Animal Sensor Networks: Animal Welfare Under Arctic Conditions

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***Abstract*—Animal tracking, which can be efficiently performed using wireless sensor networks (WSNs) is an important tool that provides useful information about animals' activities. It is also fundamental for environmental research. Under arctic conditions, WSNs face many challenges, such aslogistics costs, accessibility, danger of animals that might eat or destroy the equipment, effect of low temperatures on components, battery durability (which is drastically affected by low temperatures), effect of snow and ice on antennas and moving parts and continuous needs for calibration and adjustment due to extreme seasonal changes. However, they are a very good tool to overcome accessibility of semi-domestic animals under harsh weather conditions. One possible application of WSNs is the identification of ownership of newly born reindeer, which will be presented in this work as an example on arctic application.**

Keywords-Wireless Sensor Networks (WSN); Animal Sensor Networks (ASN); RFID; Wi-Fi Enabled RFID; ZigBee

I. INTRODUCTION

The use of WSN to monitor animal movement and behaviour is increasing rapidly. WSNs can be of great value in managing the animals and improving their productivity and impact on the environment. They are also very useful for animal owners and researchers for acquiring useful data, which can be used for the welfare of the animals.

Under arctic conditions, the environment imposes certain challenges on the network due to harsh weather conditions, such as logistics costs, accessibility, danger of animals that might eat or destroy the equipment, effect of low temperatures on components, battery durability (which is drastically affected by low temperatures), effect of snow and ice on antennas and moving parts and continuous needs for calibration and adjustment due to extreme seasonal changes. These factors are usually hard to predict by developers and will only appear through actual implementation of WSN strategies, which are much more closely integrated to the environment than other systems.

On the other hand, the harsh conditions in the arctic region necessitate the implementation of WSNs to overcome the problem of accessibility and reduce logistics and cost for acquiring necessary data about animals and the environment. This is consistent with the fact that science contributions from the computer science community have always been application-driven, which remains an essential philosophy for (WSN) community. Those challenges and contributions are presented within the Animal Sensor Networks (ASN) project.

The ASN project is part of The Botnia-Atlantica programme, which is a cross-border cooperation programme, intended to co-fund projects within the Botnia-Atlantica area. The programme is one of several European territorial cooperation programmes, co-funded by the European Regional Development Fund. The programme covers a larger area that includes the regions Ostrobothnia, Central Ostrobothnia and Satakunta in Finland, Västerbotten and Västernorrland as well as the municipality of Nordanstig in Sweden and the Nordland region in Norway, Fig. 1. The regions Southern Ostrobothnia in Finland and Gävleborg (except Nordanstig) in Sweden participate as adjacent areas in the programme [1]. Within this region, several research groups are working in the field of animal sensor networks. Some examples are Umeå University and the project "Digital Zoo" where a large scale testbed for wireless video sensor networks was built together with Lycksele zoo [2].

The Swedish university of agricultural science (SLU) and Centria in Österbotten, Finland, have already done research related to farming. The purpose of this project is to conduct applied research in the area of ASN so as to strengthen the collaboration between these groups and establish a knowledge cluster in this field. Specifically, the project will develop systems to collect information about individual animals in large areas.

Figure 1. Interest area for the EU Botnia-Atlantica project [1].

This research will be applied for the tourism sector in the test-bed that has been developed in Lycksele Zoo [2]. The technology will also be applied for farming applications both in the SLUs experimental farm in Umeå and at Centria, Finland [3].

So far, a competence cluster around WSNs for animals has been established in the region and one test-bed and reference deployment for sensor networks applied in tourism application has been established in Lycksele zoo, together with two test-beds for sensor networks applied in farming applications has been established. Furthermore, new sensor network hardware and software platforms for collecting information from animals have been developed and long-term tests have been carried out at the test-beds for wireless sensor networks. The goal is to make the system easy to deploy and maintain. This is of high importance to create business opportunities from the technology. The project also tries to verify new innovative ideas and applications based on the technology developed in the project and develop animal tracking algorithms based on multi-modal sensor fusion. The project also aims at developing new sensor network platforms for collecting information from animals. One platform of particular interest is smart ear tags containing sensors, microcontroller, wireless transceiver, batteries and solar panel for energy harvesting. This platform can be used to collect information from animals both in farming and in tourism applications.

Tracking of animal's movement is a fundamental tool to provide good and efficient management of these animals. The study of animal's movement is also a foundation for environmental research. One possible application of this approach is the identification of ownership of newly born reindeer which will be presented in this work as a study case. ASN also have potential applications in animal monitoring for farming improvement because with this system the farmers can systematically optimise their animal business [3].

