DEPARTMENT OF
COMPUTER SCIENCE

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BsC in Computer Science

IOC: INTERNET OF COWS

COWS WIRELESS TRACKING

Dissertation Plan
MASTER IN COMPUTER SCIENCE AND ENGINEERING

NOVA University Lisbon
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Abstract

Resumo

Contents

List of Figures

List of Tables

Acronyms

CREW Concurrent Random Expanding Walkers *(p. 7)*

GPS Global Positioning System *(p. 2)*

MAC Media Access Control *(p. 10)*

NeEM Network Friendly Epidemic Multicast *(p. 7)*

RF Radio Frequency *(p. 15)*

Scamp Scalable Membership Protocol *(p. 7)*

TCP Transmission Control Protocol *(p. 7)*

WSN Wireless Sensor Networks *(pp. vi, 8–10, 12–15)*

1 Introduction

This chapter will explore the motivations for the work to be conducted, the underlying problem that motivates our work, the objectives and expected contributors to achieve during its development. This Chapter closes with a brief presentation of the structure for the remainder of the document.

1.1 Motivation

In the Coitadinha Farm, located in Alentejo, Portugal, they have over 150 cows, alongside many other animals, spread throughout thousands of acres. Controlling that many animals in such a vast terrain is quite a difficult task. In this context. the manager of the Farm have interest in monitoring the behaviours of cows. Obtaining useful data such as their daily patterns of movement, where they spend time and, potentially, manage their location through the use of adjustable virtual fences. From a research prespective from ecology and conservation, the aforementioned data is also relevant to understand the impact of cows behaviour on the ecossystem, in particular, vegetation. Unfortunately there are not many technological solutions to this end, and those that exist are expensive and based on closed solutions. Furthermore, the region lacks quality cellular service, which complicates further the use of technological solutions to simplify this task.

These cows are kept separated in herds depending on their ages, which means that the younger cows are not in the same herd as the older ones. This kind of separation is quite important for them to coexist. Inside each herd they follow a hierarchical structure, having a leader that all the other cows in the herd tend to follow.

The Coitadinha Farm currently has physical fences in place to maintain the multiple herds separated from each other and protected. However, these fences are not very durable, which lead to an often replacement and potential danger for the cows. In addition, since the farm covers an immense amount of land, it is reasonably strenuous to locate all cows and make sure all are healthy and safe.

Having already available some great options of collars that create virtual fences for all kinds of animals, there are still no alternative that would work for the Coitadinha Farm.

Mainly because of the lack of cellular service available, but also do to the large number of cattle herds in this production.

Furthermore, it of the upmost importance to be able to change the herds' location considering the effect in plant communities from cows grazing in the exact same area for long periods of time, this should be possible to do with minimal effort from a control station in the main farm building for instance.

1.2 Problem Statement

Currently the cattle in farms are separated with physical fences, which needs to be constantly repaired or even replaced, that culminates in a costly and laborious task.

Furthermore, seeing as most farms have a vast amount of land where their cows are scattered on, it becomes quite difficult to provide help if a cow is in danger or lost, especially considering that this information is often obtained too late.

Another challenge arises when the farms do not have network coverage. This creates obstacles to propagate messages from the fields to the user, even assuming that cows wear devices capable of monitoring their behaviours and communicating with a centralized infrastructure.

Ultimately, there is no low consuming, reliable and robust collar for tracking wildlife in a rural area, with no access to network infrastructures, and with the option to create a virtual fence. We will tacle this problem by proposing a novel and innovative solution.

1.3 Objectives

During this dissertation we expect to develop a fully functional prototype of an animal collar, adaptable to any cow, that connects to a Global Positioning System (GPS) and creates a virtual fence for each herd. This fence should be adjustable accordingly to the user's desire and the collars should send a vibration to the cows, if they are located outside the fence area, in order to get them back inside.

