Cloud-based Wireless Sensor Network System for Smart Livestock Monitorization

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Abstract

New applications have been emerging worldwide based on Wireless Sensor Networks. The amount of data that is generated by such networks require high storage and processing power, for which Cloud Computing can give an effective contribution. In this report, a cloud-based WSN system is proposed in order to be applied to the Livestock sector, more specifically for the monitorization of dairy sheep. The monitorization was centered on the collection and processing of each animal's location, in order to extract valuable information to the farmer (e.g, alterations in the normal bustle of each animal, the propagation of possible diseases in the flock of sheep or thefts) and even combining it with other sources of information (e.g., milking systems, etc.). Such solution gives the farmer a broader vision of the business. In this context, it was implemented a functional system prototype experimentally evaluated in real deployment scenarios.

Keywords: Internet of Things, Machine-to-Machine Communications, Wireless Sensor Networks, Cloud Computing, Livestock, Localization.

1. Introduction

Livestock represents a vital sector for the economy of several countries. In recent decades Livestock production has experienced a tremendous growth stimulated by the population growth and changes in dietary preferences [1]. Nowadays Livestock industry has associated with it several requirements, a lot due to the demands of our modern society [2]. In order to give an efficient response to the presented demanding requirements, it is necessary to monitor a large number of variables related to this sector. However, together with the increasing scale of the farms and the high number of animals that compose it, it is infeasible to continuously monitor the animals through visual observation during twenty four hours a day [2]. In the past, Livestock management was based on farmer's observation, judgement and experience. Indeed, the only way to locate the animals was to have people watching them, which is a time consuming and expensive approach. In this context, a new concept of management named Precision Livestock Farming (PLF) arises.

Technology is a key part of the PLF vision. Nowadays, the technology is evolving at a very fast pace and spreading to many sectors of our society. Indeed, the Livestock sector is no exception, with the lower costs and miniaturization of the sensor boards, using WSNs' technology the Livestock monitorization can be made more effectively than using human observation alone. It allows to continuously and remotely monitor and capture measurements related with the condition of individual animals in a very detailed level as well as reporting these data to the farm manager [3].

The adoption of technologies for tracking Livestock animals is an example with plenty of potential that illustrates very well the benefits of allying WSNs with the Livestock sector [4]. In this field, if there were for instance animal's collars that allow to capture the location of each animal, it would be possible to track real-time free-grazing animals' movements in large dimension pastures area, without the need of observations on the ground.

This location information can be employed by different applications. For instance, it could be possible to deduce automatically the grazing habits of free ranging animals, which can be very useful to the farmer for making better decisions on the efficient usage of land. Additionally, it could also be possible to know the path of the animals in a certain time, and so determine exactly the utilized grazing area. This could be very useful, when the farmer pays for the grazing land that was used, avoiding this way costs for unused resources. Collecting the location of each animal can be also very interesting when it is detected an infectious disease in an animal, isolating only those animals that had direct or indirect contact with it, avoiding slaughtering

healthy animals. On the other hand, knowing in real-time the location of each animal may be very useful when the farmer wants to fetch free-grazing animals at the end of a season, avoiding searching for them in a certain region. In certain countries, insurance companies pay in case of death of an animal if the body is found. Therefore knowing the location of the dead animal body could mean recover some money. Besides these facts, the cost of building and maintaining fences is expensive, and it is one of the most expensive costs associated with Livestock grazing [5]. Therefore, two interesting concepts can be used in order to minimize these costs: geo-fencing and virtual-fencing. In both of them, there are no physical fence, which makes them very advantageous solutions in terms of cost savings.

This new monitoring paradigm of networked Livestock leads to an enormous quantity of information that must be efficiently addressed. For instance, applying this paradigm to the cattle monitorization, each cow will generate on average about 200MB of information per year [6]. Making the calculation for the entire cattle, it becomes clear that there is more information than a local server can manage. Based on this fact, how to deal with this quantity of data? Cloud Computing offers an attractive solution for this issue, making it the solution data back-end. All its well known advantages have an end result, which is a substantial reduction of costs, making this kind of technological solution attractive for big Livestock producers as well as to medium and small scale producers.

2. Related Architectures

There are several works done in the environmental monitorization area using WSNs systems. Although none of them satisfies completely the requirements of this project, it was possible to extract some interesting approaches from each one of them.

ZebraNet project [7] implemented a system that captures wild animals data and brings it back to biologists, so that the research process can be done more efficiently. In this specific case, the project goal is monitoring zebras that are located over a large wild area, at the Mpala Research Centre in Kenya. Since there is no cellular service covering the region, this project is based on an ad hoc topology in order to route data across the mobile nodes (i.e., zebras) to the base station, which in this case is the final receiver. Unlike the usual, the base station is also mobile and corresponds to a researcher that periodically drives or flies through the area in order to collect the data stored on the nodes. This way, the base station corresponds to a data MULE (Mobile Ubiquitous LAN Extension). All zebras have a collar that is responsible to periodically store information about the location of the node in question, having for that a GPS receiver.

