Long-term wildlife monitoring using wireless sensor networks

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1. Introduction (Stage 1)

1.1. Idea

The idea consists in finding a solution for a scenario that resulted from a discussion with some Spanish biologists. The scenario consists in tracking and monitoring the behaviour of 50 wild horses, for a continuous period of one year. The information that interests is the horses’ location, activity, and neck/head orientation at time intervals of 30 minutes.

1.2. Motivation

Biologists find it useful and relevant to have high-resolution data regarding the location and the activity of animals, and to use this data for movement ecology analyses and conservation studies. Through this, they gain better understanding of environmental and biological factors that relate to animals’ movement patterns and behaviour. Through animal tracking can be exposed the effects of the monitored animals over the vegetation, and the other way around, how the animals move based on the vegetation quality. It can also reveal information about group relations.

1.3. Solution

Deploy a wireless sensor network consisting of mobile nodes attached to horses, which collect data and upload it to fixed nodes called base stations. This requires building collars that can be attached to horses and that contain a wireless sensor node placed in a waterproof, ruggedized casing. The node would have the following main components: EFM32GG microcontroller, NRF24L01+ radio, RFX2401C radio amplifier, 8MB flash chip, GPS module, accelerometer, magnetometer and light sensor. These nodes will also benefit from enclosure-mounted antennas for an improved radio range. The nodes attached on the horses will upload their data to other nodes mounted on 2-meter poles, which have attached an external antenna and benefit from more battery power (base stations).

1.4. Challenge

Capturing of wild animals, for example horses, is complicated and problematic, and cannot be done excessively. Thus capturing an animal each time it is desired to retrieve data (which is stored locally on a device attached to the animal) is not an option. This implies the need of collecting the data wirelessly from the nodes attached to the horses.

For some animals (such as wild horses) the methods for capturing them can affect their health if captured more than once a year. This fact implies that the wireless sensor network deployed must run for the entire year without any outside intervention.
1.5. Why the EFM32GG is a good fit?

In order to meet the main requirements (1 year battery life, wireless upload of data and size and weight restrictions of the node), we need to have low power sleep and precise radio timing. For this, we are taking advantage of the low power nature of the Energy Micro processor and the advance functionality of the LE Timer in order to precisely control the timing of radio transmissions and receptions times, based on the timing established from the GPS module. Also, the use of large buffers in the large RAM of the Giant Gecko allows for efficient use of the radio and external flash.
2. Background

Animal tracking and behaviour monitoring applications are able to offer biologists high-resolution data of the activity and location of animals. This can help them in understanding key concepts of animal ecology such as resource use, home range, animal dispersal, and population dynamics. [1]

Until present time, a wide variety of animal tracking and monitoring deployments took place, all presenting interesting solutions for overcoming the challenges that were faced. These deployments tracked and monitored different types of animals on the ground [2, 3, 4, 5, 6, 7, 9, 10, 11, 12], in the air [10], underground [8, 13, 14] and underwater [15]. The solutions presented in these papers do not satisfy the requirements for the horse scenario, as each of them has its own weaknesses.

For many wireless sensor networks applications, the option of replacing the battery of the nodes once they are deployed does not exist. Thus, the conservation of energy is very important, especially for long-term deployments, since battery life determines the length of the deployment. The best way to save energy is to have the nodes sleeping as much as possible. However, the challenge is to wake them up at the same time, so that they can exchange information.

In order to test our solution we have deployed few nodes on a herd of domestic horses. The pre-deployment on the domestic horses has the role of testing the behaviour of the collars, the hardware and the algorithm under realistic conditions, and of obtaining immediate feedback about the deployment. It is extremely convenient to have access to the horses, and thus the nodes after they have been deployed. This allows testing several software iterations in the case that bugs are discovered or new functionalities need to be added, during the deployment.
3. The Hardware

The hardware platform was custom designed by Janek Mann from the Centre of Speckled Computing, at the University of Edinburgh, and it was subjected to extensive testing over a period of 2 months.

3.1. Prospeckz-5 Platform

This platform’s shape was designed so that it can fit in the lid of a hard and ruggedized off-the-self case. The board was also designed as a multi-purpose sensor PCB, as it offers the possibility of attaching other external sensors to it. This design is further referred to in this document as the Prospeckz-5.

![Figure 01: Prospeckz-5 (the horse platform): Shape and Pinout](image)
The Prospeckz-5 platform has the following hardware characteristics:

- 128KB RAM, 1MB ROM
- EFM32 Microcontroller (Cortex-M3)
- NRF24L01+ radio, operating at 2.4GHz
- RFX2401C radio amplifier (providing 24dBi end-to-end gain)
- External interfaces: I2C, SPI, GPIO, Analog
- 8MB flash chip
- Solar battery charging circuit
- Dual battery interface
- FTDI compatible header for RS232
- Sensors
  - GPS
  - Accelerometer
  - Magnetometer
  - Light

In order to meet the length of the project and considering the power consumption requirements, a solar cell battery charging circuit was added to the Prospeckz-5 platform. Also, in order to obtain good radio range for the communication between the nodes that will be attached to the horses and the base station nodes, the board was designed to have a radio amplifier and an external antenna connector.