These collars should provide accurate information about the cows' locations as well as be highly scalable to handle all the cows' data. The ultimate goal is to find a reliable and not much consuming solution to deal with the sensing information collected and transmit it back to the users. To minimize cost and deal with the lack of infrastructure we plan to explore the hability of collars to exchange information directly through the use of gossip protocols. This will allow to minimize the number of collars that need a GPS tracker and more powerful radio devices.

1.4 Expected Contributors

1.5 Document Structure

The remainder of this dissertation is organized as follows:

Chapter 2 - Related Work: includes research on existing protocols for broadcasting, particularly the Gossip Protocol, presents wireless sensor networks and some of its applications, reflects on how cows behave in a herd and their habits and lastly introduces a few existing collars and their specifications.

Chapter 3 - Work Plan: a description of the future work organization and explication of each work phase.

2

Related Work

In this chapter we examine some topics and techniques that are vital for the work proposal presented in this document. These topics include Gossip Protocols, a dissemination method, Wireless Sensor Networks and of particular interest for applications devoted to tracking animals, and, lastly, the Cattle Production, that explains how the cows behave in herds, their diet, and its consequences to the plant communities.

2.1 Gossip Protocols

2.1.1 History and Overview

Gossip protocols, also known as epidemic protocols, as the name indicates, was created based on how rumors are propagated in social groups. In a gossip protocol, nodes in a network send the information, randomly, to other nodes in the same network, similar to how a rumor is spread between members in a social group [13].

Gossip protocols are known as highly scalable and resilient approach to implement reliable broadcast These protocols are based on every participant propagating their messages collaboratively throughout all the members of their group.

This process starts when a node desires to propagate some piece of information to the other members of his network. This node will send his message to t nodes, chosen randomly, (t being a parameter called *fanout*, which is better explained in the Section 2.1.1.1). When the receiving nodes receives the message for the first time, they will do the same as the previous node and resend the message to t, randomly chosen nodes. If a node receives the same message twice, it will discard it. When this happens, which may occur quite often since the nodes are unaware of which nodes have already received a message, there is communication redundancy, which while undesirable, serves the purpose of omissions (e.g. messages that are not correctly received).

However, since neither node knows who has received each message and who has sent a message to whom, each node will have to keep a log of all messages that it has already received, to avoid delivering it multiple times to the application and to circulate in the network forever.

2.1.1.1 Parameters

Gossip protocols have parameters that should be taken in consideration when using this class of protocols. The most relevant ones are [14]:

Fanout: represents the number of nodes that each node will propagate its message to, in each propagating step of the

Maximum Rounds: represents how many times a message can be retransmitted. Each message has a value of rounds associated to it, starting with zero and adding one unit every time a node retransmits the message to a neighbour. When this value reaches a maximum round value the message is no longer retransmitted and is simply dropped.

Both these parameters demonstrated a clear tradeoff between reliability and redundancy. If the fanout or the maximum rounds values has a high value the reliability of the protocol will increase, meaning that the probability that all nodes receive the message increases. However, the amount of redundancy will also grow, potentially saturating the network, which in extreme cases can impact negatively the reliability of the dissemination process. The opposite will occur for low values of each of the parameters.

2.1.2 Strategies

A Gossip protocol may be executed between pairs of communicating nodes following different approaches [11]:

Eager push approach: As soon as a node receive a message for the first time, it sends it to t randomly selected nodes immediately. This approach consumes a great amount of bandwidth, considering it leads to multiple copies of the same messages being delivered to each target node.

Pull approach: Periodically, nodes inquire each other on new messages they have recently receive. If they acquire information about a message they have not receive yet, they will request it explicitally from that node. This approach leads to higher latency to a message to be received by all nodes, derived from the extra round trip needed to obtain a message at each hop of the network.

Lazy push approach: When a node receives a message for the first time, it will only broadcast to its neighbours a unique identifier of the message, as an example a hash of the message. If the neighbour never receives the given identifier, it will request the payload of the message. As in the pull approach, there will be a higher latency, although somewhat smaller since the transmission of the identifier speeds up the propagation of the messages throughout the network.

