Detection and Protection of the Attacks to the Sheep and Goats Using an Intelligent Wireless Sensor Network

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Abstract- Wolves attacks to sheep and goats are very frequent at night. It has caused great economic losses in some countries. When an animal feels the presence of people or different animals, it experiences an increase of its cardiac frequency and corporal temperature. In this paper, we present a network of wireless nodes using IEEE 802.15.4 technology, which are capable of monitoring the vital signs of the sheep and goats. This smart system allows us to detect the collective stress caused by the attack of any predator during the night. It uses a learning system which decision is taken after having received 5 messages. When the system detects these anomalies in the animal's behavior, it sends an alarm signal to alert the person in charge of the livestock facility and activates visual and acoustic alarms capable of frighten the predators and prowlers.

Keywords- Wireless sensor network, intelligent detection system, sheep and goats stress, wolves attacks.

I. Introduction

Wireless sensor networks (WSNs) can be defined as a group of nodes which can interact with the environment. These nodes can register variations in the medium, thanks to the physical transducers, and transmit this information to the network. Nowadays, the use of WSNs is spreading more and more in rural areas. This happens because WSNs allow environmental monitoring and the management of several activities in agricultural and rural areas [1]. In addition, the infrastructure needed for this task is simple while it has quite low economical costs and other benefits compared to other infrastructures [2].

WSNs can be used in several activities in the agricultural sector where the combination of new technologies and the knowledge of some existing problems can provide many benefits. In the livestock sector, a WSN could be used for controlling the animals and other environmental parameters, such as attempts of animals' theft or flock attacks by wild animals, among others.

There are several published news in Spain and France that show the number of wolf attacks. These attacks are registered mainly in the north of Spain and in most of the pastoral areas of the rest of Europe. Massive wolf attacks cause the illegal hunting of these predators and the incompatibility of the wolf recovery (because this species is considered endangered). Furthermore, the financial resources designed for rural areas are also negatively affected.

The aim of this paper is to show the development of a WSN capable to intelligently detect when a flock is being attacked by wild animals. The data generated by the WSN is processed by a smart algorithm which will decide what kind of alarm has to be generated and consequently, the system will warn the owner and other services such as the environmental unit of animal control.

The rest of this paper is structured as follows. Section 2 shows several related works where sensors or sensor networks are used for monitoring farm animals. Section 3 explains the operation of the sensor network, its infrastructure, the communication between devices and the alarm system. The protocol and smart algorithms designed and developed for the proper operation of our system are presented in section 4. They are able to send the appropriate alarm in each case by using a learning phase. Section 5 shows the performance of the developed system. Finally, section 6 draws the conclusions and analyzes the designed system.

II. Related Works

Currently, sensor networks are widely used in livestock for health monitoring and for animal identification [3]. In intensive farming, sensor systems are mainly used to control several environmental variables, such as temperature and humidity [4]. In extensive cattle, sensor networks are also used to monitor remotely the flock position in the area of livestock grazing [5].

Another important application of sensor networks is a system for detecting the collective stress in livestock. The stress in animals is usually related with variations of corporal temperature, heart rate and respiratory rate [6]. For this type of monitoring, it can be used under skin sensors [7, 8] or outer sensors [9]. The monitoring of these parameters allows us the modeling and detection of collective stress episodes in sheep and goats flock caused by wolf attacks. So, if we are able to detect any sign of attack (by the animal behavior), we will able to generate acoustic and visual alarms in order to scare the wild animals, and avoid the attack.

In [10], authors show an experiment where a sheep, in a regular situation, has heart rates between 60 to 80 beats per minute. When the animal is being attacked or stressed by other causes, it can register heart frequencies up to 225 beats per minute. Finally the biologist and inventor of this prototype Jean-Marc Landry, aims to study a system that strews a chemical repellent on the wolf to generate its flee.

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III. SENSOR NETWORK

In order to repel wolf attacks, we propose to use a WSN connected to an access point (AP) forming a wireless network infrastructure. Each animal (or some percentage of animals) wears a wireless node provided with a temperature sensor and an ECG circuit. This section presents the wireless node of our system. Figure 1 shows the structure of the proposed network.