Nadimi et al. [8] propose a system capable of monitoring behavioural parameters of individual animals and transforming them into the corresponding behavioural mode, using for that an Artificial Neural Network (ANN). Farm animal's behaviour and physiological responses can provide important information about their health status and welfare. For instance, the length of the grazing period is an extremely relevant factor that can indicate to a farmer the sufficiency of food, which directly affects both animal welfare and production. The purpose of this work was to monitor the behaviour of a herd in Denmark. For that, the system design consists on a ZigBee-based mobile ad hoc WSN that is responsible to measure and monitor behaviour parameters (i.e., head movements through an accelerometer) of each individual sheep. Using an ANN, the data collected from the WSN nodes is processed and the behaviour mode of each animal is constructed. This behaviour mode varies into five types: grazing, lying down, standing, walking and other modes. This classification can be very useful to the farmer and potentially improves farm management.

Sikka et al. [9] have deployed a large WSAN on a farm in order to understand the animals behaviour and, at the same time, to improve the farms management as well as to maximize the farm production. These studies were made by two research teams on a cattle breeding station at Belmont, in Australia. Two type of nodes have been deployed: static and mobile. The static nodes consist of twelve geographically distributed soil-moisture nodes and the mobile nodes correspond to collars installed in cows, in order to track their movements. These collars have equipped several sensors, such as a GPS receiver, accelerometers, temperature sensor, etc. Besides the tracking of animals, the authors also focused on actuation, i.e., providing animals with haptic or audio feedback. This way, based on the animal position, the system applies various stimuli (such as sound, vibration as well as low-level controllable electric shock) to the animal in order to change its behaviour. The animal actuators have the potential of influencing the environment, and this fact combined with virtual fences brings extra benefits for farm management. The long-term vision of this work is to implement an autonomous farm management system. For that, from the data collected by the moisture sensors, the system will automatically determine the areas more suitable for grazing and, according to this, it will build the virtual fences, which will contain the animals that are automatically guided to these locations through stimuli. This approach has tremendous potential

and has the ability of making all the system more optimized and smarter.

Martinez et al. [10] have developed and deployed a glacier monitorization system at Briksdalsbreen, Norway. The nodes that will be situated in/under the glacier are called probes, and are equipped with a variety of sensors (e.g., temperature, pressure, orientation, external conductivity, etc.). Beyond these nodes, there is also a base station on the ice, a reference station that acts like a gateway, measures the supra-glacial movement using a GPS and it can also be used for controlling remotely the entire system, as well as a Sensor Network Server (SNS) located at Southampton, UK.

3. Architecture

The generic architecture that will be later presented is intended to be applied in the monitorization of Livestock animals (e.g., horses, cows, sheep, etc.), specially when they are freely grazing. In this architecture the monitorization will be centered in the collection of the animal's geographical information and through the exploitation of this information, it is intended to make important deductions about the actual status of each animal. In a very simplified approach, the information is collected by each WSN's node and, after going through several layers of intelligence in order to perform data processing, it can be finally delivered to the end-user.

This architecture can be divided into three relevant components; the WSN infrastructure, the Cloud Computing platform responsible for the data processing, as well as the Web application that will allow the farmer to visualize the status of the system as well as to interact with it. This way, only the functions that are critically needed for data collection will be carried out by the WSN, leaving the heavy processing for the Cloud Computing platform. An architecture design scheme is presented in figure 1 that illustrates the three main components previously mentioned as well as its subcomponents.

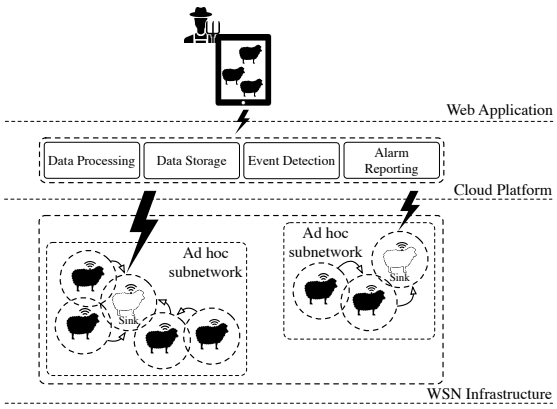

Figure 1: Generic system's arquitecture design scheme

3.1. WSN Infrastructure

Each node of the WSN infrastructure will correspond to an animal that will be equipped with a device that provides sensing, computation as well as communication capabilities. Therefore, in this system, each animal will correspond to a mobile node that communicates wiressly with the other system nodes. Additionally, it will sense its current geographic location, through GPS or other localization method, following a time-driven data reporting model. All this sensed information is aggregated in a sink node and then uploaded to a back-end infrastructure to be later processed. In order to accomplish these functionalities, each animal will have to use a technological device that must not interfere with its normal activity and at the same time must be robust to the surrounding environmental conditions. The technological device installation depends on the specific use-case as well as on the animal that is intended to be monitored. For instance, in cow monitorization it can be used a collar, which was extensively tested in several other past projects, or even a device inserted in a bolus that is ingested and remains in the animal's rumen.

