WSN for Cattle Monitoring – Related Work and Design

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I. Introduction

A. Background

The livestock industry constitutes a considerable part of the worlds economy. In fact, it generates some € 8.6 billion every year in the Netherlands alone [1]. At the same time, there is a clear trend of automatization 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 diseases contracted by their animals. By developing a system that could detect such diseases, and other abnormal behavior, one could potentially reduce this costs 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: fever, lameness and mastitis, and to detect if a cow is in estrus. This can be accomplished by the use accelerometer-, microphone-, and temperature sensors in the sensor nodes [3]. Every 4 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 and thus, the limited time (only a few days at most) these nodes can function. 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 studies for sheep health and behavior monitoring [19] or 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 the disease prediction, with continuous monitoring of cows, also the pregnancy detection is possible [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; wireless sensors are used to monitor the health condition of animals moving freely around open fields. 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

The key challenge in any wireless network is the coverage of the all the wireless nodes. In the Cattle Monitoring WSN the network architecture should account to cover the average size of fields and must be scalable when needed accordingly for larger fields. As per now the average size of fields in Netherlands is 100,000 m^2 and maximum coverage done in Zigbee WSN protocol is approx 500 m so by using one or two relay nodes the sufficient area of average cattle field can be covered.

C. Wireless Communication

As the animals move freely in the cattle.Wireless technology is considered the only feasible method to establish and maintain communications between a base station and network nodes attached to cattle animals. The wireless communication has various challenges 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 from the animal tissue. For maximum signal coverage from relay node the antenna on the animal is placed on a neck belt 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 the major constraint in the Cattle Monitoring System because the radio collar used for cattle monitoring is expected to run for 5 years without battery replacement. As there is limited battery power available per node the design should account for low powered, lightweight radio antenna. 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 processing capabilities of the node should be in a way that it consumes minimum amount of power from the battery and perform the necessary operations on the data as requested by the network protocol.

E. Cost of the System

The Wireless Sensor Network developed will be used to monitor the health of the cattle which in turn should reduce the cost of keeping the cattle in good health. For a cattle WSN it should be cheap and the wireless nodes must be low-cost with high lifespan and low maintenance to reduce the average cost of maintaining the cattle. Another reason for sensor nodes to be low-cost is the requirement of potentially high number of nodes needed for monitoring an entire herd of cattle. Also as the WSN becomes more widespread and general the average cost of having a WSN monitoring system will reduce considerably over a period of time.

III. Requirements

To ensure that the designed system can meet the needs of real-world usage, 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 of the network, 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 1 minute 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 every 12 hours.
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 100 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.
8) sensor node must not be out of coverage for more than four hours at a time.

A. 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 limiting 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 could potentially store this data using only two bits per sample.

Using two samples for both the temperature and the heart rate, while also rounding up to the nearest byte, total amount of data needed to be sent each five minute interval would be five bytes.

IV. Simulation Software

The design of the network will be tested using cooja, which is a simulator for contiki nodes and thus no experiments will be done on real hardware. This simulator is compatible with the following platforms: TI MSP430x, TI MSP430x, Atmel AVR, micaz, TI MSP430 and TI MSP430.

The number of emulated nodes that that can be simulated using this software depends on memory and the application running on 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 Coojas 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. As simulating a more complex 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(10). Furthermore, Contiki supports different protocol stacks like uIP which is a very small and fully compliant TCP/IP stack. Contiki supports Rime stack which consists of small layers built on top of each other and has single and multi-hop broadcast [25].

V. Network Architecture

The system will 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.

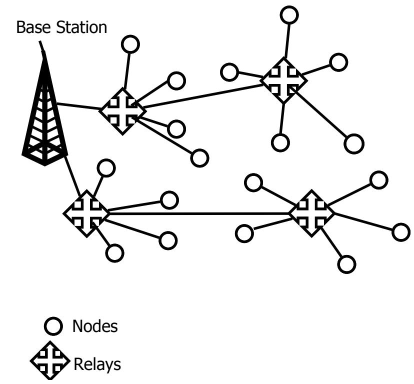

Fig. 1. An overview of the network topology.

Moreover, a routing algorithm might possibly be designed, if the routing algorithms present in ContikiOs are deemed unfitting for our application.

A. Network Topology

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

B. Physical Layer

To mitigate the problems with coverage, tranceivers with carrier frequencies between 902 MHz and 928 MHz of the IEEE 802.15.4 standard, will be considered in order to get an increased range. Even though these frequencies provide a lower datarate, of around 40 kbps [23], it is still sufficient for the small amounts of data collected by the sensors. Furthermore, the modulation scheme to be used will either be ASK-, BPSK or O-QPSK.

C. 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 the nodes it is 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 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 only 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 have to listen, 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.

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