Our system determines that there is a situation of collective stress, when it detects 5 alarms, from 5 animals, within a maximum period of 5 minutes. When an alarm is generated, the AP communicates the situation to the server. The server is the responsible to activate the acoustic and visual alarm. The first stage is intended to frighten and scare off potential predators or intruders. Moreover, the server sends a text message, warning of the time of the alarm, followed by an automatic call, to the farm owner.

A. *Placement of sensors on the animals*

Figure 2 shows the sensors placement on the animal. On the one hand, the sheep wears two electrodes attached with a wrist band to the front legs (the same procedure can be used for a goat). The connection with the belt is made by a wire protected by a metal mesh that will prevent that the animal can gnaw the cord. On the other hand, the temperature sensor is located in the inner part of the belt. The metallic encapsulated is in contact with the skin of the animal. All circuits are protected by a small box which is attached in the belt.

B. *Desing of the network topology*

Our design uses ZigBee as a wireless communication protocol. This communication standard has been designed by ZigBee Alliance. It is a standardized group of solutions that can be implemented by any manufacturer. ZigBee is based on the IEEE 802.15.4 standard for wireless personal area networks (WPAN). Its low power consumption feature make this protocol ideal for high that require secure communications, but with low data rates at short distances that maximizes the network lifetime [11].

The sensor node is made using Waspmote node. It is designed by Libelium Company. It is able to combine several sensors and actuators by using its programming environment. The programming language is C++ simplified restricted it to the API provided by the manufacturers [12]. Waspmote nodes can be connected by star topology, tree topology or mesh network topology. We have implemented a network in star topology. Figure 3 shows a Waspmote node and its battery. The main characteristics of these nodes are shown in Table I [13].

TABLE I
WASPMOTE FEATURES

Microcontroller	A Tmega 1281
Frequency	8 MHz
SRAM	8 KB
EEPROM	4 KB
FLASH	128 KB
SD Card	2 GB
Weight	20 gr
Dimensions	*73.5 x 51 x 13 mm*

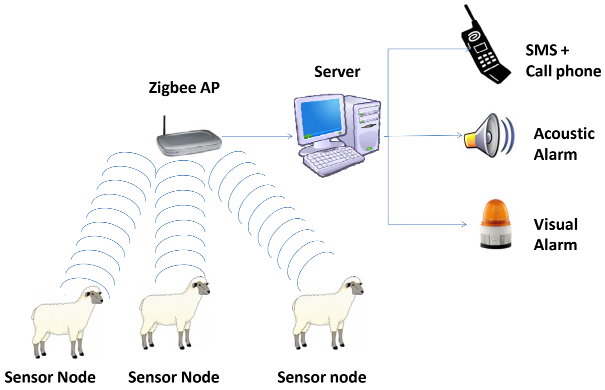

Figure 1. Structure of the wireless network

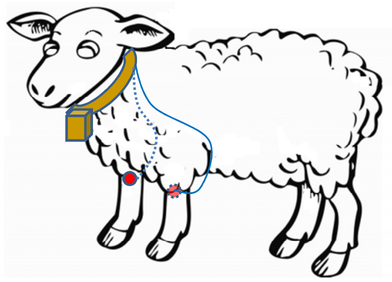

Figure 2. Placement of sensors on the sheep

Figure 3. Waspmote node and its battery

We used ezpot ZigBee 101 [14] as the access point. It acts as the gateway between the Zigbee WSN and server that process the data and takes the smart decisions. It is has a ZigBee port which allows the WSN connection and a Fastethernet port which is connected to the server. Its characteristics are the following ones:

- DIN rail or panel mount.
- Support 10/100 Mbps Ethernet.
- Compatible with RS-232, RS-422 and RS-485 serial interface
- Compatible with communications LAN and WAN.
- In Server mode supports individual customer sessions (enhances the security).
- Management password protected.
- Virtual COM drivers for Windows NT/2000/XP/2003/Vista/Win7.

AP specifications explain that the AP can be used for distances up to 100 meters, which is enough to cover the area of a stable.