As far as the research in Norway is concerned, the research teams at Bioforsk Tjøtta and Narvik University College will help to develop the cross-border network between research groups in this field within the region Botnia-Atlantica. Other Norwegian companies are also involved in this project such as Tele Track, NoFence and Biocontrol/Os ID, all of which may contribute to the further development of electronic monitoring for grazing animals [4].

In this paper, an overview of significant WSN technologies for animal welfare will be discussed. The major WSN technologies, such as RFID, GPS, Wi- Fi and Wi-Fi enabled RFID will be considered with some details; other technologies, such as ZigBee, Bluetooth and GSM/GPRS will be briefly compared to the WiFi technology; however, the description of those technologies will take a qualitative approach and will not go into technical details. An application example of WSN for animal welfare will be presented to explain the use of this technology for ownership recognition of newborn reindeer calves. This application implies the implementation of localization algorithms, which could be material for further work.

II. Overview of Significant WSN Technologies for Animal Welfare

WSNs have been used extensively for the welfare of animals. Various examples of their applications are reported in the open literature. Ranjan et al. [5] created a wireless sensor network for wildlife monitoring; in their system they utilised specially designed collars with sensor nodes, which are attached to the necks of wild animals. These collars collect data about the desired parameters from the vicinity of the animal and transmit it to the base station. This information is used by wildlife scientists for habitat monitoring and behavioural habits of the monitored animals.

Kwong [6] presented a wireless communication solution that fulfills the requirement for intensive condition monitoring of individual animals, aggregation and timely reporting of data to the farm manager designed for both loose house dairy cattle and free ranging beef cattle. The design target utilises inexpensive, low power consumption sensor nodes as the base elements of a data gathering and communication infrastructure. Laboratory experiments and farm trials have been carried out to evaluate the performance of the platform communication protocol. The results of experiments demonstrate that the platform performs efficiently while conforming to the limitations associated with WSN implementations.

In the following sections, some of the potential WSNs technologies will be considered. A study case based on Wi-Fi enabled RFID will be presented, as an example.

A. RFID

Radio Frequency IDentification (RFID) is widely used for electronic identification and tracking. RFID offers substantial advantages for businesses allowing automatic inventory and tracking on the supply chain. This technology plays a key role in pervasive networks and services [7]. Data can be stored and remotely retrieved on RFID tags, enabling real-time identification of devices and users. However, the usage of RFID could be hugely optimized if identification information was linked to location [8]. RFID networks are composed of three different entities, RFID tags, readers, and servers, as represented in Fig. 2.

All RFID tags use radio frequency energy to communicate with the readers. However, the method of powering the tags varies. An active tag embeds an internal battery which continuously powers it and its RF

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communication circuitry. Readers can thus transmit very low-level signals, and the tag can reply with high-level signals. An active tag can also have additional functionalities such as memory, and a sensor, or a cryptography module. On the other hand, a passive tag has no internal power supply.

Generally, it backscatters the carrier signal received from a reader. Passive tags have a smaller size and are cheaper than active tags, but have very limited functionalities. The last type of RFID tags is semi passive tags. These tags communicate with the readers like passive tags but they embed an internal battery that constantly powers their internal circuitry.

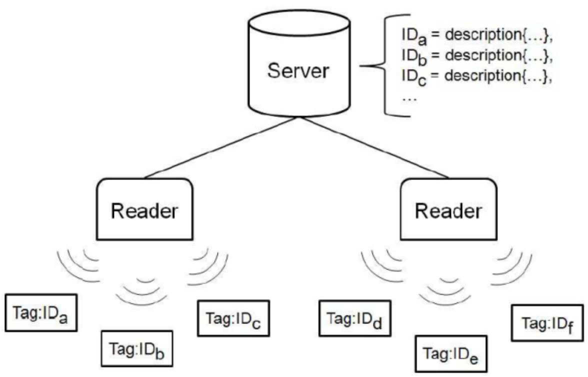

Figure 2. Structure of a typical RFID system [8].

RFID readers have two interfaces. The first one is an RF interface that communicates with the tags in their read range in order to retrieve tags' identities. The second one is a communication interface, generally IEEE 802.11 or 802.3, for communicating with the servers. Finally, one or several servers constitute the third part of an RFID system. They collect tags' identities sent by the reader and perform calculation such as applying a localization method.

RFID systems can be classified in two main categories in accordance with their usage: monitoring and authorizing. Classic applications are livestock or people monitoring. The second class includes RFID systems where the tags are not permanently attached to entities. Typical usages of authorizing RFID systems are access control in a building where tags are embedded inside cards or keys [9].

B. GPS

The Global Positioning System (GPS) has traditionally underpinned the development of ubiquitous positioning solutions. This stems from the increasing recognition across society that under ideal operational conditions, GPS can meet the majority of attributes of ubiquitous positioning system i.e. accuracy, reliability and availability. However, it is also widely acknowledged that in certain environments these performance attributes can quickly deteriorate to unacceptable levels, with often only weak GPS signals available Wi-Fi [10].

