WSN for Cattle Monitoring – Related Work and Design Proposal

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I. Introduction

A. Background

The livestock industry constitutes a considerable part of the worlds economy. In fact, it generates around € 8.6 billion every year in the Netherlands alone [1]. At the same time, there is a clear trend of automation in this sector that aims to increase the efficiency and decrease the amount of human labour.

However, one of the major costs for the farmers in this field is due to the diseases contracted by their animals. By developing a system that could detect such diseases, and other abnormal behavior, one could potentially reduce this cost by a great amount.

B. Application Description

The main purpose of this project is to design a system that can help farmers monitor the health of cattle while they are grazing. This will be done using wireless sensor network (WSN) technology, because of its ability to deliver real-time monitoring at a very low cost. However, on account of range limitations of WSN transceivers, the system will be designed for a relatively small field of 10 ha which is in the range of an average dairy farm in the Netherlands [2].

The network of the system will consist of three types of nodes: a base station, which acts as a data sink; sensor nodes, one for each head of cattle, recording health characteristics; and a number of relay nodes on fixed positions in the field, forwarding data from the sensor nodes to the base station. The reason for using relay nodes, is to be able to cover the majority of the field.

The system will be used both to detect different types of diseases, for example: fever, lameness and mastitis, and to detect if a cow is in estrus. This can be accomplished by the of use accelerometer-, microphone-, and temperature sensors in the sensor nodes [3]. Every 5 minutes, the sensor nodes will send the acquired data in a processed form to the base station for storage. The base station can analyse the sample values to detect patterns that correspond to different diseases or the onset of estrus.

C. Related Work

Wireless livestock monitoring has became a widely researched area in recent years due to the increased availability and lower costs of wireless sensor network technologies. WSN have been utilized in many livestock monitoring applications around the world such as animal localization, behavior analysis, health monitoring or pregnancy detection in cows. Several studies are concentrated to raw data collection [4], [10] for later data processing and research. The main drawback of these studies is the high energy consumption of the sensor nodes, which limits the lifetime of the nodes to only a few days at most. Also the storage and processing of collected data would be a problem in longer term.

Most of the livestock monitoring WSNs are designed for cattles [4]–[15] but there are also examples of studies for sheep health and behavior monitoring [19] and chicken monitoring for avian influenza surveillance in poultry farms with ultra low power wireless sensor nodes [17], [18]. The wireless health monitoring of cows has been one of the most important researched topic among authors. Kumar et al. [7] and Wang et al. [10] both developed cattle health monitoring WSNs based on the IEEE 802.15.4 protocol. Hwang et al. [9] showed that continuous monitoring and comparison of cattle activity can be used for disease prediction and prevention. In addition to disease prediction, pregnancy detection is also possible using continuous monitoring [13].

Wireless sensor networks can be used for livestock localization indoor [20] or outdoor [12], [14]. Panckhurst et al. [12] developed a GPS based wireless positioning system, while Huircan et al. [14] demonstrated that the link quality indication (LQI) feature of the ZigBee protocol can also be a candidate for outdoor livestock localization. Livestock positioning can have different purposes around the world, like the prevention of pastureland degradation and desertification in Mongolia [16] or cattle rustling prevention in Africa [8].

The ZigBee protocol and a carrier frequency of 2.4 GHz are widely used [7], [8], [14], [19], however some of the authors [6], [12], [17], [18] prefered sub-gigahertz carrier frequencies due to the higher communication distance. Sousa Silva et al. [6] have demonstrated that a Floating Base Sensor Network (FBSN) is also a feasible solution for data collection in large mobile wireless sensor networks. Kwong et al. [15] have analysed the problem of signal penetration through animal's body and they proposed a two antennae scheme for an optimized radio coverage of the cattle's neck collar. In this project we will not consider the interference caused by the body of the cows.

II. Application Specific Challenges

A. Mobility

Mobility presents a major challenge for sensor nodes mounted on cattle since they are subject to frequent changes in location. The animal monitoring system must be able to support animal mobility. The network topology and routing paths should therefore be dynamic, able to respond to frequent animal movement while optimising packet delivery.

B. Size of Field

A key challenge in a wireless network of this kind is the coverage of the wireless nodes. In cattle monitoring WSNs the network architecture should be able to cover enough area of the fields and must be scalable accordingly when needed for larger fields. The average size of a dairy farm field in the Netherlands is around 100,000 m^2 and the maximum range of Zigbee WSN protocol is approximately 500 m, so theoretically, only one or two relay nodes could cover a sufficient area of the field. In reality, transceivers with such range capabilities are not used in WSN applications, because of cost and power constraints.

