



XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010



EXPLOITATION OF WIRELESS TELEMETRY FOR LIVESTOCK CONDITION MONITORING

CAO DI¹, TSUNG-TA WU¹, HOCK GUAN GOH¹, BRUCE STEPHEN¹, KAE-HSIANG KWONG¹, CRAIG MICHIE¹, IVAN ANDONOVIC¹

¹ University of Strathclyde, Center for Intelligent Dynamic Communication Group, Department of EEE, Royal College Building, 204 George Street, Glasgow, United Kingdom [d.cao/twu/hggoh/bstephen/kwong/c.michie/i.andonovic@eee.strath.ac.uk]

CSBE100712 – Presented at Section VII: Information Systems Conference

ABSTRACT This paper investigates an adaptation of Wireless Sensor Networks (WSNs) to animal health monitoring. Multiple sensors are attached on each individual to monitor health condition or to study the animal's behaviour. However, the robustness of the sensor network cannot be guaranteed due to the limited transmission range on sensor nodes and the data sink as the animal mobility is considered. In this paper, two data collection approaches: router scheme and collector scheme are proposed to enhance the network connectivity. Comparisons are also made between the proposed schemes and the traditional data gathering method with fixed base station (BS). The performance of the proposed design is evaluated through an 8-day trial field experiment.

Keywords: Cattle monitoring, wireless sensor networks, mobility, network connectivity.

INTRODUCTION

The issue of animal health and care in agriculture industry has been raised for couple of years. Government agencies put many efforts to improve animals' living condition and health. Animal welfare is a frequently recurring theme in agricultural livestock industry with government agencies in most developed nations, endowed with regulatory powers to ensure a minimum standard is met. Basic animal welfare defined by the Farm Animal Welfare Council (FAWC) can be concluded as five freedoms: freedoms from hunger and thirst; freedom from discomfort; freedom from pain, injury and disease; freedom to express normal behaviour and freedom from fear and stress [Defra, 2010]. Some conditions can progress quickly and while it is commercially unfeasible to provide round the clock monitoring for individual animals, providing a remote monitoring solution can still allow these to be brought to the farmer's attention in a timely. Therefore, wireless sensor networks are implemented to detect and report onset of animal illness and other emergencies such as calving and lameness. Modern wireless sensors have the advantage of compactness, low cost and low power consumption, which are practical for farm management perspective.

Various sensor applications have been implemented to build up a real time monitoring system including precision agriculture [López Riquelme, et al., 2009], farm facilities monitoring [Darr, et al., 2005][Cugnasca, et al., 2008][Leilei, et al., 2007] and animal habit and health monitoring [Eigenberg, et al., 2008]. Both of the precision agriculture and farm facilities monitoring utilize fixed sensor nodes and the data follow the pre-designed routes back to the data sink. In contrast to the previous two applications, the moving individuals will make great impact on the connectivity of the whole network in animal habit studying and health monitoring. In Tim Wark's (2007) research, the inter-distance of each individual was monitored to prevent the fighting between bulls. The pasture time of the cow had been studied by E.S. Nadimi (2008) to efficiently protect the new grass. Ana Carolina de Sousa Silva (2005) detected the animals' health by monitoring the brain electrical activity. All these references investigate the data gathering by using a centralised system (all data forward to the BS in single hop). Milena Radenkovic (2005) and Grand Sierra Resort (2009) implemented routing scheme into their monitoring network, but the animal mobility issue hasn't been taken into consideration. Therefore, in the research two data collection approaches are proposed to monitor moving animals in a farm size environment. Comparison is made in terms of delay, buffer utilisation and network connectivity to quantify the system performance.

The organization of this paper is as follows. Section 2 investigates the animal mobility and reveals the design challenges of health monitoring using wireless sensor network. The proposed schemes are discussed in section 3. Section 4 describes the field experiment results. Finally, section 5 gives conclusions and discusses future work.

