Results from the Farm

Peter Corke and Pavan Sikka
CSIRO ICT Centre
QCAT, Brisbane QLD Australia

Abstract

This paper reports on a large, long-term mobile wireless sensor network deployment. The trial was part of an animal study involving 45 animals. During the trial, 15 animals were equipped with wireless sensor nodes for a week. The paper discusses various issues with such a deployment including electronic design, software design, animal ethics clearance, logistics, and wearable computing equipment for animals. The paper also presents some preliminary analysis of the data obtained from the deployment, both from the perspective of network parameters and animal movement behavior.

1. Introduction

Agriculture is an important activity. There is a lot of knowledge about domesticated animals and about the environment. However, sensor nets, with their macroscopic view [1], provide an opportunity to greatly enhance this knowledge and to apply it to improve agriculture[6].

Butler etal[9] describe experiments with a ten wireless nodes on a small herd of cows at Cobb Hill farm in Vermont. The nodes were based on Zaurus PDAs with GPS receivers and WiFi networking. Statistics on network connectivity and route hop-count are provided. Many of the issues they noted have also been experienced in this work, including equipment failure and variable network connectivity based on position and orientation of the animals. The Cobb Hill experiment used 2.4GHz radio which would be expected to have poorer propagation characteristics outdoors compared to the 433MHz radio used in this work.

Tracking wild animals is also an important activity — it allows us to learn about animal behavior and movement patterns in the wild in a way not possible using other older methods. There has been some interest in this topic within the field of sensor networks. The ZebraNet project [4, 10] presents a system of animal tracking devices to be used on wild zebras at the Mpala Research Centre in Kenya. The system employs peer-to-peer networking techniques that allow data to travel across the adhoc animal network to base stations and ultimately to biological researchers. Small and Haas [7, 8] present a system for tracking whales in the ocean. This system relies on using buoys and satellite communications to get data off the whales and onto researchers.

This paper is about tracking domestic animals within the confines of a farm. The farm environment simplifies the problem, compared to the wild, however it is still a difficult problem. The application has strong economic drivers that make it an attractive problem to tackle. In this paper we report on the issues encountered in deploying such a large long-term mobile animal-based sensor network. We present a preliminary analysis of results obtained from one of these deployments.

2. Deployment Issues

The experiment ‘piggy backed’ on another which was studying the associations between cows and calves. The animals were split into three groups of 15 each. The Fleck2 collars were used with 5 cows in each group and were on for a week. The three groups of animals were placed in separate but adjacent paddocks. A map of the paddocks is shown in Figure 1. The dashed lines identify the three paddocks used in the experiment: 2a, 2b and 3a. Each paddock is about 100m x 600m. This experiment ran from 25 – 29 November 2005.

2.1. Hardware

Animal tracking is a difficult task and requires significant effort in engineering design. The activities required range from designing the sensor node hardware to choosing the right batteries and enclosures to designing the collars that go on the animals.

2.1.1. Electronics We used the Fleck2 [5] for this deployment. The Fleck2 is a mote-like device [3] based on the Atmega128 processor. It uses the Nordic 903 radio transceiver and has on-board a temperature sensor, 3 accelerometers, 3 magnometers and a GPS receiver.

The Fleck2 requires a maximum of 518 mW when everything is turned on. We use two sealed lead-acid batteries

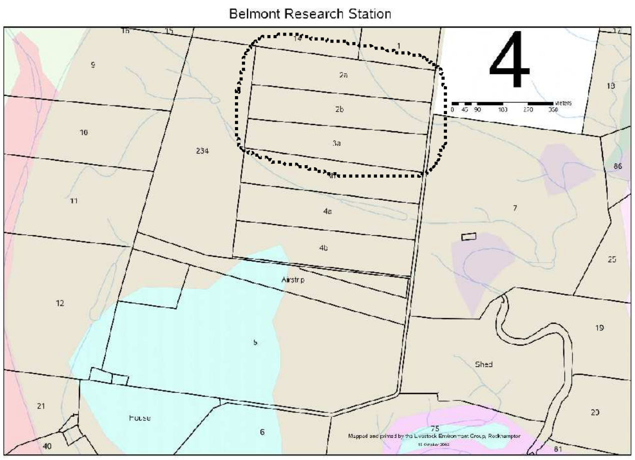

Figure 1. A map of the paddocks used for the trial.

