Wireless Sensor Nodes for Habitat Monitoring

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Abstract—**Wireless sensor networks for outdoor applications, such as habitat monitoring, are expected to require wireless link ranges that are longer than achievable with commonly available platforms. We discuss ways to extend link range within the constraints typical of wireless sensor networks and incorporate these aspects into the design of a wireless module. We report on the use of this module in a wireless sensor network designed for habitat monitoring. This application involves tracking the movement of RFID tagged bats between their nesting boxes.**

Keywords: wireless sensor networks; monitoring; RFID.

I. INTRODUCTION

Wireless sensor networks enable the monitoring and collection of data over dispersed areas. Requirements to limit the cost, size and power consumption of wireless nodes leads them to use radio transceivers with short ranges. Many wireless sensor hardware platforms developed have practical link ranges of only tens of meters [1,2]. While such ranges may be adequate for indoor applications, outdoor applications, such as habitat monitoring [3-5], are more suited to nodes having longer wireless ranges (hundreds of meters) since data gathering is typically dispersed over wider areas. However, many demonstrations of wireless sensor networks for habitat monitoring have been based on short range platforms available [3,4].

In this paper, we discuss ways to extend the link range of wireless nodes whilst still employing simple, low-cost radio transceiver devices available. From these guidelines, we have developed a simple, low-power wireless sensor module optimized for longer range making it suitable for outdoor applications, such as habitat monitoring, where expanded coverage is required. We describe the use of these modules in a wireless sensor network application to monitor the movement of RFID tagged bats between their nesting boxes.

II. WIRELESS NODE DESIGN

A. Factors Influencing Wireless Link Range

Transmission quality for a wireless link depends on the signal power at the receiver, P_R, relative to its sensitivity, P_{sens}, since this determines the signal-to-noise ratio. In the case of ideal, free-space, propagation, P_R is given by Friis equation [6]

$$P_R = P_T \frac{G_T G_R \lambda^2}{16\pi^2 d^2} \tag{1}$$

where P_T is the transmitted power, λ is the carrier wavelength, G_T and G_R are the antenna gains for transmitter and receiver, respectively, and d is the link distance. In practice the received power typically decreases faster than this ideal inverse square law relationship.

In point-to-point links the most effective way to increase P_R, and hence achievable link distance, is to increase G_R and G_P through using higher-gain, directional antennas. However, in wireless sensor networks this is generally not an option since nodes typically require omni-directional communication (at least in the horizontal plane). Increasing the transmitter power P_T will also extend range but this requires an increase in complexity, cost and power consumption of the transmitter which is opposite to many of the goals for wireless sensors. Furthermore, legislation may restrict the transmit power in license free bands used.

Remaining ways to increase link range are to increase wavelength and improve receiver sensitivity. Increasing wavelength λ, for a fixed antenna gain, leads to a quadratic decrease in path loss, see (1), however this also requires an increase in antenna size that may be practically limited. Commonly used ISM or license free VHF/UHF bands are found around 433 MHz, 868/915 MHz and 2.4 GHz. We selected the 433 MHz band due to its longer wavelength, and subsequent lower path loss. The path loss at 433 MHz is 7.4 dB lower than at 2.4 GHz (assuming omni-directional antennas). However, a longer antenna is required than for 2.4 GHz. At 433 MHz a quarter wavelength antenna is 17cm long, but we believe this length may be acceptable in many outdoor applications where size is less constrained than with indoor applications. Transmission at 433 MHz should also provide better propagation through an outdoor environment cluttered by obstacles like trees and foliage since the ratio of obstacle size to wavelength is smaller. Furthermore, using a lower frequency simplifies the RF hardware.

Range can also be increased by improving receiver sensitivity. One way to increase sensitivity is by decreasing the receiver bandwidth as this reduces the power of the detected noise. However, the signal data rate must be decreased accordingly. Many of the wireless sensor nodes in use operate at data rates on 20-40 kb/s [3,4] and up to 250 kb/s for 2.4 GHz Zigbee [2]. In many habitat monitoring applications the data to be collected is likely sparse and far lower data rates may be acceptable. We select a data rate of 4800 b/s. Decreasing the data rate, for the same transmit power, will result in higher transmit energy consumption per message. However since the power consumption for transmit mode in typical low-power

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transceiver devices is not that much greater than for receive mode, the net increase in power consumption is not substantial. Furthermore, in outdoor systems there are good options to harvest power – such as solar which we use in our application.

B. *Implementation of Wireless Node*

We developed a custom wireless node using the frequency and data rate parameters chosen above. We implement our system using the CC1020 transceiver device from Chipcon [7]. This device has considerable flexibility in setting frequency, receiver bandwidth and data rate. For 433 MHz operation the device has a maximum output transmit power of +10 dBm and stated receiver sensitivity of -112 dBm for 4800 b/s.