IV. System algorithms

This section shows the communication protocol and the algorithms designed to take decisions based on the information received from the sensor nodes. In addition, we are going show the procedure to generate alarms when a situation of collective stress is detected.

The operation of our wireless sensor network is based mainly on a smart decision algorithm based on the signals received from the flock of sheep or goats. The algorithm goal is to assess whether it is producing a collective stress situation by the presence of a predator. Because our nodes only work during the night hours (during the day, sheep and goats are with the shepherd, the energy regulator is the responsible of determining when the node will be working, and when the battery must be recharged.

This section shows the three necessary algorithms for the operation of the wireless sensor network. They help us to determine if the flock is being attacked. We are also going to explain the smart algorithm that analyzes the received data. Using a previous learning phase, the system will be able to define the type of alarm and alert that should be generated.

A. Decision algorithm based on an smart tagging system.

An animal can register an increase of their vital signs due to multiple causes. However, this does not mean that the animal is being attacked. But, generally, when a wolf or an intruder is near the flock, several animals are altered.

Our system tries to control this behavior by following next procedure. When an animal registers elevated body temperature and heart rate, the system process the event as an individual alarm signal, which is sent to the AP. The AP will send this event to the server responsible of the control of the area and it will generate a message. At this time, a 5 minutes timer is activated. If there are 5 or more messages before the account expires, the system will consider that it is being produced a collective stress situation. The detection of a collective stress situation activates the acoustic and luminous alarms. Simultaneously, the server will send a text message to the farm owner or other people depending of the type of case, which is decided by a smart algorithm.

The system can detect several types of cases. Each situation will generate a different type of alarm, which will advise different persons.

Firstly, a sheep or goat may be altered by natural causes, such as the presence of a female in mating season (alarm level 1). But the animals may be frightened by the presence of thieves (alarm level 2), by the presence of wild animals (alarm level 3) or by the presence of some kind of natural phenomena, such as a fire, a flood, etc (alarm level 4).

Each type of alarm (from the lowest, level 1, to the highest, level 4), must be addressed. For this reason, when a level 1 alarm is generated, the system will only notify this status to the farm owner. When an alarm of level 2 is generated, the system will warn the farm owner and the police (to try to catch the alleged thief). A level 3 alarm will generate a warning message to the farm owner and to the environmental unit for animal control. Finally, a level 4 alarm means that due to an unusual event, the entire flock is in danger. So, the alert will be communicated to the owner and to the emergency services.

Figure 4 shows the decision algorithm which will control the generation of alarms.

For the proper operation of our intelligent algorithm, we must perform a training system for alarm tagging. In order to achieve this goal, we need to establish a period of manual alarms tagging. This allows us to create an initial alarm database. This database will provide the flock behavior patterns.

When the system detects a collective stress situation (5 o more messages received in less than 5 minutes), the time values and messages are stored. Then, the algorithm will analyze each received data which will be compared with the data from the database (the initial data comes from the training phase). After determining the priority of the alarm, the system will perform, on the one hand, an alarm tagging and then, it will be save in the database, and, on the other hand, the communication and the alarm generation (Visual alarm, acoustic alarm and GPRS communication).

The intelligent algorithm, allows the WSN reporting the status of the animals. In addition, when there is a threat, the system will generate several deterrents (visual and acoustic alarms) that may scare the threats, while the owner is going to the farm.

B. Energy regulator control Algorithm

One of the most important issues to be considered in WSNs is to have as low as possible power consumption. This will prolong the network lifetime and facilitate to maintain more stable communications [15].

In order to prolong devices lifetime, we use an energy regulator algorithm which is able to control the periods when a node will work and when the battery needs to be recharged. Figure 5 shows the control algorithm to control the energy regulator. First, we should detect if it is night or not. During the daytime, the system must check the battery status. If the charge level is below 100%, the battery should be recharged through the solar panel. Otherwise, the system will remain in idle mode and it will turn off the node. When night falls, the energy regulator control activates the relay that controls the battery connection to the sensor node, enabling wireless link with the AP.