ANALYSIS OF ANIMAL MOBILITY

The research aims to provide an animal monitoring system which takes the animal mobility into the consideration. The wireless sensors are used to monitor the health condition of attached animals which freely move around the open field. The system performance is highly relative to the animal mobility. Since the radio link between wireless sensor and data sink is said to be sporadic due to animal movement, a farm trial has been carried out during the summer months on a farm in Lothian, Scotland to provide a better understanding of animal mobility. The tracks of 13 free ranging cows are recorded by using GPS equipped collars during the trial for 2 days. The captured position data are analysed from the perspective of network connectivity. The network connectivity in this context is defined as measuring of a network's ability to access individual animal in real-time fashion. It is closely related to the network performance in terms of delay and buffer utilisation. In order to evaluate the network connectivity from the recorded position data, the following two assumptions are stated. Firstly, each cow has worn a wireless sensor node which has communication capability for data forwarding with transmission range of 30m. Secondly, a base station is used to collect the data from each individual sensor node with transmission range of 30m.

Figure 1 shows the cows' distribution in a farm environment. It is clear to see that herds of animals do not uniformly distribute themselves may not always move as a single collective. Instead, the herd may break up into independent sub-herds each with their own dynamics. Such behaviour of herds leads the network topology to change dynamically. Due to the mobility of the cows, the communication between the cows and the base station (marked as 'X') is said to be sporadic. Figure 1 also shows the data

communication either is established when the cows moving in the radio range of the base station or is facilitated by multihop transmission.

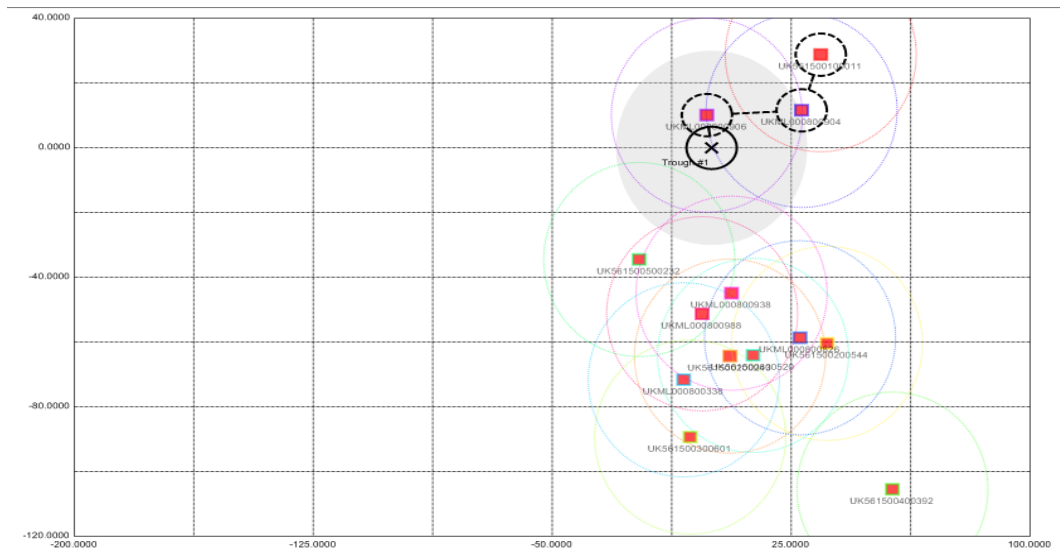


Figure 1: A snapshot of network connectivity during the farm trial.

To further investigate the animal mobility, analytical metric for network connectivity is proposed to quantify the impact of the cow mobility in farm environment. The network connectivity, NC_i is defined as the fraction of time which the wireless sensor node on cow i is capable to communicate with base station. As mentioned earlier, the communication is either established by direct transmission from node to base station or is facilitated by multihop transmission via other intermediate node. Other interferences such as noise and collisions are ignored.

