Low-Weight Wireless Sensor Network for Encounter Detection of Bats

Martin Hierold #, Simon Ripperger *, Darija Josic *, Frieder Mayer *,
Robert Weigel #, and Alexander Koelpin #

#Institute for Electronics Engineering Friedrich-Alexander University of Erlangen-Nuremberg
Cauerstrasse 9, 91058 Erlangen, Germany
*Museum fuer Naturkunde, Leibniz-Institut fuer Evolutions- und Biodiversitaetsforschung
Invalidenstrasse 43, 10115 Berlin, Germany

***Abstract*— In this paper a compact low weight wireless sensor node for proximity detection is presented. The energy-efficient system design enables an operation time of more than 9 days at a total weight of the tag of less than 2 g. Test measurements in a colony of bats proof the applicability of the system for encounter detection of individual bats based on received signal strength measurements.**

I. Introduction

In recent years technical advances could significantly improve the potential of wildlife observation. However, for very small sized animals like bats only relatively old fashioned radio-telemetry systems are applicable [1]. These systems use simple transmitters mounted to the bats emitting signal pulses in the Very High Frequency (VHF) band that have to be detected by a researcher with a directional antenna and a receiver to locate a single bat at a time by manual triangulation. Even though first approaches have been made to avoid this tedious tracking procedure, only very course locations can be recorded [2] making the detection of encounters between single individuals impossible. Such encounters however are extremely interesting to the biologists to study the bats' social behavior. To enable the recognition of these encounters, a wireless sensor network (WSN) for proximity detection is presented here which satisfies the very severe requirements for this application. Due to the small weight and size of the bats, the tags must weigh less than 2 g and should not exceed a size of about 1 cm^3. Furthermore, the tags have to be water resistant and the operation time of the system is desired to be about one week.

II. System Architecture

To detect encounters between individual bats, the tags send out a unique identification (ID). To obtain an estimate for the distance to another tag a received signal strength indicator (RSSI) value is used. If the ID of another tag has been received and a certain RSSI threshold is exceeded, the IDs of both tags, a global time stamp, and the corresponding RSSI value are stored in a ring buffer and

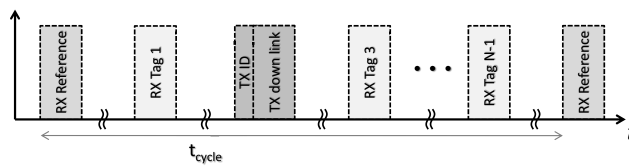

Fig. 1. Time slotted communication pattern of the system. Exemplary for tag 2.

transmitted to a stationary base station receiver. Caused by the demanding weight restriction only a very small sized battery can be used to supply the tags. To handle the energy constraints associated with this restriction a time slotted approach is used. The communication pattern of the system is shown in Fig. 1. A dedicated timeslot is assigned to each node to send out its ID. In N-1 subsequent timeslots each tag listens for the ID of another tag, where N is the maximum number of tags in the system. Due to the limited timeslot length a precise time synchronization is necessary that exceeds the tolerances of low power oscillators. Therefore, the tags are synchronized to a global time reference signal that is broadcasted by a stationary transmitter which together with the stationary receiver forms the bistatic ground node of the system. So an additional timeslot is needed for the reception of the time reference. The periodic reception of the time reference also serves as an indicator if the ground node is within the communication range. Only in this case, the stored data is downloaded to the ground node directly after transmitting the tag's ID to avoid the loss of data. The stationary receiver then forwards the data to a PC where the data is stored for offline processing. A trade-off exists between power consumption, the update rate determined by the cycle time t_{cycle}, and the maximum number of tags N in the system. In the proposed demonstrator system a cycle time of 2.1 s and a maximum number of 5 tags is implemented. As it is unpredictable, if and when adequate bats for a field test can be catched, an activation scheme is needed. Due to the necessity of water resistance the tags are completely sealed which eliminates the possible use of a simple power switch. In this system the internal temperature sensor of the microcontroller is used for (de)activation of the tags. The temperature is sensed at the end of each cycle. If it falls below $5°C$ the tag goes to sleep mode permanently and only wakes up for the temperature measurement. If the temperature raises above $50°C$ the tag is activated and works as intended. Activation and deactivation can be realized by coolant spray and hot air gun, respectively.