The monitorized animals will form a Mobile Ad Hoc Network (MANET), providing high scalability and robustness to the network. For instance in the cows' monitorization field, some authors [9, 11] support this model by showing evidence that the animals of a cattle remain close to each other (typically herd together), so that an overall connectivity between them was maintained using a multi-hop approach. Due to the fact that the presented network will not have any kind of actuation and the data will be only uploaded from the ad hoc network to the back-end infrastructure, it was chosen a convergent protocol in order to route the data to the back-end infrastructure using a multi-hop approach. All the nodes of the system will use the short-range radio with low power consumption, in order to communicate with the other animals inside the WSN and only the sink node will upload the data collected from the WSN's nodes to the Cloud platform, through a gateway, using for that a long-range communication interface.

Due to the natural mobility constraints of this system, even using a multi-hop communication approach, some nodes eventually may become disconnected from each other, therefore forming independent and isolated ad hoc networks. Despite the low vulnerability to disconnections presented in similar deployments [12], it is necessary to attenuate the consequences of this situation. Therefore given these conditions, if the sink node corresponds to a node from the ad hoc network and some nodes may become isolated in separated ad hoc networks, it is not possible to assure connectivity with the

back-end continuously in time. Depending on the application use-case scenario, this situation can be tolerated or not. Therefore, two approaches were identified for the system's architecture:

Sparse Cloud Connectivity In this approach the system does not require that all the WSNs nodes maintain connectivity with the data back-end continuously in time. In this case, the network will have a certain number of sink nodes, being the remaining mesh nodes, setting this way a given ratio between sink and mesh nodes. This number of sink nodes in the network depends on the real scenario case, in particularly depends on the total number of nodes. In order to add some redundancy to the system, at least two of them will correspond to sink nodes. Since the disconnected nodes cannot propagate the collected information to the cattle's sink nodes, each network node is equipped with a buffer that can be used in order to store temporarily the collected information until the network connectivity is resumed. For instance, if the sink nodes use a GPRS module in order to upload the information to the data back-end infrastructure, it is only necessary for the farmer to pay the costs associated with the data plans of the sink nodes and not for the whole network.

Full Cloud Connectivity In this case it is necessary that all the WSNs nodes maintain connectivity with the data back-end continuously in time. In this case, it is necessary each network node to be equipped with the long-range communication radio (besides the short-range radio for the ad hoc communications). The distinction between sink node and mesh node continues to be applied in this architecture, as for each sub ad hoc network only a certain number of nodes will act as sinks and turn on that long-range radio. So it is necessary that all the system's nodes could adapt themselves depending on the network's current situation and so may alternate between sink nodes and mesh nodes in order to maintain network communication with the data back-end infrastructure. For instance, there is an ad hoc network that is composed by only one sink node, the animals had moved around in the grazing field and the network was divided into two independent networks. In this situation, the nodes from the ad hoc network that becomes without the sink node detect the absence of the sink node and elects one of its nodes to become the new network sink so that the collected data Hence, the system becomes robustness to node failures, tolerating the failure of any kind of nodes by automatically adjusting to each existing scenario and maintaining this way connectivity with the back-end infrastructure.

Depending on the specific real deployment scenario, there are two main approaches communicate with the Internet (for uploading the collected data to the back-end infrastructure, through a gateway). In the ideal case, there exists a cellular service covering the system deployment area, so that the long-range communication radio could use, for instance, the GPRS technology, and so the node that turns on this communication interface becomes also the system gateway. This solution could be interesting in the case of extensive grazing areas. Otherwise, if there is no cellular service covering the area, the sink nodes, using a long-range radio link, could deliver the sensed data to an Internet gateway, which in this situation corresponds to a node outside the ad hoc network (for instance located in a farm office). This could be done using intermediate relaying nodes, depending on the specific real scenario. For instance, if the distances between the gateway and the pasture fields are too large, it may be necessary the usage of static intermediate nodes on the field.

3.2. Cloud Computing Platform

The back-end infrastructure that supports the WSN corresponds to a Cloud Computing platform. This back-end platform is in charge of four relevant functions: data processing, data storage, event detection as well as alarm reporting. As this solution is Cloud-based, the Cloud Computing resources can be easily and automatically adjusted according to new application's demands, or as the application's requirements grow, without the farmer having to invest more money in back-end infrastructure. The Cloud Computing platform will also be in charge of sending to the end-user digests (e.g., via email) containing a summary of the monitorization done during a period of a day, week, month, etc.

3.3. Web Application

The end-user application will correspond to a Web application. In order to get access to the system information, the application will connect to the Cloud platform and will make requests to it. Using this application, the farmer can visualize the last reported state of the system and of its nodes, consult historical information that have been saved, see the events that have been detected by the platform as well as interact with the system.

4. Implementation

As mentioned above in chapter 3, the system's architecture is intended to be generic, although its implementation decisions depend directly on the real application scenario where the system will be deployed. In this context, this project has the collab-

oration of the enterprise *Sensefinity*®[1], which is a startup company that provides M2M solutions as a service to other companies or partners in the most varied areas, allying the development of hardware and software. This collaboration allowed to support the development of this project. The enterprise *YDreams Robotics*[2] has also supported this project and allowed to test and validate the first prototype in a real application scenario, using the network of Fundão's *Fab Lab Aldeias do Xisto*. In this context, the company *Queijaria Ribeira de Alpreade*, located in the Portuguese village named Zebras near Fundão, has immediately demonstrated interest in this project in order to innovate the monitorization done on its assets.