C. Communication Protocol

When a sensor node wakes up, it attempts to communicate with the AP. In order to do this, the node scans the wireless networks that are within range. The AP configured to let the access to the sensor nodes will reply with an ACK message. Each node will request the authentication to the AP which will respond with a confirmation (if the node is registered).

Finally, the node of each sheep or goat will be associated with the AP. From that moment, the AP will await the arrival of any alarm message. Figure 6 shows the message flow procedure between a sensor node and the AP.

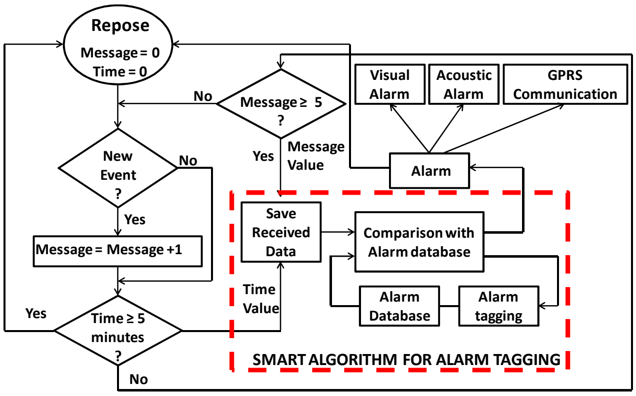

Figure 4. Decision algorithm

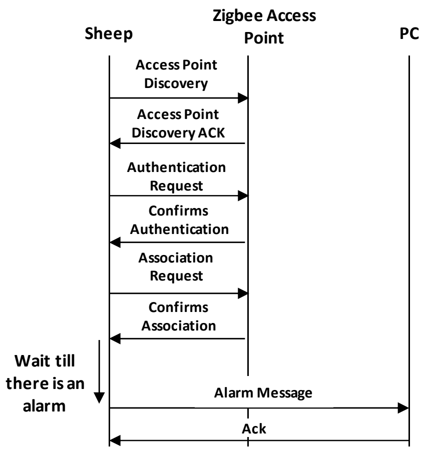

Figure 6. Communication Protocol

V. Performance Study

This section simulates the decision algorithm that generates the alarms. We also show real measurements from a real environment using Zigbee wireless technology.

Figure 7 shows the simulation results of our decision algorithm. As we can observe, an alarm is generated individually at 50 seconds causing the first signal message. After 5 minutes no more alarms are registered and consequently, the value of the alarm signal returns to 0. From the second 390, different individual alarms are generated, so the message value increases. When this value is equal or higher than 5, the alarm is activated.

In order to show the performance of our Zigbee network, we have connected a node Zigbee and Zigbee AP. This allows us to study the individual network performance due to the operation of a single node placed in single sheep or goat.

Figure 8 shows the bandwidth in bits per second consumed in the network due to the communication protocol. In 15^{th} second, the node sends a broadcast message to discover the reachable APs. Immediately, it receives an ACK message from the AP. After this reception, the node authenticates with the AP using the password that was previously configured. The node receives the confirmation

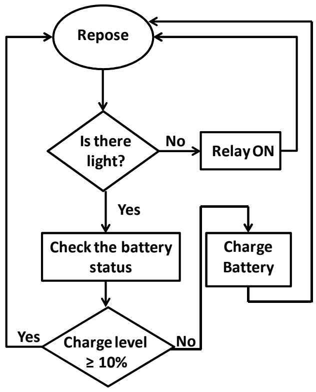

Figure 5. Algorithm to control the energy regulator

of this authentication (which is received approximately on the 18^{th} second). Finally, the node sends an alarm message in the 31^{st} second and receives the ACK message.

Figure 9 shows the bytes sent by the sensor node during the above described communication process. The moment with greater registered number of bytes is when the node tries to associate with the AP. We noticed that there is another peak of number of bytes when the node sends the last alarm (last peak of the graph).

Figure 10 shows the responses of AP to messages sent by the node according to the described communication protocol. We can see that there are more number of bytes sent during the sensor nodes registration process, so the system does not consume too much bandwidth once all sensor nodes have been registered.