C. Wireless Communication

As the animals move freely on the field, wireless technology is considered the only feasible method to establish and maintain communication between a base station and network nodes attached to the cattle. The wireless communication imposes several challenges on the design, like signal attenuation in the medium, interference from other radio signals, crosstalk from the other nodes, etc. As the radio signal generated from the node is weak owing to preserve battery on the node, a significant amount of wireless signal is attenuated by the animal tissue. For maximum signal coverage from relay node the antenna on the animal is placed on a neck collar with two antenna on both sides of the neck to have spatial diversity. Also the radio element is switched off as soon as the data transmission is finished so as to maximize battery life.

D. Energy Consumption

The battery usage is one of the major constraint in cattle monitoring networks because the radio collars used for cattle monitoring are expected to run for up to several years without battery replacement. As there is limited battery power available per node, low powered, lightweight radio antennas should be considered for the design. The network protocol should be designed so as to use limited battery power and only communicate with the base station, to provide adequate amount of data required for monitoring health of cattle. The processors used by the nodes should be chosen so as to consume a minimum amount of power, while still being able to perform the necessary operations on the data as required by the application.

E. Cost of the System

The design of a WSN should not be too expensive. Furthermore the wireless nodes must be low-cost with high lifespan and low maintenance in order to reduce the cost of managing the system. Another reason for the sensor nodes to be low-cost is the potentially high number of nodes needed for monitoring an entire herd.

III. Requirements

To ensure that the designed system can meet the challenges described in chapter II, it needs to meet the following requirements:

1) The network must be implemented in such a way that if a sensor node moves out of coverage, the sensor node will be reassigned to the network once it moves into coverage again.
2) The end-to-end latency between the sensor nodes and the base station must be less than 2 minutes for at least 90 % of data packets.
3) For every sensor node at least 70 % of the recorded sensor data must be delivered to the base station during a 5 hour period.
4) The time until the first sensor node of the network fails must be greater than one year.
5) The network must function and be scalable for up to 30 sensor nodes.
6) The network must continue to function whether nodes are added or removed.
7) When out of coverage, each sensor node must be able to store sensor values for a period of up to four hours.

A. Herd size

B. Resting Time

C. Data size

One of the most important requirements for the system is to be able to handle the amount of data generated by the sensors. Estimating this amount is thus also very important. For storing the temperature of the cow after processing the raw data from the sensors, one byte is enough to give a reasonable resolution. This is because a dairy cows normal rectal temperature lies between 38.3°C and 38.9°C [21] and one could limit the byte to represent values between 30°C and 50°C without losing any information. Using the same argumentation, one byte could also be used to store the average heart rate, because the normal heart rate for a dairy cow lies between 40 and 84 beats per minute [21].

In addition, to store the data gathered from the accelerometers, one could devise a similar strategy to the one used in a study where the behaviour of sows were classified [22]. In this study, the activities of the animals were organized into four different sets, using a method specifically developed for low powered embedded devices. This resulted in a classification with an accuracy of close to 90 %. Using data in this format, the researchers were able to detect the onset of farrowing. In this study only four sets of behaviours were used, if it is possible to develop similar sets for behavioural studies on cows, one byte would be more than enough to describe the behaviour.

If five samples for each category are generated, the total data amount needed to be sent each five minute interval would be 15 bytes.

IV. Implementation

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The system will be developed for platforms supporting ContikiOs. For the physical- and MAC layers, the standard protocol IEEE 802.15.4 [23] will be used. For the network- and application layer, features from ContikiOs will be used. Moreover, a routing algorithm might possibly be designed, if the routing algorithms present in ContikiOs are deemed unfitting for our application.

A. Simulation Software

The design of the network will only be tested in simulation, no real world experiments will be done. We will use cooja, which is a simulator for contiki node. This simulator is compatible with the following platforms: TI MSP430x (TI CC2420), TI MSP430x (TI CC2520), Atmel AVR (TI CC2420), TI MSP430 (TI CC2420) and TI MSP430 (RFM TR1001).

The number of nodes that can be simulated using this software depends on memory of the machine running the simulation and the application running on the nodes. As there is a main simulation thread, using more than two cores (one for the simulation and one for the rest) gives no significant improvement [24].

To simulate the movement of the cows in Cooja, a mobility plugin first has to be installed. However, to be able to generate our own specific mobility file, another tool like BonnMotion has to be used to make the mobility output format compatible with Cooja's mobility plugin format. We will only be considering a few simple mobility models like: the gauss-markov-, the random waypoint- and the reference point group mobility models. Simulating more complex and accurate mobility patterns of the cows is not the goal of this project.