The connectivity over a typical day was simulated and 24 hours' GPS data from 13 cows were fixedly recorded. All the cows were allowed to move unconstrained in a 6 hectare open field. The average network connectivity represents the real-time communication capacity of network system, which can be obtained by:

$$\overline{NC} = \frac{\sum_{t_1=0}^T \sum_{i=1}^N NC_i}{N} \quad (1)$$

where T is evaluation time and N is the number of mobile nodes. Figure 2 shows the average network connectivity versus radio communication range of base station. The network approaches full connectivity as the radio communication range exceeds 100m. However, wireless sensor network is power constrained which will result in limited communication range of typically less than 30m. The result also shows the network connectivity is in the order of 10% when the typical communication range of 30m is considered. This low network connectivity will seriously decrease the network performance in terms of delay and buffer utilisation.

The analysis result of network connectivity concludes that there are two options can be used to improve the network connectivity. The first option is to increase the transmission

power of sensor node. However, the increment of transmission power implies that more energy resource will be consumed for radio propagation. As the result, whole network lifetime will be decreased significantly. This research takes the similar approach but alternatively enhance radio converge of base station by using additional access points or mobile collector. The second option is to facilitate the multihop communication which is a subject of future research.

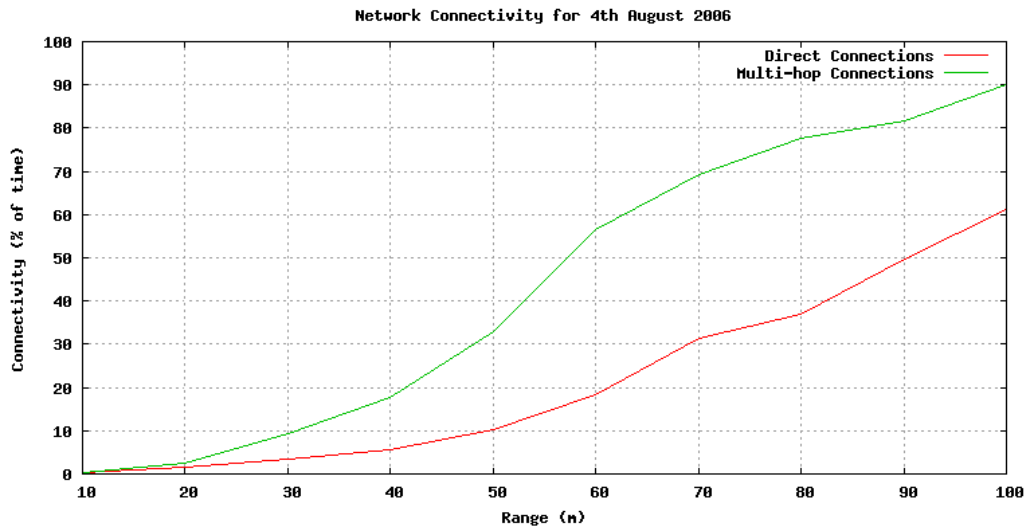


Figure 2: Percentage of connected nodes from various ranges for two different types of connection.

DATA GATHERING APPROACHES

Two schemes are proposed to overcome low transmission range of wireless sensor node and improve network connectivity.

- **Data Collector Scheme**

Data collector, also known as a data mule, is a mobile/portable device that can be brought into the operational field where the animals gathered to download data [Anastasi, et al., 2007]. The scheme is used when the animals are beyond the transmission range of any access point. Thus a data collector can be used to relay the information back to the data sink. The hardware structure of data collector is composed of processing unit, memory unit, radio transmission unit and power unit. There is no power constrain on the collector and in order to cover a large area of signal, high gain antenna and large battery pack are installed to fulfil the requirements. With these additional add-ons, the collector can continuously detect the sensor nodes nearby and download the data from them.