A requirement analysis was made in the *Queijaria Ribeira de Alpreade*'s offices involving various experts in this field that work directly with the animals or who are directly involved in the management activities of the business. Through the interviews it was identified that the monitorization will be made in dairy sheep that are usually freely grazing in a large dimension pasture (tens of hectares) with cellular service covering the region. They spend most of their time alternating between grazing and resting/ruminating, presenting slow movements (except during short stress periods). Sheep graze in cohesive groups and isolation is a source of stress to them. They are social animals and form strong social hierarchies between them. Generally, in the top of the hierarchy there are some leading sheep that influence the other animals, particularly their grazing movements, therefore the other sheep tend to follow all their decisions. Usually, the farmers tag these leading sheep with a bell on their collars to easily locate them.

Hence, it was identified the main functionalities that needed to be supported, according to priority requirements defined by the staff for the first system prototype, which are illustrated in figure 2. Although these functionalities are specific to this pilot company's interests, some of them are transversal to the branch of the farm animals monitorization and even common to other sectors of our society:

1. Determine the current position of an animal based in the last reported position;

2. Build the route taken by a sheep as well as by the whole flock of sheep, to clearly identify the pastures used as well as the ones with better quality;

3. As the sheep are freely grazing sometimes they surpass the farm limits, therefore it is intended to have a geo-fencing functionality that sends an alarm to the farmer staff indicating this occurrence;

4. Inform the farmer when the system detects a cut in the collar, indicating a possible theft;

5. Alterations in the normal bustle of an animal may indicate to the farmer valuable informations, therefore the farmers want to be informed when an animal presents movement values that are significantly above or below the mean for each individual animal, taking into account the history of that specific animal;

6. As when an animal picks a particular infectious disease it is necessary to slaughter the whole flock of sheep, therefore it is very interesting to infer the direct/indirect interactions between the various animals, based on the historical distance between them, in order to isolate only the potentially infected sheep, thereby avoiding slaughtering healthy ones that were not in danger of contagious.

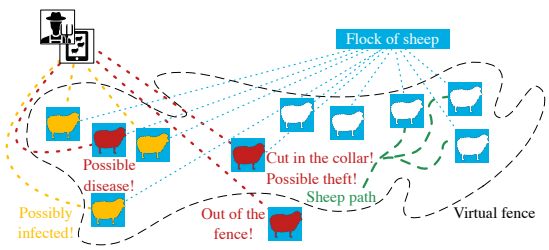

Figure 2: The use-case illustrated.

These leader sheep will correspond to the sink nodes of the WSN as they tend to have more sheep close to them. The other sheep will correspond to mesh nodes that will send its data through multi-hop to the sink nodes, using for that a short-range radio. As the region is covered by a cellular service, it was chosen the GPRS technology to send the collected network information to the data back-end. Therefore, using the GPRS module, the sink nodes of the network will also play the role of gateway nodes.

Due to the natural mobility of the animals, the flock of sheep may become partitioned in various sub ad hoc networks, which may not have connectivity with the sink nodes. In order to overcome this fact and as all the sheep will be equipped with the ultimate version of the first prototype that includes a GPRS module, the mesh nodes could turn temporarily into sink nodes when they detect that its sub network has no connectivity with any sink node.

[1] `http://www.sensefinity.com` (accessed last time on 19th December 2014)

[2] `http://www.ydreamsrobotics.com` (accessed last time on 19th December 2014)

This way the information collected by the network may continue to reach the data back-end infrastructure through the recently elected sink node.

The Cloud Computing Platform used was the *Machinates*® designed and maintained by the Sensefinity® enterprise. The *Machinates*® platform only understands the messages that are formatted following the *Columbus*® model. Therefore the WSN nodes have to send the information in *Columbus*® messages. The information collected by the WSN and stored in the *Machinates*® can be consulted by the farmer through a GUI provided by the *Machinates*® platform.

4.1. Network Protocol

The implemented gradient-based routing protocol was designed for convergent traffic in mobile large scale networks where the data packets flow to sink nodes, which aggregate all the information collected by the network. This protocol has two network phases; the first one corresponds to the *network configuration phase* responsible for informing to each network node the current one-hop neighbours connected to the sink nodes and their heights on the network in relation to the sink nodes. Such information will allow in the future (i.e., in the *data exchange phase*) to deliver data packets to the sinks through a multi-hop approach. As this protocol is intended to be applied in a mobile network, the *network configuration phase* will be periodically repeated in order to allow each node to refresh its vision of the current network state, having origin in the sink nodes that broadcasts a network configuration packet. It was chosen a single-path routing approach in order to forward the data packets to the sink nodes, sending them through the most adequate neighbour (the one-hop neighbour that is closer in hops to a sink node, i.e. the neighbour with lower height). It was also used a point-to-point message delivery confirmation. Each network node will communicate in the *data exchange phase* adjusting its radio communication signal strength according with the targeted neighbour for communication, allowing to saving energy and reducing the network interference.