III. Hardware

The key component is the System on Chip solution CC430 from Texas Instruments comprising a microcontroller and a sub gigahertz frontend which is operated in the 868 MHz band. The tag is powered by a lithium coin battery. To facilitate the drawing of the high current peaks necessary during the active phases of the tag a 330 µF buffer capacitance is applied. For signal emission a matching network connects the chip's output pins to a thin 14.5 cm long copper wire antenna. This is acceptable as the flexible wire does hardly disturb the bats. However, the antenna has to be mechanically stabilized by a steel wire to ensure proper functionality. The assembled circuitry is shown in Fig. 2 a). It requires an area 12 x 10 mm^2 weighing only 615 mg including the antenna. Tags were set up with two different battery types. The 0.8 g BR1225 and the 0.6 g CR1025 batteries were chosen which results in a total weight of the tags of 1.8 g and 1.4 g, respectively, already including the sealing. This gives the opportunity to equip lighter weight bats with the lighter tag at the cost of a shorter observation time for these individuals. Fig. 2 b) shows the final assembly of a tag.

a) b)

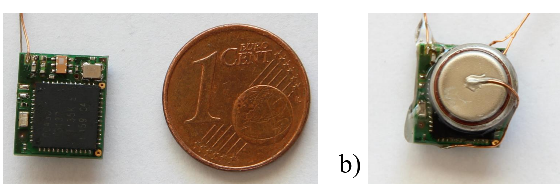

Fig. 2. Hardware implementation.

IV. Timing Considerations

For proper operation of the time slotted communication scheme synchronous transmission and reception must be guaranteed. This is given if the cycle time after which synchronization of the tag's clock to the global time reference is performed is less then the upper boundary

$$t_{sync} = \frac{t_{guard}}{\tau}. \quad (1)$$

This boundary depends on the guard interval t_{guard} of the receive (RX) timeslot and the frequency tolerance τ of the

TABLE I

Current consumption of CC430 @ 3V [3]

Condition	**current**	**duration**
sleep	2.2 µA	~ 2.1 s
transmit ID burst (TXID)	17.8 mA	370 µs
down link transmit burst (TXDL)	33 mA	2.15 ms
receive time slot (RX)	16 mA	2.5 ms
sense temperature (ADC)	150 µA	100 µs
microcontroller active (µC)	3.45 mA	< 3 ms
crystal oscillator start up (XO)	9.5 mA	~ 1 ms

crystal used for the tag's internal timer. The guard interval can be calculated as

$$t_{guard} = 0.5 \cdot (t_{RX} - t_{TXID}). \quad (2)$$

The RX timeslot length t_{RX} is set to 2.5 ms and the transmission duration for sending the ID is calculated as

$$t_{TXID} = \frac{n+m}{DR}, \quad (3)$$

with n the number of data bytes being 1 for the ID, m the number of overhead bytes being at least 7 for the CC430 and the data rate DR which is set to 175 kbps. The tolerance τ of the deployed crystal of ± 20 ppm leads to t_{sync} of 53.4 s. This shows that for the desired operation time of the system a time synchronization is inevitable. But even if some of the 2.1 s spaced synchronization attempts fail the system operates as intended.

V. Current Consumption

Table I gives an overview of the current consumptions and durations of the different modes of the tag. The current consumption in transmit mode is determined by the output power of the signal. For proximity detection a low output power of 0 dBm is sufficient as only nearby tags should be detected. For the down link an output power of 10 dBm is used to cover a large area with a single ground node receiver. With these values the average current consumption can be calculated as follows [4]

$$\begin{aligned} I_{avg} = (&t_{TXID} \cdot I_{TXID} + t_{TXDL} \cdot I_{TXDL} + \\ &N \cdot t_{RX} \cdot I_{RX} + t_{ADC} \cdot I_{ADC} + t_{\mu C} \cdot I_{\mu C} + \\ &(N+1) \cdot t_{XO} \cdot I_{XO} + t_{sleep} \cdot I_{sleep}) \cdot t_{cycle}^{-1}, \end{aligned} \quad (4)$$

with N the number of tags in the system and t_{cycle} the cycle time. All further parameters are listed in table I. Hence, the average current consumption is 166 µA. The capacity of the used batteries are 48 mAh for the BR1225 and 30 mAh for the CR1025 at a recommended discharge current of 30 µA. Measurements have shown that a loss in capacity of ~ 20 % has to be expected at a discharge current of 200 µA. Considering this loss a total operation time of 9.6 and 6 days, respectively, can be achieved.