Besides the previously mentioned differences in latency and bandwidth, there is another important distinction between the eager push approach and the pull and lazy push approaches. Considering that the eager push approach sends the entirety of each message immediately after receiving it, the nodes do not need to maintain a copy of these messages, contrarily to the other two approaches that may need to resend these messages later. This leads to a higher memory requirement for these approaches [14].

By combining the approaches studied above, we can get better results, obtaining a better latency/bandwidth tradeoff. This are two of the studied combined approaches [5]:

Eager push and pull approach: This method is divided between two distinct phases. The first phase consists of using the eager push approach to disseminate messages straightly to the nodes in the network. The second phase uses the pull approach to recover the omissions that might have occurred during the first phase of this approach. This strategy reduces the amount of redundancy in comparison with the eager push approach, without decreasing its performance. It will, however, lead to a higher latency due to the use of the pull phase for recovering from omissions.

Eager push and lazy push approach: In this approach eager push is used only to propagate messages to a subset of nodes. Then it uses the lazy push approach on the remaining subset of nodes to recover from omissions that might occur and guarantee the reliability of the dissemination process.

2.1.3 Tree-based Approaches

Tree-based broadcasting methods have a small message complexity, however, they are not particularly resilient to faults. On the other hand, gossip protocols, as mentioned earlier in Section 2.1.1, are known for their resilience, but have a high message complexity [15].

In order to obtain a small message complexity and high reliability, previous approaches have considered combining both these methods.

With this approach we obtain the nodes organized in a tree structure topology, where each node knows to whom forward its messages. To achieve this structure we have many approaches, one of the most popular is to rely on the PlumTree protocol.

PlumTree protocol This protocol uses eager push and lazy push gossip, previously explained in the Section 2.1.2. It separates the nodes in the network in two subsets of randomly selected nodes. The first subset of nodes uses the eager push protocol to disseminate the messages, while the other uses the lazy push protocol. The links that the eager push method uses to propagate the messages are chosen to create a randomized broadcast network that converges to a tree-based structure. While the links used during the lazy push gossip are used to ensure the reliability of the method when nodes fail and potentially heal the broadcast tree when needed [15].

Additionally, in opposition to other dissemination protocols, that rely on tree-based gossip the connections first made by the eager push propagating will remain until it is detected a failure. This will allow us to use Transmission Control Protocol (TCP) connections, which will provide extra reliability and failure detection.

2.1.4 Examples

Throughout the last years there have been proposed numerous gossip-based protocols. During this section we will discuss some of them:

Scalable Membership Protocol (Scamp): Contrarily to many other gossip-based protocols, with Scamp it is proposed that the individual nodes have a randomized partial view of the global members in the network, leading to a fully decentralized system. This is quite an important advantage for large scale groups, since it requires a significant amount of memory and generates a lot of network traffic to maintain the system's overall consistency in extensive groups. Additionally, the scalable membership protocol is also compelling for its natural increase and reorganization of the partial view of the system when new nodes are added to the network. Having this partial view around *log n* nodes (being *n* the number of overall nodes in the network) [8].

Network Friendly Epidemic Multicast (NeEM): One of the biggest problems in most gossip-based protocols is when the network gets congested and, subsequentially, the messages get lost. NeEM uses TCP to disseminate the messages and resolve this problem, with the usage of its inherent flow and congestion control mechanisms. In order to maintain the protocol's stability, NeEM uses a buffer management technique that utilizes different approaches to discard messages on overflow. It also includes the knowledge about the messages' types in order to ensure that the buffer retains enough space and bandwidth is used to better fit each request [18].

Concurrent Random Expanding Walkers (CREW): Is a gossip-based protocol designed to minimize the messages dissemination speed. This is acquired by maintaining in cache the information about the already established connections, which will reduce the latency of reopening a TCP connection [7].

2.1.5 Gossip Limitations

Throughout this Section it has been vastly mentioned the advantages provided by gossip protocols. Mainly, it was referred the resilience and scalability offered by this approach. However, as any other protocol, it has its limitations. A few of this are [4]:

1. Fixed maximum message size - gossip protocols have a fixed maximum message size which may lead to problems. As an example, if we desire to propagate a message with a larger size than this fixed maximum message size, we will have to divide the

message into multiple segments. When this happens, some of these segments may be lost, since each node can only gossip a certain amount of information per unit (occasionaly named round), which will increase the number of rounds required to deliver a single message to all participants.