To provide a reliable transmission range, there is a UDGM (Unit Disk Graph Radio Medium) implementation that can be configured to change some parameters like transmission range and interference range. Depending on the transmission power parameter, the resulting transmission range will differ [24].

Contiki supports different MAC layers: X-MAC, LLP (Low Power Probing), Simple TDMA and nullmac (non-persistent CSMA). X-MAC and LPP are low power MACs that work best under low traffic loads [25]. Furthermore, Contiki supports different protocol stacks like uIP which is a very small and fully compliant TCP/IP stack. Contiki also supports Rime stack which consists of small layers built on top of each other and has single and multi-hop broadcast [25].

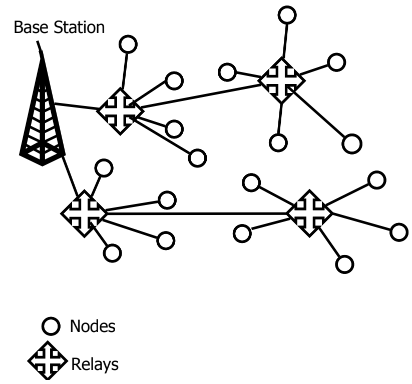

Fig. 1. An overview of the network topology.

B. Network Topology

The network topology of the implementation has a tree like structure with the base station acting as the root of the tree, see Fig 1. The relay nodes act as the branches of the tree, being connected to the base station through each other, while the sensor nodes behave like the leaves of the tree.

The sensor nodes send data to any relay node that is within transmission range. Once received by a relay node, the data will be forwarded to the base station with the help of a routing protocol.

C. Physical Layer

In order to get an increased range and mitigate the problems with coverage, carrier frequencies between 902 MHz and 928 MHz of the IEEE 802.15.4 standard, were originally considered. However, as these frequencies are not supported by the TI CC2420 transceiver of the Telos B, a frequency of around 2.4 GHz was used instead.

For the modulation, the direct-sequence spread spectrum is used, because it is implemented in the transceiver mentioned above.

Different transmission powers are used for the different node types used in the implementation. The base station and relay nodes both use the maximum transmission power of the transceiver to ensure that the relay nodes can be placed as far apart as possible. The sensor nodes, on the other hand, use half of the maximum transmission power to save energy. Because the sensitivity of the Telos B nodes cannot be changed, this introduces an asymmetry between the nodes: relay nodes can reach the sensor nodes at maximum range while the converse is not possible. Even though this reduces the coverage compared to the case where maximum transmission power is also used in the sensor nodes, there is still one benefit: few relay nodes are needed to create a chain to a relay node placed far away from the base station (for example in a remote corner of the field). Thus the sensor nodes will still have a short distance to the nearest relay node.

According to an experiment performed in an outdoor environment, the average propagation path loss at 60 m for a link between two Telos B Nodes was estimated to be 92.3 dB. Using this value, along with 0 dBm, the maximum transmission power of the Telos B node, in the path propagation loss formula:

$$P_r[dBm] = P_t[dBm] - P_L[dB]$$

where P_r is the received power, P_t is the transmitted power, and P_L is the propagation path loss gives -92.3 dBm which is greater than -94 dBm, the nominal receiving sensitivity of a Telos B node. Taking this into account, the maximum transmission distance of the nodes are set to 60 m in the simulation.

D. MAC Layer

For the MAC layer, there are two modes to be used in the IEEE 802.15.4 standard: nonbeacon-enabled mode and beacon-enabled mode. In the former a unslotted CSMA/CA mechanism is used. In the latter one, a more elaborate scheme is used, wherein special nodes of the network, called coordinators, regularly send out beacons to synchronize with the nodes they are associated with. The period between two beacons is called a superframe, and within this the nodes use a slotted CSMA/CA mechanism.

Because of the need for synchronization, the beacon-enabled mode might cause problems if a sensor node moves out of the coverage of a coordinator for a longer period of time, or if a sensor node needs to switch to a different coordinator. The sensor node might have to listen for a very long time to receive the next beacon, possibly even the whole time while it is out of range, thus consuming a lot of power.

On the other hand, the unslotted CSMA/CA mechanism of the nonbeacon-enabled mode, in addition to being less complex, does not require the nodes associated with a coordinator to regularly receive a beacon, and is thus suitable for the mobile nature of our application. The main drawback is the power consumption required for continuously listening at regular intervals. However, since the relay nodes and the base station are the only ones that need to receive data, only these will have to listen continuously, and not the sensor nodes. In view of these arguments, the design will use the nonbeacon-enabled mode. However, as contiki does not implement unslotted CSMA/CA, we will use one of the congestion-based MAC layers that contiki provides, in its place.