### 3.2. Mobile nodes for horses

The mobile nodes are the nodes that go attached to the horses, as can be seen in Figure 02 below:

![Figure 02: A mobile node attached to a horse](image)
In order to obtain this, a custom strap was manufactured keeping in mind veterinarians' advice. It can be better observed in Figure 03. The case attached to the strap is a NEMA 4X rated enclosure with transparent lid and it contains the following:

- Prospeckz-5 board
- Li-Poly battery (3.7V, 600mAh)
- Lithium Thionyl Chloride backup batteries (3.6V, 2 x 2500mAh)
- Solar Cell (30x30mm)
- Enclosure-mounted antenna
- Potted with re-enterable silicone compound providing vibration protection and waterproofing to IP68

**Figure 03:** A fully assembled mobile node attached on a strap

**Figure 04:** View of the contents of the mobile node

### 3.3. Base station nodes

Base station nodes are mounted on two-meter aluminium poles so that the external antennas can be placed at a reasonable height, as can be seen in Figure 05, right side. This way we achieved 500 m communication range between the mobile node and the base station. The poles are held into position by being
placed into a metal fixing bracket, which is attached to the ground using four 60 cm metal ground anchors.

The base station case is built similarly to the mobile node. The case is a larger NEMA 4X rated enclosure with transparent lid (as can be seen in Figure 05, left side) and it contains the following:

- Prospeckz-5 board
- Lithium Thionyl Chloride backup batteries (3.6V, 3 x 2500mAh)
- Li-Poly battery (3.7V, 600mAh)
- Solar Cell (3 x (30x30mm))
- External antenna lead
- Potted with re-enterable silicone compound providing vibration protection and waterproofing to IP68

![Figure 05: Base station](image)

### 3.4. Assembly and potting process

#### 3.4.1. Lid subassembly

1. Clean lids
2. Remove backing from antenna adhesive
3. Assemble antenna into lid
4. Use hot melt electronic potting adhesive to reinforce wire joints on solar cells

5. Clean solar cells

6. Mount the solar cells in the lid
7. Orient wires in final assembly position

8. Prepare optically clear silicon encapsulation compound according to instructions

9. Pot lid with silicon encapsulation compound

10. Allow the silicon compound to cure for 24 hours
3.4.2. **Case subassembly**

1. Drill the bits of plastic that stick out at the bottom of the case

2. Clean the cases

3. Mount cases on the straps

4. Measure the voltage of the Lithium Thionyl Chloride backup batteries (3.6V, 2500mAh) and group them 2 by 2 based on the similarity of these measurements

5. Solder a pair of batteries together
6. Attach wires to batteries

7. Attach the batteries to the board
8. Attach the Li-Poly battery (3.7V, 600mAh)

a. Cut wires (cut the red and black ones separately to avoid shorting the battery)
b. Attach the battery to the board
9. Attach solar cell to the board (previously attached to the lid of the case)

10. Connect the antenna to the board (previously attached to lid)

11. Apply hot melt electronic potting adhesive to reinforce all connections and wire joints

12. Use hot melt electronic potting adhesive to glue the batteries together and then to glue the batteries onto the back of the board
13. Place the board with the batteries in the case

14. Pot with re-enterable silicone compound providing vibration protection and waterproofing to IP68

15. Screw the lid to the case

The same process is applied to the base station nodes.
The difference is that this node has 3 solar cells, 3 Lithium Thionyl Chloride batteries and an external antenna.
4. The Communication Algorithm

4.1. Basic concept

The proposed TDMA algorithm uses two types of time slots. These are called *Opening* or *Primary* slot and *Upload* or *Secondary* slot. The opening slot has the purpose of determining if a certain horse node is in range of a base station node. A horse node will send only one packet in this slot, and if it receives an acknowledgement it schedules an upload slot. If not, it will go to sleep and wake up in 30 min and try again. The base station has the radio ON in receive mode for the period of all the opening slots. If in one of the slots it receives a packet, it acknowledges that packet and schedules to turn on the radio for the corresponding upload slot.

Figure 06 presents a diagram of the process explained above:

- Opening Time Slot
- Upload Time Slot

![Figure 06: Time Slots Allocation](image)

If a horse node does not get to upload all of its data in the first upload slot (and it does not go out of range of the base station during this slot), another upload slot is scheduled.

The radio on one of the horse nodes is configured to have up to 15 retransmission of a packet in case it does not receive an acknowledgement for it. This was timed to slightly over 8ms. Thus the opening time slot was configured as 10ms, and the upload time slot as 100ms.

4.2. Detailed explanation

**BASE STATION NODE**

The base station node will wake up every 30 minutes and it will turn on the GPS module and waits until it gets a fix. This should be achieved in a matter of seconds or in a worse case scenario tens of seconds, since before the starting of the algorithm it was assured that the GPS module obtained a first fix thus it avoids performing a cold start. Once a fix is obtained, the 1 second PPS pulses are enabled along with the ZDA messages in NMEA mode, which outputs the time associated with the current 1PPS pulse.