2. Slow rate - the rate of messages exchange in a gossip protocol is typically quite low, which can cause some challenges when managing sudden and urgent events. This situation might be surpassed by reducing the periodicity of messages exchanges; however, this often leads to yet another problem, the increasing of overhead and potentially network congestion.

3. Malicious behaviours and correlated loss patterns - another limitation of gossip protocols is that when the nodes behave in a malicious way, intentionally, such as disseminating of false information or when nodes malfunction, even if unintentionally, gossip protocols can be disrupted, or effectively propagate incorrect information.

2.1.6 Discussion

Throughout this Section it has been described the fundamental approaches of gossip protocols, the main strategies, a tree-based approach, some interesting examples of gossip-based methods and finally their limitations.

This class of protocols is crucial for the development of this dissertation

Since it is highly scalable and reliable, the gossip protocol will be helpful while dealing with the propagation of data in a system with over 150 cows. Due to the lack of network coverage in most of the farm, the information collected from devices on each cow will have to be communicated to their neighbours until it reaches a point of connection to the management platform.

The PlumTree approach is quite interesting for addressing some of the challenges in this work considering that the cows follow a hierarchy just like a tree-based protocol is design to do. The PlumTree can then mimic the herds' hierarchical system and find the cows that spend more time in close proximity making sending the information throughout the herd until the user easier. Unfortunately PlumTree was proposed for wired networks, where devices by cows will necessarly communicate via wireless, potentially in an infrastructure network (ad hoc network) which is

2.2 Wireless Sensor Networks

2.2.1 Definition

Wireless Sensor Networks (WSN) is a technology with many applications ranging from remote environmental monitorization to target tracking. These networks are composed by multiple small cheap and low-power sensor nodes distributed throughout various locations.

Usually, the nodes are scattered in a sensor field, as demonstrated in Figure 2.1. Individually, each node can perform sensing tasks, which implies:

- collecting data, for example, from its surroundings, such as temperature, light, humidity, and many other types of data, depending on the types of sensors in the device;

- process it, using its on-board processor;

- and finally, transmit it back to the sink (a node that has the capacity to communicate with external devices, such as phones and laptops) by multi-hopping. It eventually reaches the end users via internet or a satellite from the sink node [2].

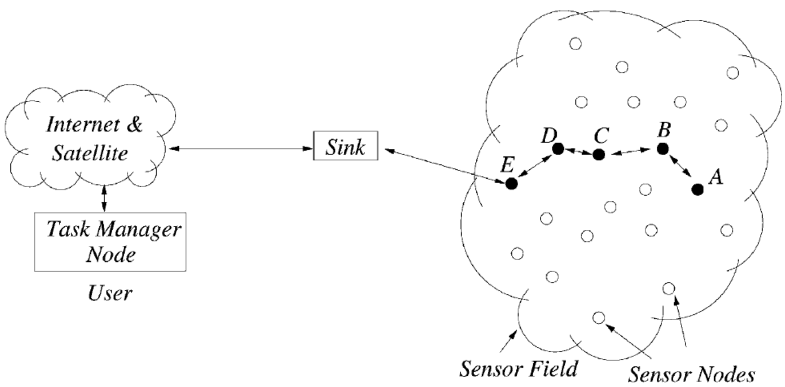

Figure 2.1: Sensor nodes in a sensor field [2]

2.2.2 Wireless Technologies

2.2.3 Communication Architecture

The most common architecture for WSN follows the OSI model. This model is composed of five layers: application layer, transport layer, network layer, data link layer and physical layer, and three cross plane layers: power management plane, mobility management plane and task management plane, as shown in Figure 2.2.