C. Wireless-Fidelity (Wi-Fi)

Wi-Fi signals are different in this regard. Over the last few years, millions of Wi-Fi access points have been have been established to facilitate more efficient and flexible access to data and communications around the world. However, these access points repeatedly broadcast a signal the strength of which can be measured and used in algorithms to locate a Wi-Fi enabled device. Unfortunately, the positioning capabilities of Wi-Fi are weakened by the fact that positioning performance is highly dependent on the strength of the signal received from nearby access points, which are affected by a diversity of uncontrollable environmental effects, e.g., people, building material, etc. Despite this significant limitation Wi-Fi signals continue to be an attractive alternative positioning technology due to the growing number of Wi-Fi enabled mobile devices being produced (over 360 million Wi-Fi handsets projected to be sold annually by 2011) combined with the rapid growth in Wi-Fi access points being installed globally (shipments of consumer oriented Wi-Fi access points are expected to grow from 6 million in 2008 to 88 million in 2013) [10].

D. Wi-Fi Enabled RFID

Wi-Fi-enabled RFID is commonly used for location-based services that track objects in a specific physical context, like children in a theme park, cars in a parking lot, equipment in a manufacturing plant, etc. It is considered a more accurate system than a traditional RFID network for determining the location of tagged objects. A regular RFID system can give what is called the "choke point" location, or zone-based location, meaning the location of the tag is known only in relation to the reader detecting its presence. A Wi-Fi network on the other hand can determine the precise *x*,*y* coordinates of a tag using triangulation methods, similar to how GPS works [11].

In these RFID systems, tags are Wi-Fi devices, and Wi-Fi access points function as readers. These tags can have an accuracy of 3-5 meters when determining the location and a large number of tags can communicate simultaneously with a single access point without choking the Wi-Fi network. These tags are generally capable of bi-directional data exchange [12].

The MAC (Media Access Control) Address uniquely identifies each node of a network and serves as the unique identifier on the tag, while the location software determines the specific coordinates. Additional application software can transform coordinates in terms that are meaningful to a user by matching them to specific locations. A Wi-Fi application then can identify the tag and its location. Some tags may contain additional data derived from integrated sensors [13]. This technology has been used and proven in many applications [11].

To simplify the manner of operation of the Wi-Fi-based active RFID tags, they simply send a wireless 802.11 signal at a regular interval, the signal is received by the Wi-Fi access points or location receivers, and is sent to a Location Engine which determines the tag's location, and sends it to the visibility software. The visibility software uses location data to determine the exact location of the RFID tag [14]. The Wi-Fi (IEEE802.11WLAN) can support many devices (max. 128) within one network, it can transmit data up to 30m distance, needs more power, and cost is more than Bluetooth or ZigBee [15].

E. *Wi-Fi vs. other wireless technologies*

Table I compares Wi-Fi technology to ZigBee, Bluetooth and GSM/GPRS technologies. Obviously the ZigBee is more efficient in terms of reliability, cost, size and battery life compared to Wi-Fi, while Wi-Fi is recognised for its flexibility, speed and availability.

TABLE I. COMPARISON OF WI-FI TECHNOLOGY WITH OTHER WIRELESS TECHNOLOGIES [16].

Market Name/ Standard	ZigBee (802.15.4)/(Helicomm)	WI-Fi (802.11b)	Bluetooth (802.15.1)	GSM/GPRS
Application Focus	Monitoring and Control	Web, Email, Video	Cable Replacement	Wide Area Voice and Data
Success Metrics	Reliability, Power, Cost	Speed, Flexibility	Cost, Convenience	Reach, Quality
Battery Life (days)	100–1000+	.5–5	1–7	1–7
Network Size	Unlimited (2^{64})	32	7	1
Bandwidth (KB/s)	20–250	11,000+	720	64–128+
Transmission Range (meters)	1–100+	1–100	1–10+	1000+

Hence, for an application such as the identification of calf and mother reindeer, the existing Wi-Fi network at the premises can be used and the tags can be used for this particular purpose for a limited time each year which reduces the cost of the equipment needed, a further economic study of the required equipment should however, be performed.