VI. Conclusion

In this work we show the design and development of a WSN based on the IEEE 802.15.4 standard. Our system is capable of measuring the episodes of collective stress in the sheep and goats flock by using the variations of heart rates and corporal temperature of the animals. Taking into account this monitoring, we can detect the attack of predators or thieves. Our system is combined with an alarm system to scare predators and to generate the appropriate alerts to the owner of the livestock and to other people.

The sensors used are placed on a belt that does not disturb the animal to walk. The system is totally self-sufficient because it provides an energy saving system, which is based on recharges through a solar panel. In addition, the sensor node only works when its use is necessary.

So, our system can be considered as a tool to prevent the loss of the cattle, increasing production and profits from livestock facilities. This system can be implemented in any type of livestock facilities and can be used to alleviate the economic losses.

As a future work, we would like to improve the ECG electrodes attached with a wrist band to the front legs. We want to avoid the wire connections in order to prevent that animals can get caught in the branches of shrubs, so we will deploy a wireless body area sensor network to interconnect them.

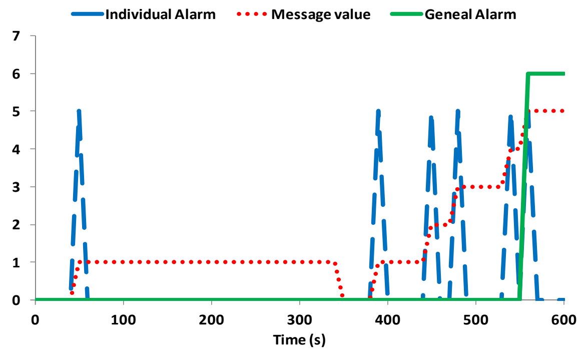

Figure 7. Simulation of the decision algorithm

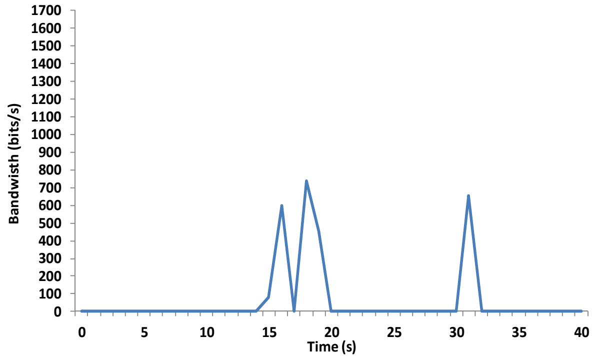

Figure 8. Consumed bandwidth.

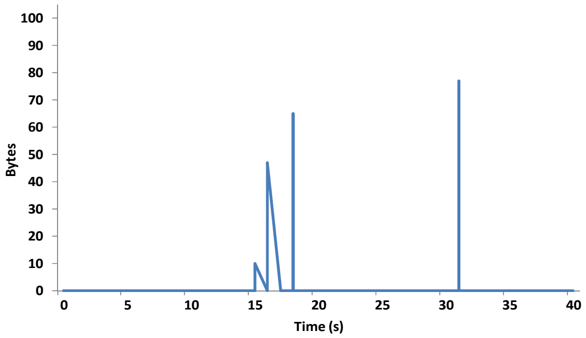

Figure 9. Bytes sent by the node

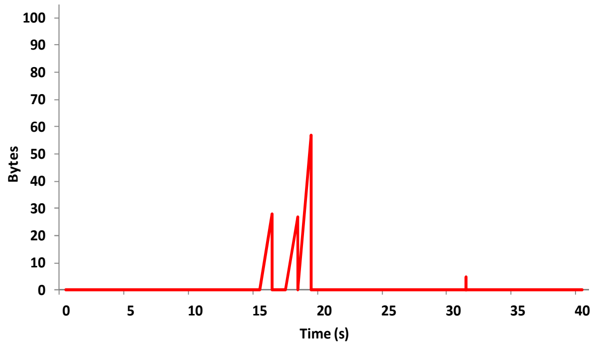

Figure 10. Bytes sent by the AP.

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