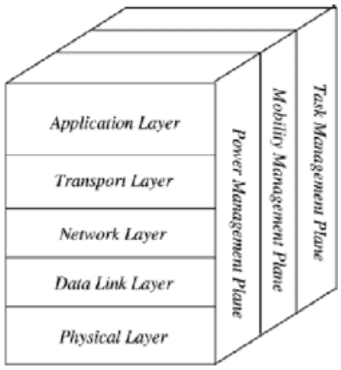

Figure 2.2: WSN Communication Architecture [2]

The five layers above mentioned work together to ensure the data is properly transmitted to the network, each with a specific functionality [2, 17]:

Application Layer provides to the end user an interface that he can interact with. Depending on the sensing tasks there are various types of application software that can be built.

Transport Layer ensures the transportation of data in a reliable and orderly manner, even if the network suffers disruptions.

Network Layer maps to where the data supplied by the transport data should go to next.

Data Link Layer is responsible for confirming that the data transmitted is reliable and the transmission itself is efficient and secure. The main tasks of the data link layer are: 1) reducing the data received from the network layer into frames; 2) find and correct errors in the frames, when possible; otherwise, discard them; 3) multiplexing of data streams; 4) Media Access Control (MAC)

Physical Layer addresses the need for a simple but robust modulation, transmission and receiving techniques.

The management plane main roles are to include managing the network and optimize the sensor nodes performance to improve the overall effectiveness of the network, considering the advantages acquired by all sensor nodes working together. Each of these planes manages a specific area [2]:

Power Management Plane manages how the sensor node uses its power, choosing when to turn off its receiver to save energy or to keep it from receiving repeated messages. It also informs its neighbours when it reaches a low power mode.

Mobility Management Plane: keeps track of the sensor nodes neighbours and always distinguishes a route back to the user.

Task Management Plane: administers the periodicity and schedule that each node needs to maintain in order to perform their sensing tasks based on their power dependency and task requirements.

2.2.4 Network Topologies

There are several different topologies regarding the connection between nodes and their message exchange routes, as represented in the Figure 2.3 [16, 23]:

Star Topology: all nodes are connected to only one node, the coordinator. This means every node will communicate via this central node and every node that requests to enter this network will have to send its information to the coordinator, which will then send it to the other nodes. The principal limitation of this topology is that if the coordinator malfunctions the whole network will fail.

Ring Topology: all nodes are equal connected, having no coordinator. Contrarily to the star topology, if a single link is broken the whole network will fail.

Bus Topology: all nodes broadcast their messages using the bus. Each message has a header with the destination address so that every node can see if the message is for them or another node. This topology is passive, since the nodes are not responsible for retransmitting messages.

Tree Topology: similar to the star topology where the coordinator is the tree root, on the other hand the nodes at different levels of hierarchy are connected to sub-coordinators that lead to the root [21]. In this topology, as in the star topology, if the coordinator malfunctions, the whole network will fail. However, differently from the star topology, will also have problems if a sub-coordinator fails as it will lead to the failure of every subordinate node.

Fully Connected Topology: every node is connected to every other node. This will lead to a routing problem when dealing with large networks.

Mesh Topology: the nodes are generally identical, so the mesh connections are commonly referred as peer-to-peer connections. However, even though the nodes are generally identical some of them can be assign as coordinators that take additional functions and if one of these coordinators stops working, another just takes over his work. An interesting aspect of this topology is that the communication can be done between any two nodes in close proximity, which makes this topology quite robust to the failure of nodes or links, since the messages can use other routes to be delivered, and it is quite efficient for large scale networks.