III. APPLICATION EXAMPLE

Reindeer herding is the major traditional economic activity of the Saami people, who are the indigenous people of Finnmark, the northern most, largest and least populated county in Norway. Herds of Reindeer of mixed age and sex varying in size from 100 to 10,000 animals are maintained on natural mountain pasture all year round and typically are moved between coastal summer pastures and inland winter pastures. Identifying the ownership of new-born calves is a major problem for reindeer herders. Recognising and matching the reindeer calves to the different mothers is a two-step process. First the animals are caught in a small pen. All female reindeer get individual numbers sprayed on the skin at each side of the animal. Each owner uses one specific colour. Calves get a collar each around their neck, with a unique number plate hanging on it. This procedure is stressful for the animals. Thereafter, the animals are released to larger pens to calm down. Several reindeer owners and herders start observing the reindeer with binoculars in order to identify/match which reindeer calf (number plate) is following which mothers (sprayed number). Thereafter, the reindeer owners compare the different observations to guaranty that the correct mother is matched to her calf.

The next step is to gather the reindeer herd again in a small pen, catch the calves, remove the number plate and replace it by an ear cutting or a tag. This handling procedure is also stressful to the animals.

In this study, a technique based on WSNs to identify the ownership of the calves is presented. It is proposed to equip the newly born calves with an active RFID tag, facilitated with receivers and gateways based on Wi-Fi network, usually available and accessible at the identification site and monitor the movement of the herd in a confined space, such as a fenced pen, covered by a grid of signal receivers corresponding to the transmitter device attached to the reindeer, which basically tracks the movement of the tags. This process is performed in a few days per year, hence the Wi-Fi network can be utilised for other objectives for the rest of the year. A suitable algorithm has to be used to analyse the gathered data and recognise the pairs of tags which keep close together most of the time, which are the mother and calf reindeer.

Being a wild animal species, the reindeers tend to be more cautious than domestic animals; hence they tend to avoid confined spaces and close objects mounted by humans, which makes the use of passive RFIDs more difficult due to their low range, because the receivers have to be placed close to the RFIDs. This will demand the attachment of active RFIDs to both mothers and calves.

In this procedure, the pen where the animals are to be gathered for tagging is facilitated with a Wi-Fi network, a group of Wi-Fi routers mounted on posts, as shown in Fig. 3.

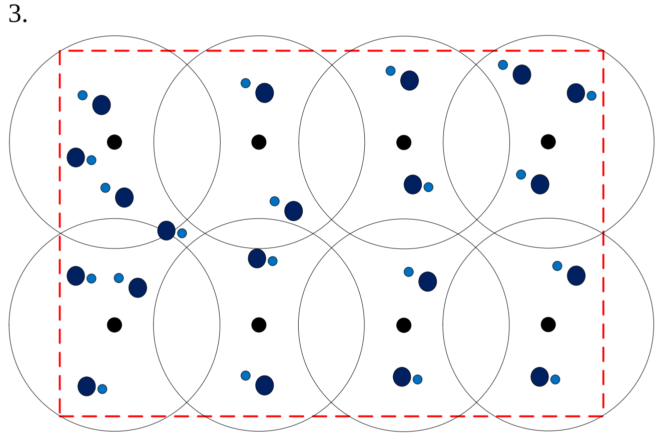

Figure 3. Animal pen of area 40 x 80 m^2 (dashed rectangle) covered by Wi-Fi network, represented by the large circles, the Wi-Fi routers are the black dots at the centres of the larger circles.

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Large and small pairs of coloured circles represent mother and calf. The schematic represents possible configuration of the Wi-Fi coverage, which covers the whole pen, with minor pockets of uncovered areas, which have to be kept to a minimum.

The locations or the RFID tags are gathered in a computer programme and analysed. However, the proposed method suffers from a few limitations pertaining to the number of tags that can be covered using one Wi-Fi reader and coverage of the pen area, which could create further problems pertaining to transmission, repeatability and accuracy. Nevertheless, those limitations can be overcome using proper antennas and larger number of Wi-Fi readers.

In the proposed set up, tags are Wi-Fi devices, which can have an accuracy of 3-5 meters. An advantage of this system is that a large number of tags can communicate simultaneously with a single access point without choking the Wi-Fi network, while a traditional RFID technology would have required hundreds of readers in order to pinpoint the location of a single tag with the same precision as the Wi-Fi network.

IV. Conclusion

In this paper, the background of the animal sensor network project, which is part of the EU Botnia-Atlantica programme, has been presented. Various significant (WSN) technologies have been presented and an example application for animal welfare has been described.

WSNs face many challenges under arctic conditions, but at the same time offer many advantages, which reflect on the welfare of the animals and environment in the region.

The problem of ownership identification of newly born reindeer calves was presented as an example application from the experience of reindeer herding in northern Norway, which lies within the arctic region. It described the process of matching new-born reindeer calves to their mothers, so that they can be given the proper RFID tags of their relevant owners, based on Wi-Fi enabled RFID tags.

This method is expected to reduce the amount of effort and time in performing the identification process under the harsh arctic conditions and paves the way for the implementation of Wi-Fi enabled RFID tags for animal welfare applications.

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