When the measured data on sensor node cannot be forwarded to the BS, it will temporally be buffered into onboard flash memory in FIFO (First In First Out) fashion. Periodically, the data will be rebroadcasted to search for the BS or relay nodes. However if the node is isolated for a long time, there is a high probability that the data will get dropped whenever the buffer is full. Therefore, a collector is required to relay the data and release the buffer on the nodes. In a farm environment, a collector can be carried by a farmer or a well-trained dog.

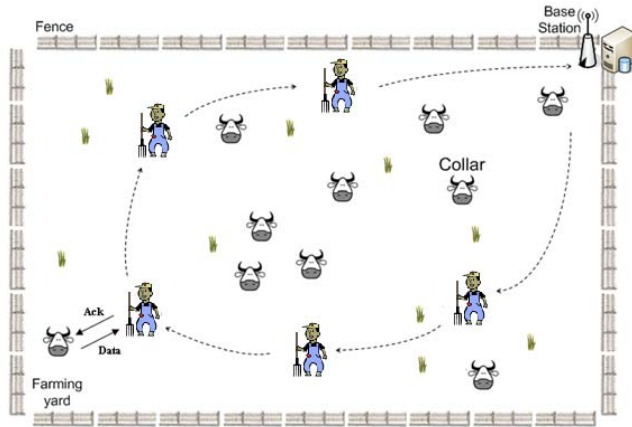


Figure 3: Operation strategy for data collector scheme.

The communication protocol of the data collector can be divided into two phases: pickup phase and dispatch phase. During the pickup phase, the collector will make a handshake with the sensor node nearby. Whenever the collector falls in the transmission range of the sensor node, it will detect the rebroadcasted data from node. And if the packet is successfully received without collision or fragmentation, it will be stored in the memory of the collector. Meanwhile, an acknowledgement packet (ACK) will be sent back to the sensor node. Once the node receives the ACK, it will wipe off the send data from the flash memory and aware that the data collector is reachable. In this case, it will continuously upload its buffered data to the using two-way communication as described above. The dispatch process is happened between the collector and base station. During the time when collector picks up the data from sensor node, it will broadcast its own buffered data periodically attempting to reach the BS. If the data collector comes within the range of BS, it will continuously upload its buffered data until the flash memory is empty. Otherwise, it defers the data transmission for T sec and rebroadcasts the buffered data. The detailed flow chart of collector scheme is provided in Figure 4.

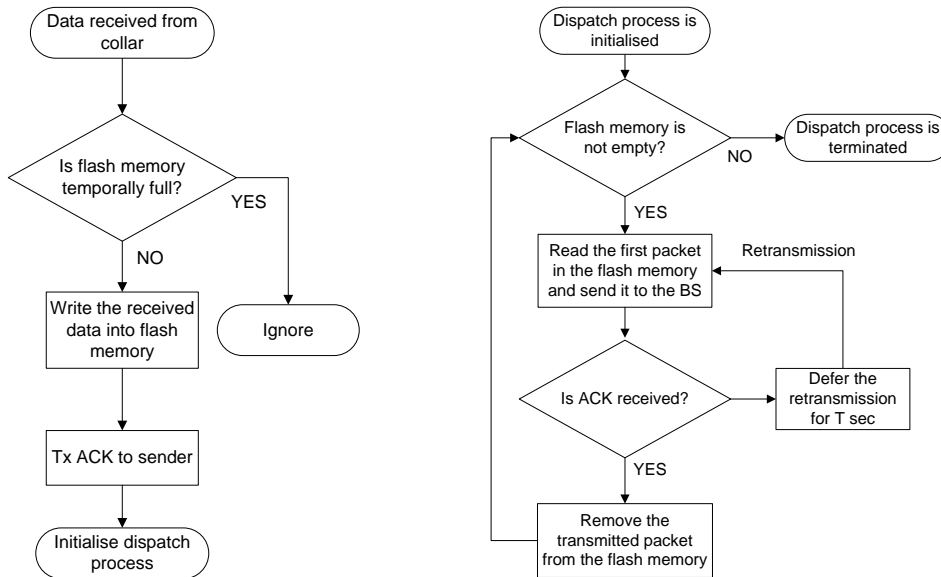


Figure 4: (a) Flowchart of pickup phase; (b) Flowchart of dispatch phase.