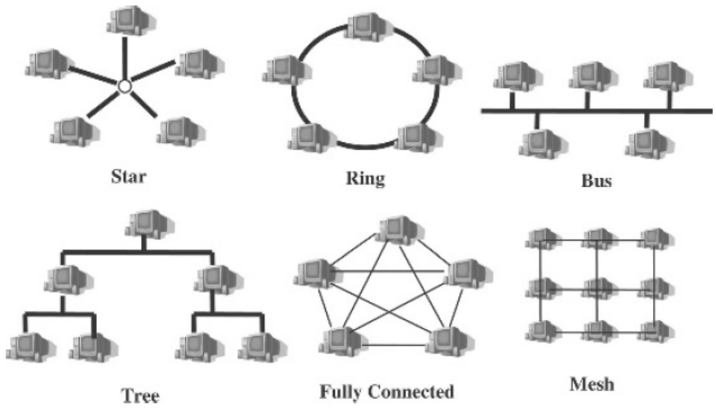

Figure 2.3: Network Topologies [16]

2.2.5 Gossip in WSNs

One of the main purposes of a sensor node is to transmit the data it has collected, via the sensors, to the sink. The route chosen by these nodes has a significant impact on the overall operation of the system, therefore various protocols were studied in [1] to understand which of these would better conduct this task.

As presented previously, in the Section **??**, during the execution of a gossip protocol each node only transmits its messages to t randomly selected nodes and not the whole network, as in the flooding protocol. This characteristic ensures that every node executing a gossip protocol will only have a single copy of the packet to be sent, which addresses one of the shortcomings of the flooding protocol, the implosion. However, this will lead to delays in the dissemination of the data which may be an important factor for some applications of the network.

2.2.6 Applications

Due to the fact that the sensor nodes in a WSN may collect distinct types of data, based on sensing task and the sensor itself, there are many applications and subsequentially many are areas of expertise in WSR. These areas may be related to health, the military, home, environmental, commercial and many more. For this thesis it is more impactful to learn about some of the applications in the tracking area, per example, ZebraNet and Wireless Tracking.

2.2.6.1 ZebraNet

One of the most revolutionary applications of WSN is the ZebraNet, a method developed to track wildlife, specifically, zebras, for biology research, using a mobile base station. The ZebraNet collects logged data from tracking collars, transported by the animals, and afterward it transmits this data back to the researchers. Considering there is no fixed antennas or cellular telephone service, the protocol uses ad hoc peer-to-peer routing to transport the data around.

The ZebraNet project focused on addressing some of the problems observed from previous studies of collecting data from wildlife. One of the main obstacles was using satellites to transport the data. The process of uploading data to satellites is slow and power consuming. Moreover, the data download from the satellite to the researchers is charged by the bit, which restricted the amount of data collected. Furthermore, these systems used batteries without solar panels, which would eventually end, and had to be recovered and recharged, losing enormous amounts of data in process [10].

Additionally, one of the biggest concerns during the development of this project was the design limitations. Due to the fact that each node would be transported by an animal, its weight and size was immediately limited. And since the nodes are difficult to retrieve, the device had to have a durable battery life [25]. Subsequentially, most of the weight would be occupied by the battery and the GPS, leaving a small space for the storage, which meant that there were a small space for redundant messages in this protocol. Lastly, it was crucial to consider the impact of the number and size of data transmissions required as well as the range of these transmissions.

2.2.6.2 Wireless Tracking

Wireless tracking is an application of WSN widely used for wildlife research, since it allows the remote monitorization of moving objects, or in this particular case, animals.

To track an object the sensor nodes detect its location and sends this information to the end user. There are mainly two options to accomplish this: using only a single node or multiple nodes working collaboratively. Using multiple nodes is an overall better choice, since it leads to higher accuracy and lower power consumption comparably to using a single node [24].

To achieve an efficient target tracking performance it was developed countless methods, contemplating the challenges existent with using WSN, discussed furthermore in the Section 2.2.7. These methods take into account the continuous localization of mobile nodes over time, determine their speed at each moment and often use their known former localization to improve accuracy [12].