4.2. Hardware

It were used the *eZ430-RF2500* module from *Texas Instruments* combined with the second generation node solution from *Sensefinity*®, called *Butterfinger*®. The *Butterfinger*® combines the *MSP430F5419A* MCU solution from *Texas Instruments* with a *SIM908* module from *SIMCom Wireless Solutions*. Using the *SIM908* it is possible to upload the collected WSN information to the data back-end infrastructure through its GPRS module and, at the same time allow to sense the current geographic information of the node through its GPS unit as well as the its current battery information. As the *Butterfinger*® has not a short-range radio for communications inside the WSN, it was necessary to combine it with an *eZ430-RF2500* module, which provides the *CC2500* transceiver. The ultimate WSN node's solution is illustrated in figure 3, which will be attached on the animals' collars.

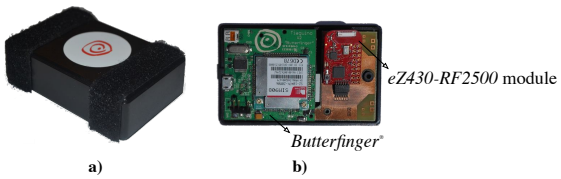

Figure 3: The ultimate solution; a) protective case; b) the hardware disposition

5. Evaluation

The implemented system was tested in real application scenarios. These field evaluation experiments allowed to validate the developed system in a real scenario context as well as to collect real environmental data. It also allowed to collect enriching opinions and other feedback given by the professionals working on this specific branch that could be very useful in future system's improvements.

5.1. *Queijaria Ribeira de Alpreade*'s Experiments

The first system deployment inserted in a concrete field testing case was made with the collaboration of the company *Queijaria Ribeira de Alpreade*, under the scope of the Fundão's *Fab Lab Aldeias do Xisto*. This company's business is based on the production of regional typical cheese. The innovation in the monitorization of their Livestock assets is seen as a challenging and important aspect.

The system prototype was applied for the monitorization of dairy sheep. A reduced number of nodes was available for these first experimental tests on the field (4 nodes), therefore it was decided to validate this prototype in a small flock of sheep that are freely grazing. Typically, between the sunset and the sunrise the flock of sheep are resting in the open barn signalled on the map, being freely grazing in the field in the remaining of the daytime inside the delimited grazing area. Usually the sheep are grouped in the barn at the beginning and end of the day in order to be milked (i.e., before being set free and after being put back in the barn, respectively).

The monitorized sheep were equipped with the ultimate node solution illustrated in figure 3. Each node was programmed to collect its GPS information each 15 minutes (T_{GPS}) and to collect its bat-

tery information hourly ($T_{battery}$). The equipment was installed in the sheep's collars as illustrated in figures 4 and 5.

Figure 4: Devices in different regional sheep collars

Figure 5: Sheep wearing a monitorization collar

Livestock Mapping

As mentioned before, one of the device's primordial functionalities is to collect its current geographic position and report it to the final data back-end infrastructure. Figure 6 shows a screenshot of the *Machinates*® GUI illustrating the overall system's look and feel, as well as the location of each animal on the grazing field.

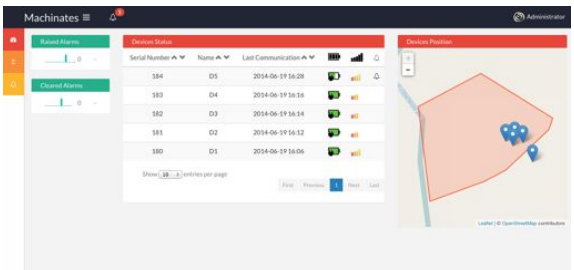

Figure 6: Overall vision of the system illustrated on the *Machinates*® GUI.

In figure 7 it is represented a heat map (built using the *Google Maps* API) whereas it is marked each geographic position reported by a given sheep during a 24 hours period. Therefore it is possible to clearly identify the areas where the animal remained more active as well as to correlate them with the period of the day in which the information was collected (i.e., if it was collected during the daytime period or the nighttime period).

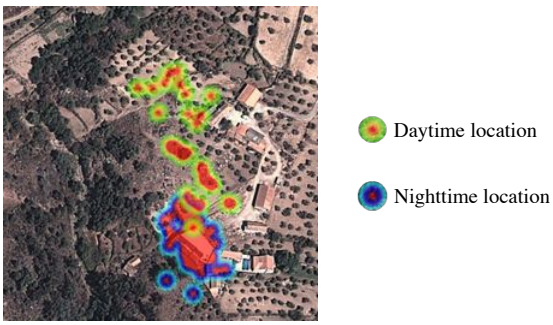

Figure 7: Animal's location heat map during 24 hours

It is also possible to observe in figure 7 that, as expected, during the daytime period (i.e., the geographical positions collected between 10AM and 20PM) the animal's locations are quite spread along the grazing field. During the nighttime period (i.e., the geographical positions collected between 20PM and 10AM), the geographical area of activity is condensed essentially over the open barn, as it was expected for this specific period of the day when the sheep are resting in the barn.