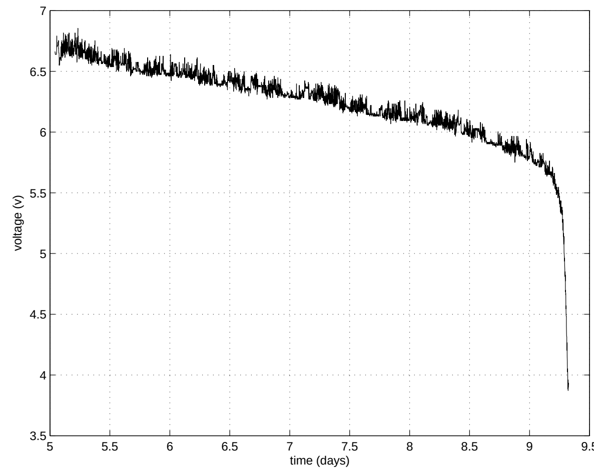

Figure 2. Battery voltage profile for one of the tracking nodes. The time is obtained from GPS time-of-week which is referenced to the beginning of a week.

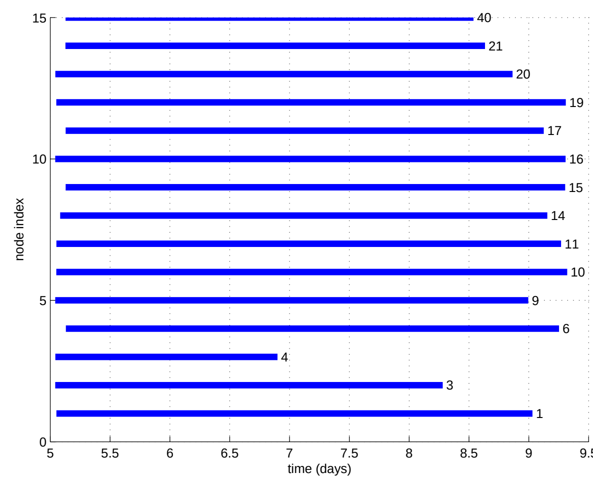

Figure 3. Lifetime of the nodes. The numbers at right of the horizontal bars are node ids.

from Panasonic in parallel. Each battery can provide 4.2 A-h at 6 V. This implies a life-time of about 4 days when fully charged. Since we keep the CPU and the GPS receiver on all the time but use the sensors on a very low duty-cycle, the power requirement reduces to about 450 mW, which gives us a life-time of about 4.7 days.

Figure 2 shows the battery voltage as a function of time. This curve is in line with standard battery voltage profiles and shows that the node lasted for about 4.5 days. However, of the 15 nodes, two did not log any battery voltage data at all. One of the nodes lasted about 2 days and the last recorded battery voltage is about 6.3 V suggesting that this node probably stopped working for other reasons.

Figure 3 shows the lifetime of all the 15 nodes used for this deployment. The average lifetime is 3.8 days with the longest being 4.3 days and the shortest being 1.9 days, and a total operating time of 57.2 node-days. Node 4 had some premature failure of unknown cause.

2.1.2. Collars The Fleck2 is mounted inside IP55 rated plastic (ABS) boxes (130x90x60mm). These boxes then fit into a pocket on a specially designed collar that goes around the animal's neck. The collar also has pockets for 2 batteries, GPS antenna and a radio antenna. The collars themselves were made of 4-inch wide webbing.

Collar design is an important issue as the more a collar affects the animal's behavior the less useful it is as a tracking device. The initial collar design had the radio antenna sticking out on the back of the animal. We found that the animals destroyed the antenna within hours by either rubbing against a tree or even by getting "mates" to chew them off. Our interim solution has been to lay the antenna flat along the collar. The antennas now last about 6 weeks (normal wear and tear) but this placement has an adverse effect on radio communications.

Each collar weighs about 2.5 kg when fully kitted out with the tracking devices and batteries. In contrast, the typical animal wearing a tracking collars weighs about 500 kg.

2.1.3. Animal Ethics Clearance The animals are located at an experimental farm used by CSIRO scientists. All proposed experiments involving animals are approved by the Animal Ethics Committee consisting of members drawn from different interest groups. The approval process is required for any experimental work and is quite rigourous.

2.2. Software

The software running on the Fleck2 uses TinyOS [3] and is written in NesC [2]. The program is fairly simple — it logs several messages from the GPS receiver and sensor values from the accelerometers and magnometers at 1 Hz to an external MMC card. It also sends a ping message, containing its GPS location, over the radio and logs any received ping messages. The decision to log all data locally was made to ensure that data can be captured reliably for later analysis. Our experience highlights the need for careful design and extensive testing, and even then real deployments raise unforeseen problems.

2.2.1. Data logging The ability to log data reliably is important for these devices — it is essential for the scientists to have complete data from a deployment. Any gaps in the data have the potential to render their experiments useless.

