSSI) based angel-of-arrival (AoA) estimation we developed a special antenna design. It consists of two directional antennas with different orientation. The patterns of this antenna are shown in Fig. 2, a more detailed description can be found in [2]. The so-called gain difference function $\Delta G_\nu(\varphi)$ follows:

$$\Delta G_\nu(\varphi) = G_{RX1}(\varphi) - G_{RX2}(\varphi) \approx \Delta P_{RX}, \qquad (1)$$

where G_{RX1} and G_{RX2} are the directional antenna gains, and φ is the AoA of the electromagnetic wave. At line-of-sight conditions with negligible multi-path the measured field strength difference ΔP_{RX} is equivalent to $\Delta G_\nu(\varphi)$. Thus, we can estimate the AoA using ΔP_{RX}. The ambiguities of the antenna patterns have to be solved by means of localization algorithms that are not part of this paper. As shown in Fig. 2 the gain difference function $\Delta G_\nu(\varphi)$ may reach values greater than $18\,\mathrm{dB}$ for specific angles φ. In combination to the limited dynamic range of the D-RX this causes additional challenges.

IV. Signal Detection and Dynamic Range

The server has to detect the signal of the bats in the sampled IQ data stream. This signal uses MSK (Minimum Shift Keying) with $250\,\mathrm{kBit/s}$ and has an overall length of $0.25\,\mathrm{ms}$. The dynamic range of the signal reception is limited by two bounds. The upper bound is the clipping of the receiver's ADC. Higher signal levels may be decoded, but the field strength cannot be measured properly. The lower bound is the sensitivity of the receiver.

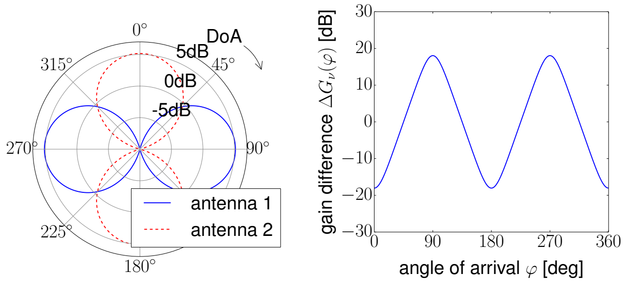
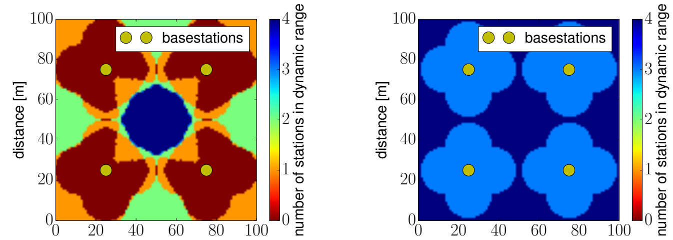


Figure 2: Antenna pattern and gain difference function



(a) Dynamic range for 20 dB (b) Dynamic range for 36 dB

Figure 3: Coverage map for $100 \times 100\,\mathrm{m}$ with four base stations

A. Power Level Detection and MSK Demodulation

Laboratory measurements showed that simple signal detection algorithms, e.g. based on a sliding average power level detector, will not lead to sufficient results. The reduced detection capability in addition to the 8-bit ADC lead to an overall dynamic range of less than $20\,\mathrm{dB}$. This limited dynamic range results in a very limited coverage like shown in Sec. V.

B. 2-Stage Correlation

Due to the limited number of 12 bats that we tracked in the field trial, there existed only 12 well known data packets. One possibility is to correlate against all 12 possible packets to increase the sensitivity, which results in 96 simultaneously running correlators for the four BS. For reducing the required processing power, we decided to use a 2-stage correlation. The first correlator uses the data that are identical for all packets (i.e. preamble, sync-word and length field). This shrinks the number of simultaneously running correlators to 8. The shortened correlator length only slightly reduces the sensitivity. However, this first correlator is purely required for the reduction of the amount of data. Therefore, we can accept a trigger level with many false positives, which partly compensates the loss of sensitivity. The second stage performs a full correlation against all possible data packages. Additionally, it does a false positive detection. A critical point for correlation-based detectors are frequency offsets. Hence, we use the differential correlator L_3 of [3], which can be described as:

$$L_3(\mu) = \left| \sum_{k}^{L-1} r_{\mu+k} r^*_{\mu+k-1} s^*_k s_{k-1} \right|, \tag{2}$$

where r_μ is the complex received signal, s_k is the searched sequence, and $*$ denotes the complex conjugate operator. This saves additional processing power as the frequency offset between transmitter and receiver have not to be estimated and corrected. One critical design parameter is the detection threshold of the first correlator. On the one hand, a low threshold will increase the sensitivity. On the other hand, a high threshold will increase the false positive detection rate. We selected a threshold that lead to 10 false-positives per second, as this seemed a suitable trade-off between sensitivity and server load. This threshold reduces the load of the second correlator by a factor of approx. 200, and enables us to process all incoming streams using a single server. Measurements show that our correlator concept increases the dynamic range to $36\,\mathrm{dB}$.

V. Coverage

The coverage in our case is defined as the number of BS that are able to detect a bat and measure the ΔP_{RX}. Already if one of the two D-RX of each BS is clipping or below its sensitivity level, no ΔP_{RX} can be estimated. Fig. 3 shows the coverage in an area of $100 \times 100\,\mathrm{m}$. For $20\,\mathrm{dB}$ dynamic range only a small area is blue, indicating that all four BS are able to estimate ΔP_{RX}. There exist also large areas where not even a single BS is able to measure ΔP_{RX}. In contrast, the dynamic range of $36\,\mathrm{dB}$, which we achieve using the two-stage correlator concept, fulfills our coverage requirements.

VI. Conclusion

We show that a low cost setup with special antennas for RSSI based AoA estimation can cover an area of $80 \times 80\,\mathrm{m}$. The challenges of limited dynamic range and processing power are solved with a 2-stage correlation concept. This highly improves the localization coverage and the trajectory estimation. The concept has been proven in a field trial in Panama.

VII. Acknowledgment

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