• Router Scheme

The router scheme makes use of several routers deployed at fixed geographical locations to extend the transmission range of the BS. As the radio coverage of the BS is extended, the probability of the sensor node fall into the communication range of BS (via routers) is increased as well. As the result, the system performance in terms of delay and system capacity can be improved. Since each router is placed on the ground, there is no constrains on the size of the hardware component. Therefore, large battery pack is installed to extend its lifetime and directional antenna is used to increase the transmission range of each router as shown in Figure 5.

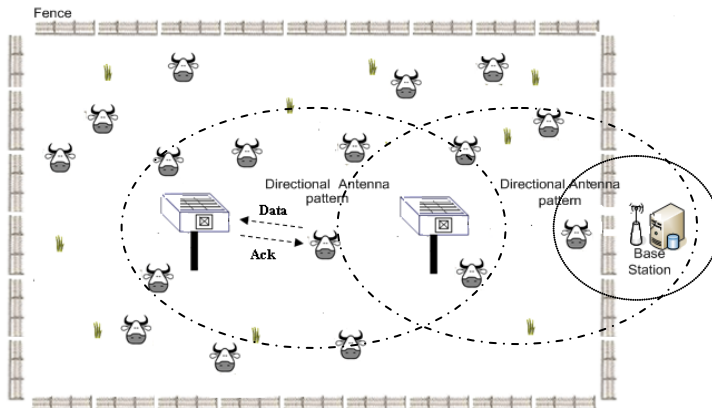


Figure 5: Operation strategy for router scheme.

The communication protocol of router scheme also includes a pickup phase and a dispatch phase. In the pickup phase, it operates exactly the same as the collector scheme. During the time whenever the fixed router captures the rebroadcasted data from the sensor node, it will reply with the ACK packet to inform that the packet has been successfully transmitted and the connection is established. Then the nodes will

continuously upload the data until the buffer is totally released or the connection breaks down again. In the dispatch phase, due to the pre-designed location of routers, each of them will only unicast data to the relay router or BS. As soon as the packets come in, it will forward them to the next hop and wait for the acknowledgement. Since the position of BS and routers are fixed and predefined, the radio link between them is assumed to be reliable. Therefore there is no need to defer T sec before data retransmission. The detail flowchart is provided in Figure 6.

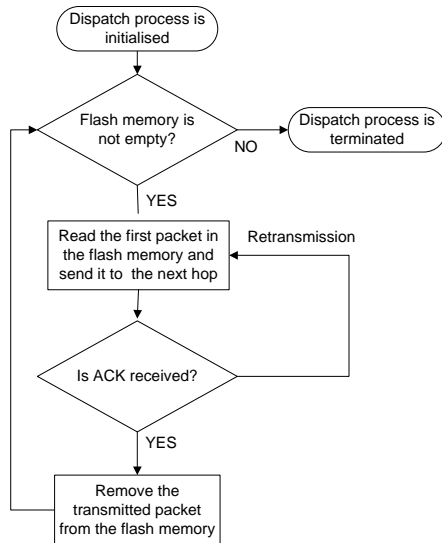


Figure 6: Flow chart of dispatch phase for router scheme.

EXPERIMENT AND RESULTS

An 8-day period farm trial was conducted to study the performance of the proposed schemes. The experiment is set up on a farm in Woodhouselee, Scotland. The data is recorded from 8 mature Limousin and Angus Crosses. A collar that using MICAz platform with GPS (Global Positioning System) sensor is attached at the neck of each Angus Crosses as shown in Figure 6(a). The GPS sensor provides the location every 8 sec. Figure 6(b) shows a typical GPS logged data for a period of 24 hours. The farm size is approximately 250x350m large with the fence divides the field into three parts. All these areas are accessible via the gates. Three water sinks are placed fairly and the base station is set up nearby one of them. Therefore, the base station will have a better network connectivity when the cows toward to drink water.