Earlier versions of the system relied on using a DOS filesystem obtained from a commercial vendor (and adapted for TinyOS). However, this proved disasterous due to overuse of the file table which destroyed every MMC card in the deployment.

This led us design our own simple data-logging system not using any of the standard file-systems and it has worked well so far. Our filesystem uses the flash as a linear buffer and logs binary data directly to flash. Each page has a header containing some useful information and a trailer consisting of a checksum. Each data item also has a small header consisting of a timestamp and data identity. The data record can be easily parsed once it is made available on a PC.

3. Results

Figure 4 presents some overall statistics per node. To account for the variable node lifetime, the statistics have been normalized to the node's lifetime (bottom plot). We see that (top plot) nodes 4, 9, 20 and 40 received very few ping messages from the network, and also that the network received very few messages from them (second plot). A total of 611,100 ping messages were received by the network over the period, an average of 7.4 pings/node/minute. A ping is transmitted by each node once per minute and under ideal circumstances would be received by all other nodes. Given that each minute 15 nodes emit a ping the reception probability is 49% over this large sample.

The number of GPS fixes received per minute (third plot) indicates that nodes 1 and 10 have GPS failure most likely due to an antenna cable fault. The ping messages contain the GPS location of the sender, so the GPS faults led to 84% of all received ping messages having bad GPS data.

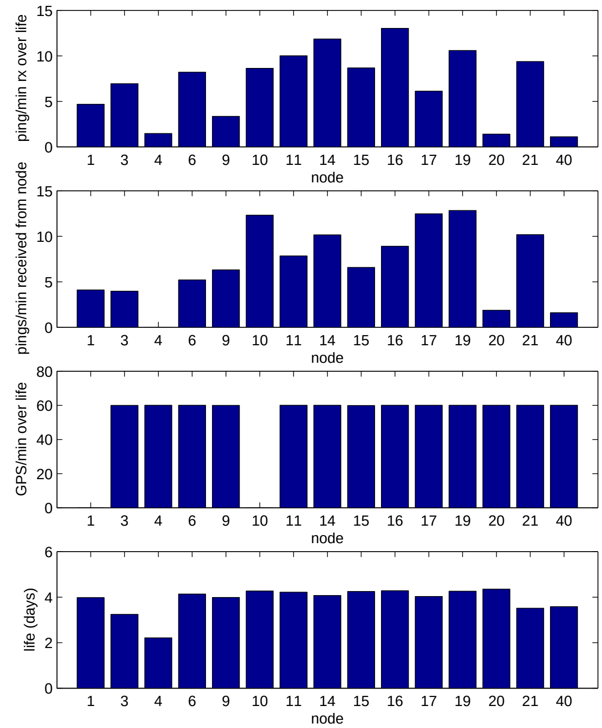

Figure 4. Some statistics about the deployment. The first graph shows the lifetime of all the nodes in hours. The second graph shows the number of GPS messages logged per minute and shows that two of the nodes failed to obtain GPS lock. The third figure shows the number of ping messages received per minute from a node, while the fourth figure (at the top) shows the number of ping messages received per minute by a node.

In Figure 5 we examine the ping reception performance as a function of distance. Nodes 1 and 10 had non-functional GPS receivers from the outset, which is unfortunate since node 10, as shown later, had unusually strong connectivity with other nodes. Although they emitted pings which were received these had to be eliminated from the analysis which requires knowledge of the location of both nodes, leaving 432,154 (71%) pings to process. Note that this is an aggregate statistic that includes all radio pairs, and that GPS errors have not been taken into account[1]. The histograms have used 10m distance bins. The top plot shows a log-histogram of the number of packets received across the network as a function of distance. The time and position of each node is logged when it sends a ping, and the position of the sender can be interpolated from its own position history. We plot the log of the histogram because of the high

1 The ping message does not include the GPS accuracy metrics.

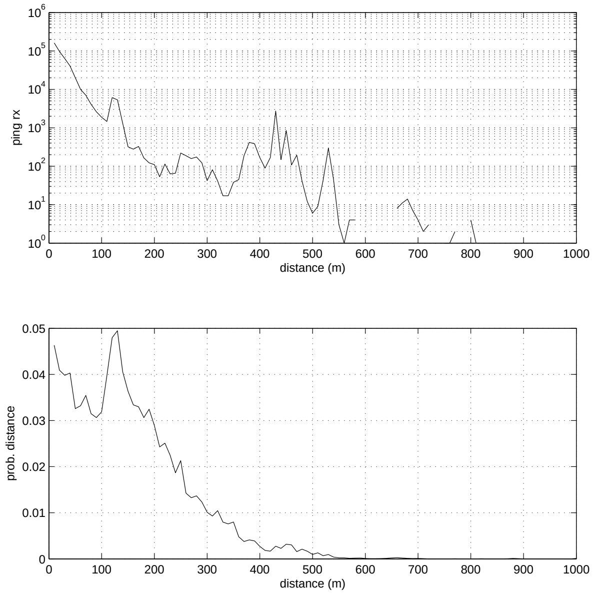

Figure 5. Histogram of number of packets received versus distance. The figure at the top shows the number of pings received by the network as a function of distance between the nodes. The figure at the bottom shows the probability density function of inter-animal distances over the period of the trial.