E. Network- and Application Layer

1) Packet Structure: For the network to function correctly, each node needs to be able to determine which type of packet it has received. This is achieved by including a one byte field in each packet whose value correspond to different packet types.

There are 5 types of packet used in the network.

- Sensor packets are broadcasted by the sensor nodes, and received by any relay node within range. These packets contain 15 bytes of data generated by the sensors.
- Init packets are broadcasted by the relay nodes and by the base station. The packets are used to configure the routing mechanism.
- Aggregated packets are broadcasted by the relay nodes and are used to aggregate several sensor packets into bigger packets.

2) Routing Mechanism: The network uses directed gossiping to route data from the sensor nodes to the base station. In our implementation, this method works by making sure that each relay node has a *hop count* that specifies the number of communication hops between it and the base station.

When a sensor node wants to transmit a sensor packet, it broadcasts the packet which will be received by any relay nodes within range. The relay nodes, after accumulating enough sensor packets, will broadcast an aggregated packet containing the aforementioned sensor packet and the hop count of the transmitting relay node. When a relay node receives an aggregated packet, it will only forward the packet if the relay node's hop count is lower than the hop count of the packet. Upon forwarding, the relay node also decrements the hop count of the aggregated packet by one.

To determine the hop count of each relay node, a configuration process is performed at regular intervals. The process is initiated by the base station, which broadcasts an init packet with a hop count and a sequence number, both set to zero. When receiving an init packet, the relay nodes compares the sequence number of the packet with the sequence number of the last received init packet. If the received packet's sequence number is higher, the relay node resets its hop count to a very large default value (initially, the hop count is also set to this default value). After this, the relay nodes compares the hop count of the received packet to its own hop count. If the former is lower, it means that the route that the init packet took has a lower hop count, the hop count of the relay node is therefore set to this value, and the init packet is forwarded with the hop count incremented by one. If the former is higher, then there is at least one shorter route and the packet is simply dropped.

3) Sensor Node:

4) Relay Node:

5) Base Station:

V. Performance Evaluation

A. Mobility Models

B. Test Scenarios

C. Data Extraction

D. Results

E. Discussion

VI. Conclusion

VII. Future Work

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TABLE I
LATENCY AND PDR USING 6 RELAY NODES

Number of sensor nodes	Mobility Type	Latency		PDR (%)
		Avg. (sec)	<2 min (%)	
5	1	44.85	90	31.58
	2	48	97.3	77.89
15	1	41.71	94.1	41.75
	2	24.73	97.3	77.54
30	1 game theory	14.9	99.6	81.75
	2	19.17	98.6	62.11

TABLE II
LATENCY AND PDR USING 12 RELAY NODES

Number of sensor nodes	Mobility Type	Latency		PDR (%)
		Avg. (sec)	<2 min (%)	
5	1	87.02	70.8	50.53
	2	65.28	87.1	89.47
15	1	36.16	98.3	41.4
	2	32.42	95.5	85.26
30	1	16.34	98.6	90.88
	2	21.86	98.3	82.81

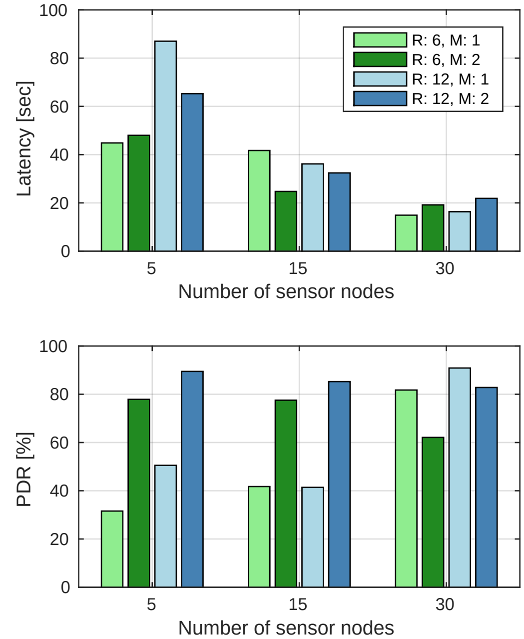

Fig. 2. Simulation results: (a) average latency and (b) packet delivery ratio (PDR). R and M denote the number of relay nodes and the mobility type, respectively

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