Assuming an ideal path loss, as described by (1), a wireless link has a margin, in dB, of

$$P_T - P_{sens} + G_T + G_R - 20\log(4\pi d/\lambda). \qquad (2)$$

To illustrate the benefit of operating at both lower RF frequency and data-rate, in conjunction with available transceivers, we compare (see Table 1) the margin from a system at our chosen parameters implemented on the CC1020 transceiver with an 2.4 GHz 802.15.4 Zigbee [1] system (targeted for short-range ~100m) as implemented on a CC2420 transceiver (also from Chipcon). We assume antenna gains of 2.15 dBi (dipole) and an example link distance of 500m. Table 1 shows that the 2.4 GHz system has a margin of only 5 dB whereas the margin with the 433 MHz system is 42 dB larger, making the 433 MHz link far more robust. Under *ideal* square law line-of-sight transmission, a 42 dB higher margin would translate to a 100 times greater achievable link distance.

Device	CC1020	CC2420
Frequency [MHz]	433	2400
Transmit Power P_T [dBm]	10	0
Antenna Gain [dBi]	2.15	2.15
Receive Sensitivity P_{sens} [dBm]	-112	-95
Margin (Eq.2) [dB]	47.1	5.3

TABLE I. COMPARISON IN SYSTEM MARGIN FOR 500 M LINK BETWEEN SYSTEMS IMPLEMENTATIONS AT 4.8 KB/S TRANSMISSION AT 433 MHZ VERSUS 2.4 GHZ ZIGBEE.

The microcontroller used in our wireless node was a Microchip PIC 18LF452 which had 32 kB of FLASH memory and 1.5 kB of RAM. A 64 kB EEPROM is used to store logged data and new code images. There is also a temperature sensor. A photo of the wireless module is shown in Figure 1.

The CC1020 transceiver does not provide any packet interface (available with more recent devices) and the microcontroller must construct and deconstruct this. The radio stack developed for the wireless board had a packet structure similar to S-MAC [8]. The PHY packet consisted of a preamble, a two byte start of frame, the PHY packet data, and terminated by a 16-bit CRC. The MAC packet nested inside this PHY packet had a destination and source address and type field parameter. The MAC layer used the radio RSSI feature for carrier sense before transmission with back-off when necessary. Acknowledgement and retries are also performed. The radio can be put in sleep-state and set to wake periodically at predefined intervals.

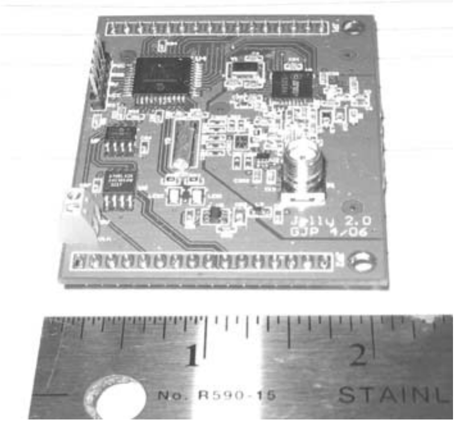

Figure 1. Wireless Sensor Module.

The node software also includes a boot-loader can can reprogram the microcontrollers' FLASH memory with a new code image uploaded over the wireless into the EEPROM storage. Remote reprogramming is an important feature for deployed wireless sensors nodes.

III. HABITAT MONITORING APPLICATION

The wireless modules developed are currently being used in a deployed system to aid zoology researchers better understand the roosting patterns of Australian micro-bats [9,10]. The bats have been implanted with small RFID tags so as to identify individuals and allow their movement to be monitored as they move between nesting boxes distributed through a forest. The architecture of the sensor node, which incorporates the wireless module, is illustrated in Figure 2. Every time a bat enters/exits the box it breaks an IR light beam which then triggers the RFID reader module [11] to scan the bat for a tag via the reader coil mounted around the entrance.

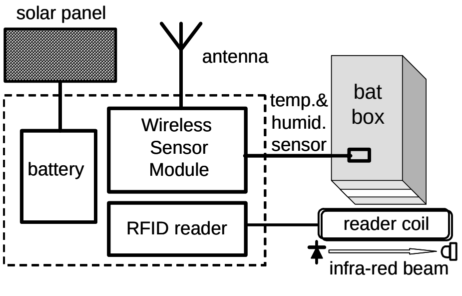

Figure 2. Architecture of the wireless sensor node attached to a bat nesting box.

Detected RFID codes are time stamped and stored on the wireless module. In addition, the unit is connected to a sensor inside the nesting box that measures temperature and humidity. Due to the high power consumption of the RFID reader, the unit is powered by a rechargeable battery that is charged with a small solar cell on the outside of the unit. The wireless links provides a convenient method to collect data since the boxes are mounted ~20 feet up in trees. Figure 3 shows a nesting box fitted with one of the wireless sensor units. The solar panel and antenna are clearly visible. The initial deployment has consisted of only four sensor units; however this is in the process of being built out to ~20 units that are distributed around a 130 acre forest [12]. Wireless networking of the sensor units will provide data collection to a centralized base station.