dynamic range. The lower plot is a probability density function of inter-animal distance based on all pairwise animal distances over the experiment. Both plots taper off with distance which says something about both radio range and animal behaviour. Such statistics could be used to design better routing algorithms for this class of mobile networking problem. An encouraging aspect of these results is that the radios have demonstrated operation at distances greater than 500m which we consider their nominal range. Nearly 2000 pings were received from 500m and beyond, and the maximum received range is 800m, but is perhaps limited by the ability of animals to obtain greater separations in this experiment.

A surprising property of early Mote radios was the lack of symmetry on a communications link, where A could hear B, but not vice versa. We have defined a simple metric which is the number of packets received over the number of packets sent and received, and would be 0.5 for a perfectly symmetric link. Figure 6 shows a histogram of the link symmetry metric for all of the unique 106 pairwise links. The median value is 0.66 and 4 links have a symmetry less than 0.1 and 32 have a symmetry greater than 0.9. Note that these results are a comination of radio characteristics as well as animal mobility.

For an adhoc network the connectivity with neighbours

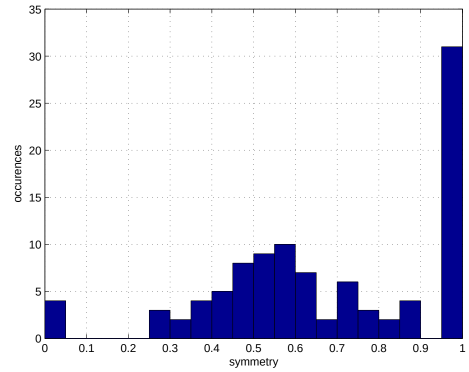

Figure 6. Link symmetry for each node pair (i,j).

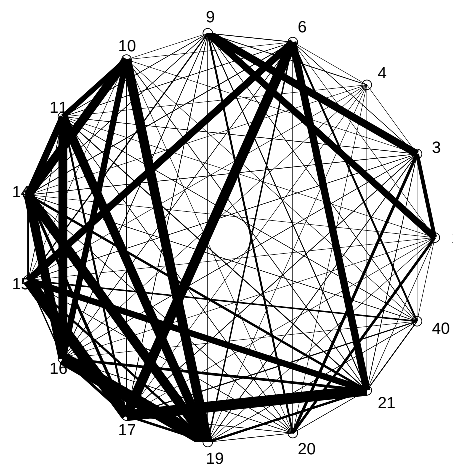

Figure 7. Connectivity graph showing strength of connection between nodes.

is an important consideration. Figure 7 shows a classical connectivity diagram in which we can see some very strong links and a large number of weaker links. The dominant nodes, those with strong connectivity to three or more nodes, are 6, 10, 11, 14, 15, 16, 17, 19 and 21. The temporal variation in connectivity is also important and is shown in Figure 8. The network ping interval is 1 minute and the connectivity measure is defined as the number of unique pinging nodes received in a moving 5 minute window. Results are shown for nodes 3 and 16 (respectively weakly and strongly connected). The mean connectivity over the experiment for nodes 3 and 16 is 1.6 and 2.5 respectively.

4. Conclusion

We have described a large, long-term animal tracking deployment that yielded valuable data about communication within a sensor network. We have presented a preliminary