VI. System Performance

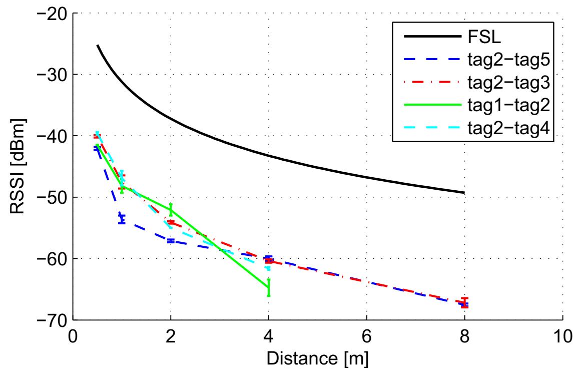

Fig. 3. Measured RSSI values of a subset of tag combinations in comparison to free space loss (FSL).

Fig. 3 shows the recorded RSSI values of a subset of tag combinations in different distances from 0.5 m to 8 m. The mean value and the standard deviation of at least 9 measurements per distance are plotted. For comparison the free space loss (FSL) of a 868 MHz signal is also shown. The measurements where performed in the roost where the actual field test of the system was carried out with nearly ideal alignment of the corresponding antennas. It can be seen that obtained RSSI values closely follow the shape of the FSL, however an offset of about -14 dBm is observable which is caused by an imperfect impedance matching between the chip and the antenna detuned by mounting tolerances on the bat's dorsum and by the reduced radiation efficiency caused by the steel wire for mechanical stabilization of the antenna. Drops that occur in the RSSI values can be explained by some misalignment of the antennas and multipath fading. Nevertheless, the RSSI value does qualify for a good estimate of the distance between the tags especially for small distances which are of interest for this application.

VII. Field Test Measurements

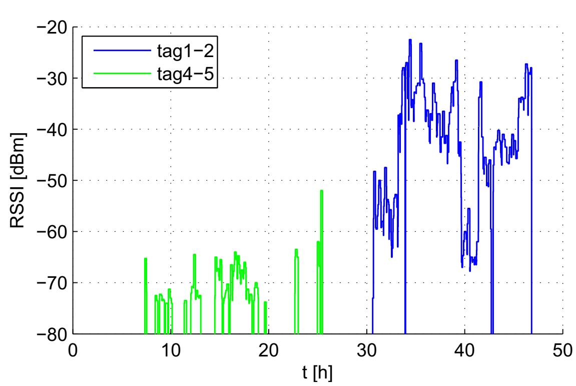

Fig. 4. Measured RSSI values with tags mounted to bats. t = 0 corresponds to 9:35 pm

The system was set up in a roof structure that serves as a roost for a colony of bats. Four tags have been mounted to bats while the fifth tag with the ID number 4 was put as a reference into the roost. As the measurements still took place during the writing of this paper only a subset of the collected data can be presented here. Fig. 4 exemplary shows the first 48 hours of recorded and processed RSSI values for the encounters between tag 1 and 2 as well as tag 4 and 5. The plotted graphs depict the maximum value of the RSSI between the two corresponding tags within a timespan of t ± 5 minutes. This is considered to be reasonable to evaluate the distance between the tags as no significant gain due to constructive interference caused by multipath propagation is expected in this scenario and rather long encounters are observed. The plot shows the presence of tag 5 in the roost during the first day with a distance of several meters to the reference tag 4. The frequent lack of data is caused by the RSSI threshold of -74 dBm. At the second day of the experiment tag 5 was not present, but tag 1 and 2 could be observed. The rather high RSSI values suggest that the two bats stayed close to each other with a distance less than 0.5 m. The colony was also filmed in the roost during the experiment. The first survey of the video material confirms the interpretation of the measured data.

VIII. Conclusion

In this paper a low power WSN was presented with ultra light weight tags for the detection of encounters between individual bats. It has been shown that the time slotted communication approach permits a system operation time of up to 9.6 days. The RSSI value of the communication was validated as an estimate of the distance between two tags. However, the antenna matching has to be improved to closely reach the theoretical limit of the FSL. In first measurements the applicability of the system has been demonstrated.

Acknowledgment

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