As discussed previously, one of the key requirements is that the radio has sufficient range. The distance between closest neighbours in our application can be hundreds of meters. Furthermore, the forest has moderate density and typically there is no clear line of sight between any pairs of boxes, which impacts on radio range. In the initial deployment, dictated by the fixed position of existing boxes, the distance between nearest neighbours ranged from about 20 to 220 metres. We achieve reliable, largely error free transmission between nodes separated by 220 meters with no line of sight.

Figure 3. Bat box fitted with a wireless sensor unit.

The temperature and humidity within nesting boxes are recorded every two hours. This microclimate data for the inside of the box is valuable to researchers to understand the bats roost preferences. A sample of this data collected over several days, and downloaded by wireless, is shown in Figure 4*a*). The unit also logs the battery voltage which allows power consumption and effectiveness of solar charging to be monitored. A sample of this data is shown in Figure 4*b*). The diurnal variations in the voltage on the battery are due to the solar panel float charging the battery during sunlight.

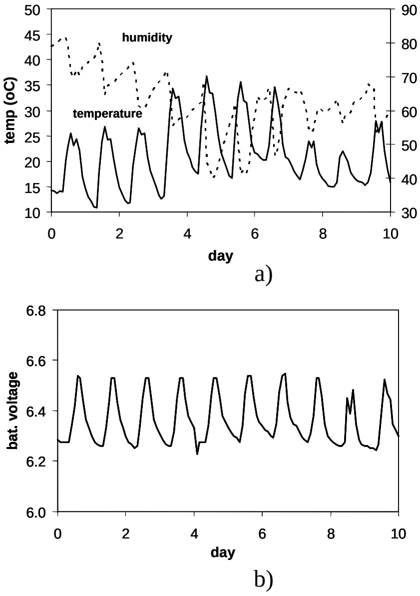

Figure 4. Sample of logged data : a) temperature and humidity in the nesting box, and b) battery voltage monitor.

The RFID data of tagged bats using the nesting box is captured, time-stamped and stored. A sample of this data for a single box is shown in Figure 5. The first column is the RFID tag code. All F's indicates the beam was broken but no tag was detected which likely indicates an untagged bat. Preliminary analysis of more extensive data from multiple boxes has begun to reveal the bats' daily activity cycles and patterns of movement between boxes.

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                         :

FFFFFFFFFF       24/03   04:14
000689F08E       24/03   06:07
FFFFFFFFFF       24/03   06:38
FFFFFFFFFF       24/03   06:52
000689F08E       24/03   19:57
FFFFFFFFFF       24/03   20:17
FFFFFFFFFF       25/03   00:46
000682D420       25/03   00:47
FFFFFFFFFF       25/03   00:47
000682D420       25/03   01:26
FFFFFFFFFF       25/03   01:28
                         :
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Figure 5. Sample of logged bat movement in a box. First column is RFID code (F's indicates no tag), then date and time of entry/exit and box chamber.

An important part of this initial deployment was to identify system problems and rectify them before a full deployment. Several issues tackled were:

i) "Human error", particularly with not having configured the software correctly at deployment. This emphasized the importance of automation in setup and operation.

ii) Software bugs. On one occasion a software bug prevented effective power conservation and consequently all node batteries were run. However, this was noted through monitoring the battery voltage illustrating the importance of such system health monitors.

iii) Corrosion from moisture caused one hardware failure. Also, small insects managed to access the enclosure through gaps in the cable exit point but had not caused any detrimental effect. Both issues have been solved with better sealing of enclosures and circuit boards.

During this three month trial deployment a number of software upgrades were performed successfully over the wireless link. This feature is extremely valuable since units are mounted up the trees. Uploading an entire code image takes ~10 minutes.

IV. CONCLUSION

Many outdoor applications of wireless sensor networks, such as habitat monitoring, will require longer link ranges than achievable with many commonly available wireless sensor platforms. We have discussed ways to extend wireless range while still satisfying the requirements for wireless sensor networks. Range in wireless sensor networks can not typically be extended by simply increasing transmitter power or using directional antennas. Two ways that range can be increased are by decreasing path loss by operating at a longer wavelength, and increasing receiver sensitivity by operating at a lower data rate. Accordingly, we have developed a wireless module that operates at 433 MHz and a data rate of 4800 b/s. We report on its use in a habitat monitoring application that tracks the movement of bats between their nesting boxes. Wireless links of ~200 metres through forest between nodes in our application were successfully spanned. The initial deployment of this network has been operational in the field for several months and has collected data on the movement of RFID tagged bats between their nesting boxes. Aside from collecting valuable data for zoologists and conservationists trying to understand these bats, it will also provide a platform for studying practical issues in wireless sensor networks.

ACKNOWLEDGMENT

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