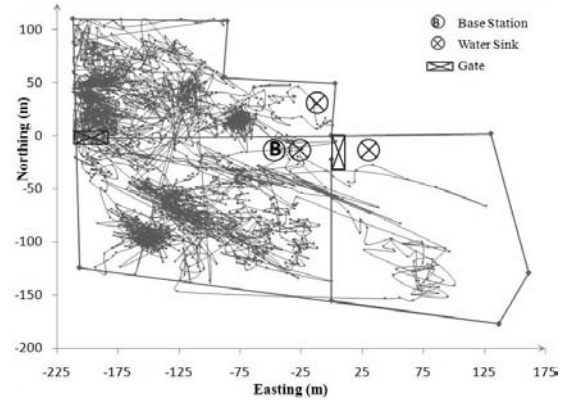


Figure 6: (a) Cattle wearing collars; (b) A 24 hours trace of a cow and the layout of the farm.

The experiment falls into three parts based on three different schemes. Single base station scheme was utilised in a two-day trial at the early beginning. The data can only be uploaded when the collar falls in the communication range of the BS. Therefore, the network connectivity highly depends on the movement of each individual cow. Then the router scheme was carried on in a four-day trail. Two routers are deployed in the middle of the pasture, which is separated in the distance of 50m. 9dBi directional antenna is installed to extend the transmission range. The routers collect the data from the sensor node in their transmission range and relay them back to the BS. The network performance of this scheme is still depends on the animal distribution in the pasture, but transmission range for collecting the data is relatively extended. Afterwards, data collector scheme is implemented for another two-day trail. The collector was sent out by human four times every day (2 times in the morning and 2 times in the afternoon). The route for the collector is controllable and takes approximately 10mins to physically access to all remote cattle and download the data through the BS.

The network connectivity is analyzed in terms of Buffer utilisation and the average delay. The buffer utilisation counts the number of packet stored in the buffer when there is no direct link between the nodes and any access points. And the value of average delay is the length of time from the packet generated at GPS sensor to the packet received at the base station. In table 1, the values represent the average data of 24 hours for each collar. Results show that the buffer utilisation in the pure BS scheme is kept at a high level which is 435.04. In contrast to the BS scheme, the average value of 8 collars has been reduced to 361.71 for collector scheme and 287.03 for router scheme. On the other hand, the average delay for each packet follows the same trend, which decreases 18.1% and 32.6% for collector scheme and router scheme respectively.

Table1: Buffer utilisation and average delay for different communication schemes.

	Pure BS Scheme		Data Collector Scheme		Router Scheme	
Collar ID	Buffer utilisation	Avg Delay (s)	Buffer utilisation	Avg Delay (s)	Buffer utilisation	Avg Delay (s)
1	709.33	5859.64	594.27	4874.56	558.42	5137.37
2	262.73	2233.48	108.49	958.75	241.59	2179.18
3	198.61	1639.03	141.87	1192.24	205.85	1714.93
4	276.75	3201.1	209.79	1923.82	138.81	1242.8
5	357.31	2972.04	301.84	2529.5	259.68	2128.62
6	360.51	3024.16	315.61	2636.93	272.95	2394.07
7	463.46	4023.57	606.49	5290.03	290.67	2586.88
8	851.58	6946.94	615.36	5073.38	328.26	2761.37
AVG	435.04	3737.49	361.71	3059.9	287.03	2518.15