Geo-fencing

The geo-fencing concept represents a valuable application that is running upon the developed system. Combining it with the component responsible to the alarms management, it is possible to be notified when an animal crosses its virtual boundaries.

It was established a small virtual fence inside the monitorized area, which forced the enabling/disabling of alarms related with the geo-fencing feature. It was verified that every time a sheep position was received with the information that the animal surpassed the virtual boundary, an alarm was triggered. In the opposite situation, every time an animal came back to the allowed grazing area, the triggered alarm was cleared. In figure 8 it is possible to view a screenshot of the *Machinates*® GUI illustrating the triggering of an alarm originated by a sheep that crossed the virtual fence, exiting this way the allowed grazing perimeter.

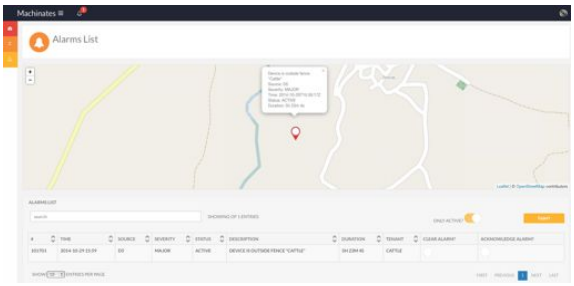

Figure 8: Geo-fencing alarm illustrated on the *Machinates*® GUI

WSN Connectivity

The mesh nodes of the network were programmed to report the amount of time (in seconds) that they had network connectivity (through single-hop or multi-hop) with at least one sink node during 30 minutes. This information was periodically collected during the daytime and the nighttime periods, being represented in figure 9. The presented information is related to 5 hours of experiment during daytime and other 5 hours during nighttime, being all data collected by a single mesh node.

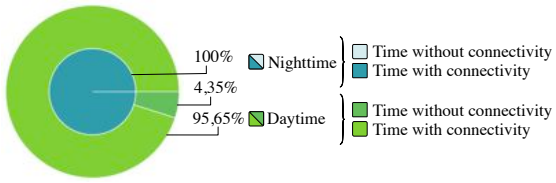

Figure 9: Mesh node network connectivity during the daytime and nighttime period

It is possible to notice as expected that during the nighttime period the sheep stay sufficiently together when resting to maintain network connectivity with at least one sink node during the whole time (100%). Looking now for the daytime period, it is possible to observe that the mesh nodes have maintained connectivity with the sink nodes during about 287 minutes out of the 300 minutes of the testing scenario, thus in most of the time (95,65%). The maximum communication range of the *CC2500* transceiver tends to 16 meters. This fact combined with the short distances that sheep usually maintain among themselves during the day and night periods, justify the connectivity time values obtained from this experience. As the sheep are freely grazing/resting in an open field during the daytime (in opposite with the nighttime), it is possible to observe also differences between the network connectivity times during daytime and nighttime, being this value lower as expected during the daytime. The information extracted from this experiment gives a good indicator for the system as the data collected from each network node can flow promptly to the sink node and in consequence to the data back-end with small delays, allowing the system to react more quickly in the existence of an anormal situation that may require special care.

Latency Times

Considering latency times collected during the field tests, it is possible to distinguish between the latency time associated with the time interval that the information took to travel since the time it was collected to the instant that it reaches the *Machinates*® back-end, and the one associated with the time interval that the data took to be processed since it enters in the *Machinates*®.

Figures 10 and 11 report the variation of the latency times associated with the data packets collected by each of the four nodes of the WSN. In each figure it was represented the latency time for each hour, corresponding this value to the average of the latency times of all the data packets for that given hour.

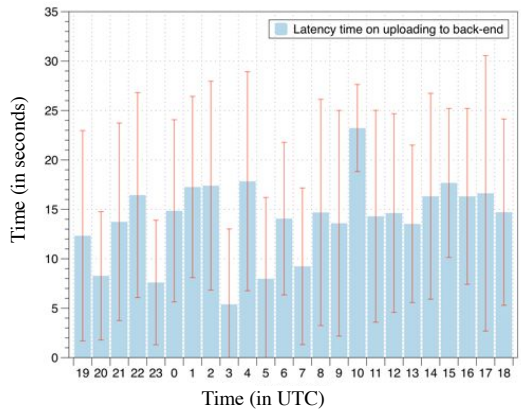

Figure 10: Latency times on data uploading to the *Machinates*® back-end

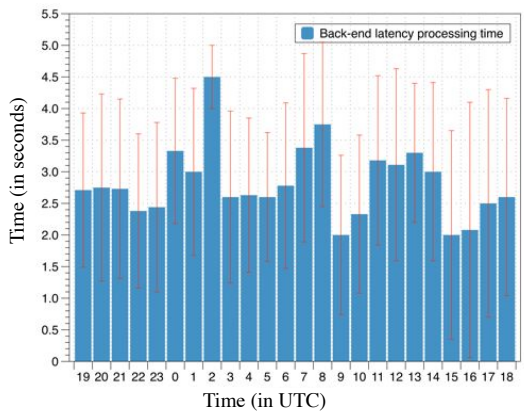

Figure 11: *Machinates*® data processing latency times

The sink nodes were programmed in order to only upload the information to the *Machinates*® back-end when they have at least 10 data packets, being each WSN node responsible to collect its GPS and battery information each 15 minutes and daily, respectively. Considering these facts, the latency values illustrated in figure 10 correspond to the expectations. The maximum latency upload value obtained was 23,22 minutes at 10AM and the minimum corresponded to 5,40 minutes at 3AM. The

average for the entire day is 14,09 minutes, which corresponds to a value that it is reasonable and tolerated by this system.