Having this information, the base station node can synchronize its internal clock, which is used by the TDMA algorithm. Using precise timing, once every half an hour, the base station turns on the radio for 500ms, which is 50 x 10ms where 10ms represents the opening slot length for one horse. Each of the 50 time slots is allocated to a horse. In these slots, horses will transmit a packet containing the horse ID, a GPS reading, and an Accelerometer reading. When receiving this packet the base station sends back an acknowledgement and schedules to turn on the radio for the upload time slot for the corresponding horse ID. If it receives
any packets during the upload slot, it will schedule another upload slot for the corresponding horse id. This will happen until either the horse node uploads all of its data or either the horse goes out of range of the base station.

The base station node stores all the data that it collects from the horse nodes in the flash memory. The horse node also stores the sensor data that it collects before it sends it over the radio. The data consists of GPS location, date, time and number of satellites, accelerometer, magnetometer and light sensor readings.

**HORSE NODE**
Each horse spec has its own slot for communicating to the base station. Every horse node will wake up every 30 minutes and it will turn on the GPS module in order to get a fix. Once a fix is obtained, the GPS module can provide time, latitude and longitude measures. Once these are available, the node synchronises its clock, builds a packet containing the required data (readings from the accelerometer, magnetometer and the GPS: time, latitude, longitude) and stores this packet in the flash memory. If the radio’s transmit queue is empty, the packet will be added to the queue. Next, the node will wait for his assigned time slot. When the time comes, the radio is switched on and the packet is transmitted. Immediately after, the radio is switched in receiving mode and listens for an acknowledgement message from a base station. If it doesn’t receive the acknowledgement it will go to sleep and will wake up in roughly 30 minutes and starts over the whole process. If it does receive an acknowledgement (this meaning that the base station is in range) it will schedule to wake up for its first upload time slot. If during this slot it receives acknowledgements for all the packets that it sends and if did upload all the new data that it has, the horse node will schedule to wake up for another upload time slot. This will happen until the horse node either uploads all its new data, or either the horse goes out of range of the base station (in this case the horse node will stop receiving acknowledgements for its packets at some point).

An improvement to this algorithm would be to have a moreToSend flag in the packet’s header. The horse spec sets this field if it has not uploaded all of its data to the base station. This will reduce the base stations’ power consumption by reducing the time the radio is kept on in receiving mode. If the base station receives a packet with the moreToSend flag zero in an opening time slot, it does not schedule an upload slot for that horse node. If it receives such a packet during an upload time slot, it turns off the radio for the remaining time of that slot.

If not for this, the base station has to keep the radio on (without actually receiving anything) for **at least** one whole upload slot every time one of the horses is in range and it send at least one packet.
5. Results

The deployment consisted of eight mobile nodes, which were attached to horses and one base station node used for collecting data. The duration of the deployment was approximately one month.

The algorithm was modified for this deployment to have a very narrow window between the data sampling occurrences. This window was shortened from 30 minutes to one minute.

The obtained results seem to be optimistic. The requirements for the one-year horse deployment ask for sensor data collection (including GPS which is the most power hungry sensor on the platform) every 30 minutes. This adds up to a total of 17,520 samples during the whole deployment, for every horse. The nodes were left attached to the horses for about 1 month, and at the collection time, the batteries seemed to be depleted. Even so, since the nodes were programmed with a accelerated sensor data collection schedule (every minute), on one of the nodes it were stored approximately 24,000 readings, which is significantly higher than 17,520. More exactly 37% more reading were obtained compared to the required number of readings. However, this percentage might even improve if its taken into account that over the period of one year, the solar cells could have provided more energy for the batteries and also that Spain has significantly more sunny weather compared to Scotland.

Representations of the data collected from the nodes can be found below.

5.1. Location

The locations presented in Figure 07 seem to be accurate, since this matches the place where the herd is located.
5.2. Light over time

*Figure 08* presents the light measurements collected by the nodes attached to the horses over time. The nights and days can easily be distinguished in the graph.
5.3. Accelerometer readings over night and day

The activity of a horse is calculated based on the accelerometer data, by using the following formula:

\[ \sqrt{(\text{acc}. \ x(i) - \text{acc}. \ x(i - 1))^2 + (\text{acc}. \ y(i) - \text{acc}. \ x(i - 1))^2 + (\text{acc}. \ z(i) - \text{acc}. \ z(i - 1))^2} \]

In Figure 09 the dotted intervals represent low light measurements of the light sensor, and the activity of the horses is presented in red.

In Figure 10 the light data is presented in blue at a different scale (logarithmic scale) than the accelerometer data (which is represented in black).

In both graphs (Figure 09 and 10) can be noticed that the activity of the horses rises during the periods with light (day) and then experiences a drop in its level after night comes. This information might be useful if it is needed to argue for acquiring less sensor measurements during night-time as the animals’ activity is reduced.
Figure 10: Activity and light: accelerometer data in black, light data in blue (plotted using a logarithmic scale)
References