There are three main types of target tracking approaches according to [19] authors:

1. Hierarchical Networks - the nodes communication follows a mesh based topology, thoroughly explain in the Section 2.2.4, using multihop radio connectivity. This enables the communication between two nodes that are not in a direct communication range, by forwarding their messages through other nodes in their ranges until the messages achieve their final destination.

    a) Tree Based Target Tracking - the nodes are organized in a hierarchical tree structure or represented as a graph, where the vertices represent the nodes and the edges the connections between two nodes that can communicate directly. The node

b) Cluster Based Target Tracking -

i. Static Clustering -

ii. Dynamic Clustering -

iii. Space-Time Clustering -

c) Mobicast Message Based Tracking -

d) Hybrid Method -

e) Activation Based Method -

2. Peer-to-peer Networks -

3. Other Network -

2.2.7 Limitations

There are multiple limitations that need to be considered while creating a WSN [2, 17]:

- **Fault Tolerance** - the sensor nodes can fail due to lack of power, hardware problems or physical damage, contemplating the harsh environments they are exposed to and their own fragility. Therefore, the protocols employed in the sensor network need to possess the ability to quickly identify any malfunctions and possess the robustness necessary to sustain the network's overall functionality, even with a large number of failures.

- **Scalability** - the sensor networks might have hundred, thousand or even millions of nodes. Therefore, the protocols employed in these sensor networks need to be scalable to these levels and maintain a tolerable efficiency level.

- **Production Costs** - since a sensor network is composed by a large number of nodes it is important that this value is quite small, ideally much lower than US$1.

- **Hardware Contraints** - a sensor node is usually constituted by a sensing unit, a processing unit, a transmission unit and a power supply, as represented in Figure 2.4. Additionally, it may be necessary to add some extra components, as per example a localization system. These need to consider the extra costs, the power consumption it will lead to and finally, the space available in the node.

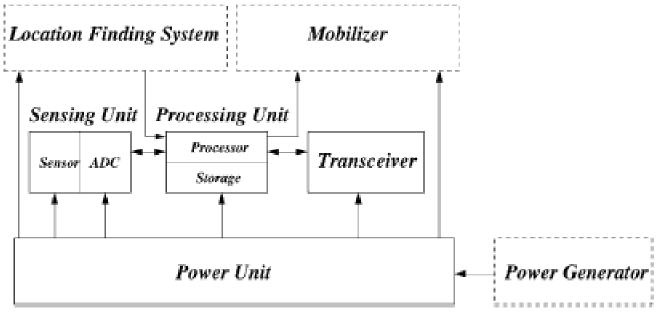

Figure 2.4: Sensor node typical architecture [2]

- **Sensor Network Topology** - energy consumption is the main obstacle regarding WSN performance and efficiency. To combate this problem it has been researched numerous algorithms, protocols and techniques, being topology maintenance one of the most important to reduce energy consumption.

- **Transmission Media** - most communication networks use Radio Frequency (RF) to connect the nodes wirelessly. There are, however, other ways of connection, using optical or infrared communication. Both optical and infrared communication require a line of sight between the sender and the receiver. However, the infrared communication has the advantage of being less affected by other electonic devices.

- **Power Consumption** - derived from the node size and the, sometimes, impossibility to recharge its battery, the lifetime of a node depends entirely on the management of this resource. Therefore, it is of the utmost importance to carefully consider the power consumption while developing the software and hardware designs.

- **Environment** - the nodes may be deployed in various different environments, ranging from a rural area to the bottom of the ocean. Therefore, it is necessary to consider the environment implications on the network nodes, in order to protect them and ensure they can perform their function properly.

2.2.8 Discussion

2.3 Cattle Production

Some animals are known to form subgroups to perform their everyday tasks. In the case of cows, these groups are called herds and they distinguish three main activities: resting, grazing, and travelling. We will discuss next how cows behave.

2.3.1 Cattle Behaviour in Herds

The cows follow a hierarchical system, where the oldest cow is regularly the leader of the herd. Scarcely, there is a younger, stronger, cow leading a group [9]. This leader can choose where the herd moves, having influence over the other cows that follow her. This effect is more pronounced when the herd is travelling in comparison to when they are grazing or resting [20].

A study was conducted that observed the interactions of cows during the course of two years. During this research the authors reached some interesting conclusion about the proximity demonstrated by these animals. It was found a correlation between the distance of neighbours in a herd and the quantity of pasturage available. When there is abundant nourishment, the herd are more compact, and the animals graze closer together [9].