In the figure 11 it is possible to observe that the latency processing times of the *Machinates*® back-end never exceeded the 5 seconds, being the average for the entire day 2,82 seconds, which gives good evidence for the system reliable operation.

5.2. Cascais Municipality's Experiments

Some complementar tests were made in order to collect more real information, in an attempt to further improve system evaluation with more subjects (animals). In this context, the Cascais Municipality provided further support, making available their sheep for carrying out further experiments.

Since the primary goal of this project was to collect the maximum possible information about the location of the monitorized animals in order to characterize their behavior, it was decided to collect GPS samples each 3 minutes and maintain the GPS module of the *SIM908* unit always on. The sheep are herding in the natural park of Quinta do Pisão, being the herd composed by 68 sheep. It were only monitorized two sheep. The sheep are set free daily in the morning and are routed to the grazing field located approximately 2km from the barn, being collected again to the barn at the end of the day. The grazing field corresponds to a large dimension space. The experiments were done during two days.

In figure 12 it is illustrated the variation of the total travelled distance by each monitorized sheep during the experiments done in two days. It is possible to observe that for each hour in the two days the two monitorized sheep have similar travelled distances, indicating they had travelled approximately the same. This fact is typically present for animal groups that maintain cohesive interactions between them, typically staying together. The collected information matches this behaviour as the sheep generally stay together, resulting this way in very similar total travelled distances between each individual sheep. The registered peaks at the 10AM correspond to the period that the sheep were been released to the grazing field and travelled approximately 2km to get there. The sheep travelled different grazing paths during distinct time periods on each day resulting in large differences in the total travelled distance between the two days.

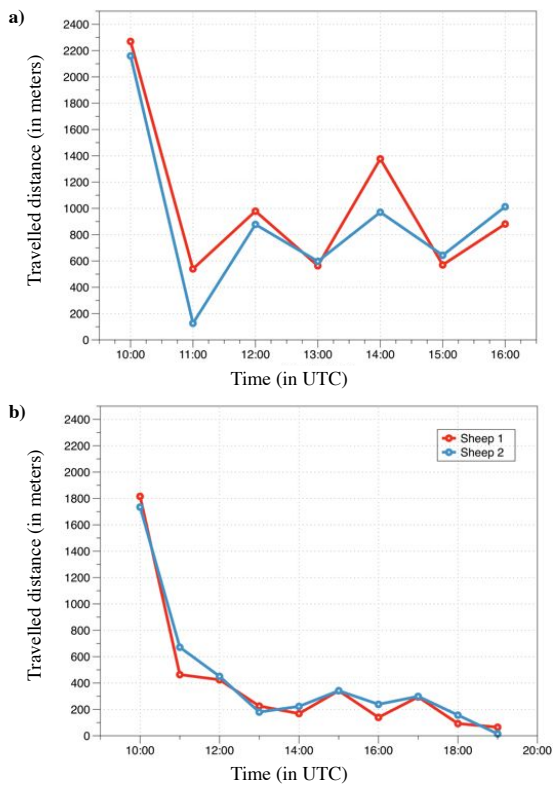

Figure 12: Total travelled distance by hour; a) experimental day 1; b) experimental day 2

In figure 13 it is illustrated the location variation for the two monitorized sheep during the first experimental day. From the observation of this figure it is possible to observe that the two sheep present similar variations of their latitudes and longitudes along time. It is also possible to observe that these two sheep travelled similar paths along the day.

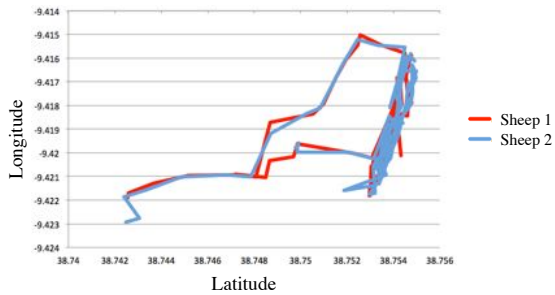

Figure 13: Latitude and longitude variation

5.3. Herdade de Gâmbia's Experiments

This project was also evaluated in the company Herdade de Gâmbia, near Setbal. The main purpose of these experiments was to infer the capability of the proposed system in detecting and distinguishing between thighs and healthy sheep. The sheep are herding in the Herdade de Gâmbia's pas-

ture area, being the herd composed by 300 sheep. It were only monitorized two sheep, corresponding to a thigh and healthy ones. The experiments were done during two days.