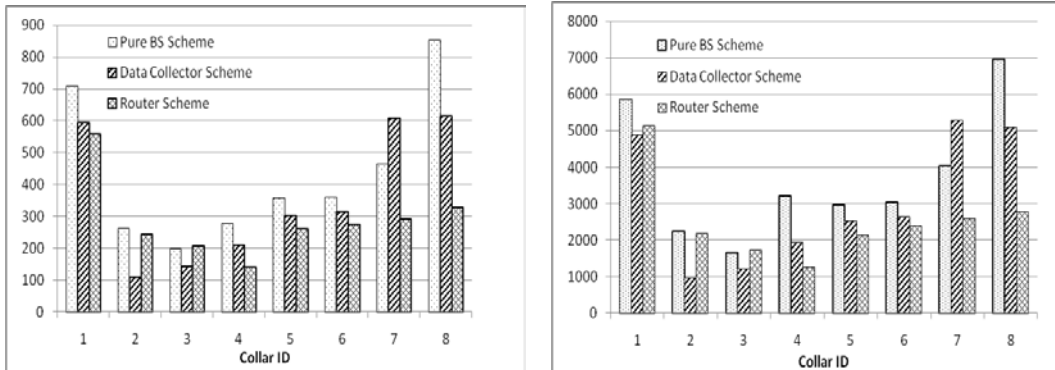


Figure 7: (a) Buffer utilisation for different communication schemes (b) Average delay for different communication schemes

The network connectivity NC_i mentioned in section 2 is defined as the fraction of time which the wireless sensor node on cow is capable to communicate with base station. In the field experiment, a timestamp is made whenever the node falls in the transmission range of the access points. Table 2 Shows the time period when the cow was out of the range of base station in 24 hours. The average time for pure base station scheme is 79493.5sec, which means approximately 22 out of 24 hours the nodes has no connection to the BS. Thus the network connectivity (NC_{avg}) is equal to 8% according to the Equation (1). For the proposed two schemes, network connectivity is equal to 14% for data collector and 38% for router respectively, which has been relatively improved.

Table 2: Length of time when the cows beyond transmission range for different communication schemes.

Collar ID	Pure BS Scheme	Data Collector Scheme	Router Scheme
1	83309	83186	77750
2	74584	55866	65479
3	74096	67209	65355
4	75535	71496	55451
5	79448	79159	65646
6	79763	76660	64597
7	80754	87580	65646
8	88459	76021	70425
AVG	79493.5	74647.125	66293.625

From the measured data above, the router scheme also outperforms to the collector scheme in the experiment. Compared to the collector scheme, the buffer utilisation decreases 20.4% and the average delay reduces 17.7% respectively. Note that the number of the router will directly affect the performance of the network. As the number of scattered router increased, the radio coverage of BS can further extended consequently the system performance is relatively improved. For the collector scheme, the network connectivity is also influenced by how frequent the collector is sent out. The trade off between the system performance and the additional cost for installation and farm management is required to be taken into consideration.

CONCLUSION

This paper addresses the problem of low network connectivity for animal health monitoring in the farm. Instead of increasing the transmission range of a single node, two schemes are proposed to improve the network performance, which are data collector scheme and router scheme. Data collector scheme utilises a moving collector to actively pick up the data from all the nodes and router scheme implements multiple access points to extend the coverage range of single BS.

This paper also presents an initial result of the field experiment. The comparison is done among BS using two schemes in terms of buffer utilisation and average delay. The network connectivity is calculated and the results show the network performance has been improved by using the proposed schemes. More work remains in the several farm trails, the further investigate will focus on the multi-hop routing scheme, which also can be implemented to enhance the network performance.