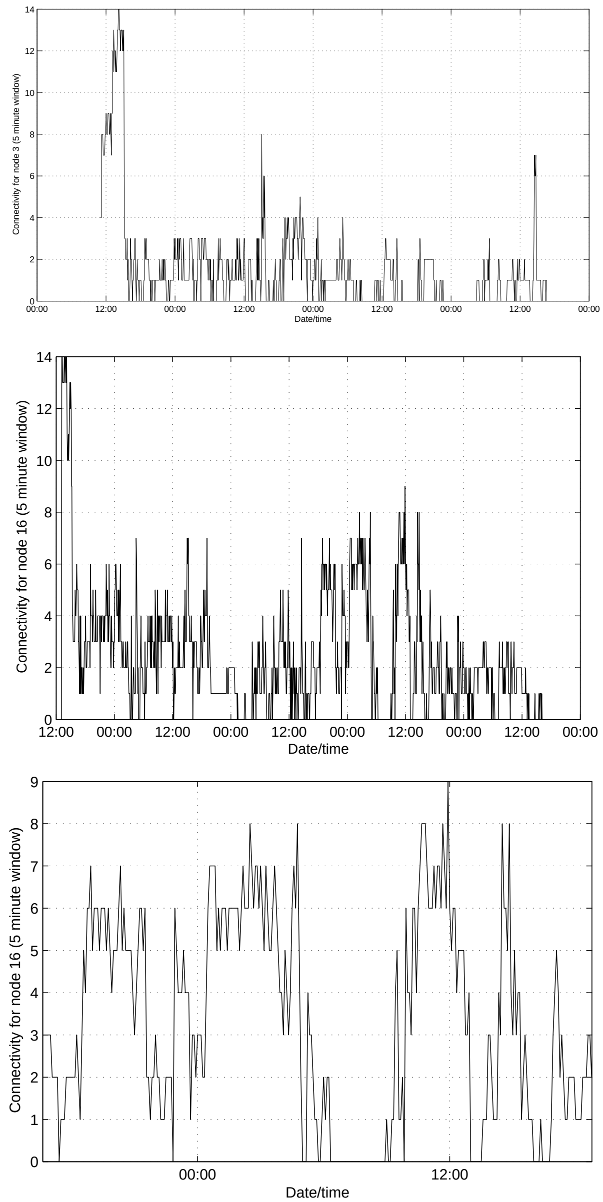

Figure 8. Connectivity as a function of time. Top is node 3 (poorly connected), lower two plots is node 16 (well connected).

analysis of some of the data arising from the deployment and have also identified various practical issues from a real deployment.

In the future, we would like to study ways of extending the life-time of nodes, for example by sensor duty-cycling. We will also address some of the practical problems, especially with antennas. Finally, we would like to explore network topology and routes to base as a function of time. This would provide insights for both animal herd characteristics as well as for communication within such a sensor network.

Acknowledgements

The authors would like to thank Dave Swain and Greg Bishop-Hurley at CSIRO Livestock Industries, Rockhampton for running the experiments at Belmont. We would also like to thank Chris Crossman and Phil Valencia at CSIRO ICT Centre, Brisbane for developing the code running on the collars.

References

[1] J. de Rosnay. *The Macroscope: A new world scientific system*. Harper & Row, 1979.

[2] D. Gay, P. Levis, R. von Behren, M. Welsh, E. Brewer, and D. Culler. The nesc language: A holistic approach to networked embedded systems. In *Programming Language Design and Implementation*, 2003.

[3] J. Hill, R. Szewczyk, A. Woo, S. Hollar, D. Culler, and K. Pister. System architecture directions for network sensors. In *Architectural Support for Programming Languages and Operating Systems*, 2000.

[4] P. Juang, H. Oki, Y. Wang, M. Martonosi, L.-S. Peh, and D. Rubenstein. Energy-efficient computing for wildlife tracking: Design tradeoffs and early experiences with zebranet. In *Tenth International Conference on Architectural Support for Programming Languages and Operating Systems (ASPLOS-X)*. ACM Press, 2002.

[5] P. Sikka, P. Corke, and L. Overs. Wireless sensor devices for animal tracking and control. In *First IEEE Workshop on Embedded Networked Sensors in 29th Conference on Local Computer Networks*, pages 446–454, 2004.

[6] P. Sikka, P. Corke, P. Valencia, C. Crossman, D. Swain, and G. Bishop-Hurley. Wireless adhoc sensor and actuator networks on the farm. In *IPSN'06*. ACM, Apr. 2006.

[7] T. Small and Z. J. Haas. The shared wireless infostation model — a new ad hoc networking paradigm (or where there is a whale, there is a way). In *MOBIHOC*. ACM Press, 2003.

[8] T. Small, Z. J. Haas, A. Purgue, and K. Fristrup. A sensor network for biological data acquisition. In M. Ilyas, editor, *Sensor Networks*. CRC Press, 2004.

[9] Z.Butler, P. Corke, R. Peterson, and D. Rus. Virtual fences for controlling cows. In *Proc. IEEE Int. Conf. Robotics and Automation*, pages 4429–4436, New Orleans, Apr. 2004.

[10] P. Zhang, C. M. Sadler, S. Lyon, and M. Martonosi. Hardware design experiences in zebranet. In *Proceedings of the 2nd international conference on Embedded networked sensor systems*. ACM Press, 2004.