In each day and for each sheep, it was determined the velocity between two consecutive measured points. Thereafter, several features were extracted, namely average and standard deviation values for the two experimental days, as well as an entropy measure (corresponding to the entropy value determined for the maximum scale according to Costa et al. [13]). The results extracted from the two experimental days are presented in table 1 and illustrated in figure 14.

Day 1	**Avg**	**Std**	**Entropy**
Normal Sheep	0,21	0,15	1,56
Thigh Sheep	0,18	0,17	1,42
Day 2	**Avg**	**Std**	**Entropy**
Normal Sheep	0,22	0,16	2,44
Thigh Sheep	0,21	0,24	1,80

Table 1: Statistical information collected from the two experimental days

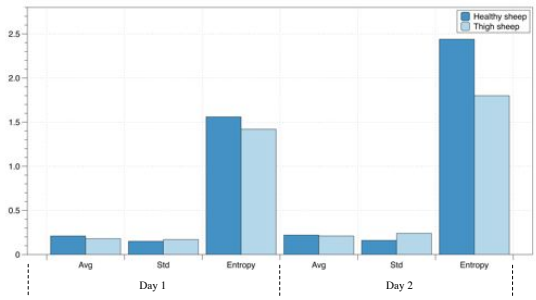

Figure 14: Illustration of the statistical information collected from the two experimental days

It can be noticed that the value of entropy is smaller for the thigh sheep during the two days of experiments. This may give some initial hint for a mechanism to identify healthy from non-healthy sheep. Our hypothesis concerning learning animals health remains to be tested upon the future availability of more training data (just two collars were available for this experimental evaluation). It concerns the variation of the entropy values over several days, namely if for non-healthy individuals the entropy value over several days gets consistently lower than for healthy individuals (as shown in figure 14 just for two experimental days). On a neural network, the inputs could be the entropy values of an animal over several days, and the output a value giving the probability of an animal being healthy, or not.

However, given the extremely small dataset available, no meaningful conclusions can be extracted concerning:

- The best features to extract from the data in order to feed a learning mechanism;
- The capability, or not, of identifying healthy animals from non-healthy ones using their patterns of motion.

Concerning the last point, Costa et al. [13] have shown that the fractal property of organisms, such as given by multi-scale entropy measure, gives a measure of an organism healthy, and have shown this strategy applied to Electrocardiography (ECG) signals, as well as motion data. However, on their experiments the sampling frequency is significantly higher than 3 minutes, and windows of analysis contain thousands of points (compared to nearly 100 to 200 data points for 6 to 8 hours collection of sheep location data), and hence is arguable if such approach could bring in the future some benefits, or not, for the problem at hand.

6. Conclusions

This work proposes a WSN system based on a Cloud Computing platform specifically designed for the Livestock monitorization area. This monitorization was centered on the periodical reporting of the animals' geographical location, and correspondent extraction of useful information to the farmer. After carrying out interviews with specialized staff, it was possible to make important design decisions.

The WSN is formed by the group of animals to be monitorized, being each device installed in each individual animal. The animal's location is collected using a GPS receiver. The information collected by each animal is propagated in the mobile ad hoc network following a gradient routing protocol strategy. The network nodes have the capability of proactively adapting themselves between mesh or sink nodes, according to the current network topology. Besides collecting information, the sink nodes have the important role of transmitting the WSN information to the Cloud Computing platform through GPRS. The Cloud Computing platform gives support to the WSN by storing and processing its data.

Finally, it was produced the first system functional prototype that was submitted to a rigorous evaluation process. This first prototype was tested in real scenario applications, in particular for the monitorization of free-ranging dairy sheep. The results obtained from these experimental tests were quite positive, giving good indicators of its effectiveness in this kind of monitorization solutions. The

implemented system endured the demanding and unpredictable conditions that characterize these environmental scenarios. During these experiments, it was possible to extract very interesting real information as well as enriching feedback from specialized staff, which will certainly be used for future system improvements.

In conclusion, this first system prototype that was used as a proof of concept has demonstrated that it can be effectively employed in this kind of monitorization scenarios, giving automatically valuable information to the farmer that would otherwise be very difficult to extract using traditional monitorization mechanisms.

6.1. Future Work

As future work and in order to improve the implemented system, there are some topics that may be improved or completed, namely:

- Optimizing the hardware solution;
- Explore the Wake-on-Radio (WOR) feature of the *CC2500* transceiver;
- Adopt an energy harvesting solution;
- Replace the current GPS antenna with an active antenna;
- Optimize the *Columbus*® messages in order to reduce the size of the messages;
- Allow to change system parameters through the *Machinates*® GUI;
- Implement some features that were not completed in this first prototype system (such as detect and report cuts in the sheep's collars and allow to identify the direct and indirect interactions between the animals);
- Particularly in the *Queijaria Ribeira de Alpreade*'s use-case, extend in the future the monitorization to other components of the business (e.g., milking system);
- Continue the experiments done in the company Herdade de Gâmbia with a higher number of monitorized animals in different health conditions for a longer period of time in order to test the solution's effectiveness in detecting and distinguishing between healthy and non-healthy sheep;
- Apply machine learning strategies to collected data in order to detect certain abnormal behavioral patterns that may suggest possible animal diseases.

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