REFERENCES

- Department for Environment Food and Rural Affairs (Defra) Online: Cattle Health and Welfare. Available at www.defra.gov.uk. Accessed 22 February 2010.
- J.A. López Riquelme, F. Soto, J. Suardiáz, P. Sánchez, A. Iborra, J. A. Vera, *Wireless Sensor Networks for precision horticulture in Southern Spain*, *Computers and Electronics in Agriculture*, Volume 68 , Issue 1, August 2009.
- M.J. Darr, L. Zhao, M.R. Ehsani, J.K. Ward, and T.S. Stombaugh, *Evaluation of Controller Area Network Data Collection System in Confined Animal Feeding Operations*, *ASABE Proceedings of the Seventh International Symposium*, 18-20 May 2005.
- C.E. Cugnasca, A.M. Saraiva, I.D.A. Naas, D.J. de Moura, and G.W. Ceschini, *Ad Hoc Wireless Sensor Network Applied to Animal Welfare Research*, *ASABE Livestock Environment VIII*, 31 August – 4 September 2008, Iguassu Falls, Brazil, 2008.
- Leilei Pan, Rui Liu, Shanghong Peng, Simon X. Yang and Stefano Gregori, *Real-time Monitoring System for Odours around Livestock Farms*, *Proceedings of the 2007 IEEE International Conference on Networking, Sensing and Control*, London, UK, April 2007.
- R.A. Eigenberg, T.M. Brown-Brandl, J.A. Nienaber, *Sensors for Dynamic Physiological Measurements*, *Computers and Electronics in Agriculture*, Page 41-47, 2008.
- Tim Wark, Chris Crossman, Wen Hu, Ying Guo, Philip Valencia, Pavan Sikka, Peter Corke, Caroline Lee, John Henshall, Kishore Prayaga, Julian O'Grady, Matt Reed, Andrew Fisher, *The Design and Evaluation of a Mobile Sensor/Actuator Network for Autonomous Animal Control*, *Information Processing In Sensor Networks*,

- Proceedings of the 6th international conference on Information processing in sensor networks, 2007.
- E.S. Nadimi, H.T. Sogaard, T. Bak, F.W. Oudshoorn, ZigBee-based Wireless Sensor Networks for Monitoring Animal Presence and Pasture Time in a Strip of New Grass, *Computer and Electronics in Agriculture*, Page 79-87, 2008.
- Ana Carolina de Sousa Silva, Aldo Ivan Cespedes Arce, Sergio Souto, Ernane Jose Xavier Costa, A Wireless Floating Base Sensor Network for Physiological Responses of Livestock, *Computers and Electronics in Agriculture*, Page 246-254, 2005.
- M Radenkovic, B Wietrzyk, Wireless Mobile Ad-hoc Sensor Networks for Very Large Scale Cattle Monitoring, *Proc. of ASWN*, 2006
- M Radenkovic, B Wietrzyk, Mobile Ad Hoc Networking Approach to Detecting and Querying Events Related to Farm Animals, *Proc. of ICNS*, 2006
- E.S. Nadimi, R.N. Jorgensen, V. Blanes-Vidal, S. Christensen, Monitoring and Classifying the Behavior of a herd of Sheep using ad hoc Wireless Sensor Network and Artificial Intelligence, 2009 Reno, Nevada, June 21 - June 24, 2009.
- K H Kwong, H G Goh, Craig Michie, Ivan Andonovic, Bruce Stephen, Toby Trevor Mottram, David Ross, Wireless Sensor Networks for Beef and Dairy Herd Management, 2008 Providence, Rhode Island, June 29 – July 2, 2008
- Benahmed Khelifa, H. Haffaf, Merabti Madjid, and David Llewellyn-Jones, Monitoring Connectivity in Wireless Sensor Networks, *International Journal of Future Generation Communication and Networking*, Vol. 2, No. 2, June, 2009.
- M.A. Kossaibati, R.J. Esslemont, The costs of production diseases in dairy herds in England, *The Veterinary Journal*, Volume 154, Issue 1, July 1997, Pages 41-51.
- G Anastasi, M Conti, E Monaldi, A Passarella, An adaptive data-transfer protocol for sensor networks with Data Mules *Proc. of IEEE WoWMoM*, 2007.