2.3.2 Diet Impact on Plant Communities

The diet of an animal has a profound impact on the quality of the products derived from it [3]. Therefore, it is reasonably for farm owners to feed their cattle with natural vegetation, when possible, instead of synthetic one.

In 2018, a study was conducted in the Netherlands that distinguished the dieting habits of three species: cattle, bison, and horses [6]. During this study it was discovered that the cattle eating habits, in a landscape without supplementary feeding, consisted mostly on grass (around 80%) and woody plants, twigs and leaves, (around 20%). It was supposed that the consume of woody plants was derived from the lack of grass during the winter. Without the data from a similar study convened in Portugal, we can only presume that with the more favorable climatic conditions the cattle would feed almost completely on grass.

A study was conducted on three ranches in Texas with the purpose of understanding the impact of distinct types of grazing on the soil and vegetation. In the first ranch it was used the multi-paddock technique, in the second one it was used light continuous grazing and in the last one it was used heavy continuous grazing. With the multi-paddock method, the terrain is divided in multiple smaller paddocks and regularly each herd rotates from one paddock to the next. In the end, it was concluded that this type of grazing management is overall better for the soil and vegetation that the light or the heavy continuous grazing methods [22]

2.3.3 Discussion

It is imperative to understand how cows behave to correctly develop a tracking system that works for them and considers their behaviour, to minimize costs and ensure correct operations.

Comprehending the relation and the distance between individual cows and their neighbours is of utmost importance for my future work, considering that the messages collected from each cow will have to be disseminated using a peer-to-peer based protocol.

Furthermore, it is fundamental to consider in my next steps that the farm owners should be able to shift the grazing location of the herds to obtain a wealthier vegetation and soil, leading to overall better cattle.

2.4 Summary

3

Work Plan

Bibliography

[1] K. Akkaya and M. Younis. "A survey on routing protocols for wireless sensor networks". In: *Ad hoc networks* 3.3 (2005), pp. 325–349 (cit. on p. 12).

[2] I. F. Akyildiz et al. "Wireless sensor networks: a survey". In: *Computer networks* 38.4 (2002), pp. 393–422 (cit. on pp. 9, 10, 14, 15).

[3] J. Araújo et al. "Extensive beef cattle production in Portugal". In: *Proceedings of the International Worskshop "New Updates in Animal Nutrition, Natural Feeding Sources and Environmental Sustainability"* (2014), pp. 31–44 (cit. on p. 16).

[4] K. Birman. "The promise, and limitations, of gossip protocols". In: *ACM SIGOPS Operating Systems Review* 41.5 (2007), pp. 8–13 (cit. on p. 7).

[5] N. Carvalho et al. "Emergent structure in unstructured epidemic multicast". In: *37th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN'07)*. IEEE. 2007, pp. 481–490 (cit. on p. 6).

[6] J. P. Cromsigt et al. "Rewilding Europe's large grazer community: how functionally diverse are the diets of European bison, cattle, and horses?" In: *Restoration Ecology* 26.5 (2018), pp. 891–899 (cit. on p. 16).

[7] M. Deshpande et al. "Crew: A gossip-based flash-dissemination system". In: *26th IEEE International Conference on Distributed Computing Systems (ICDCS'06)*. IEEE. 2006, pp. 45–45 (cit. on p. 7).

[8] A. J. Ganesh, A.-M. Kermarrec, and L. Massoulié. "Scamp: Peer-to-peer lightweight membership service for large-scale group communication". In: *International Workshop on Networked Group Communication*. Springer. 2001, pp. 44–55 (cit. on p. 7).

[9] N. R. Harris et al. "Social associations and dominance of individuals in small herds of cattle". In: *Rangeland Ecology & Management* 60.4 (2007), pp. 339–349 (cit. on pp. 15, 16).

[10] P. Juang et al. “Energy-efficient computing for wildlife tracking: Design tradeoffs and early experiences with ZebraNet”. In: *Proceedings of the 10th international conference on Architectural support for programming languages and operating systems*. 2002, pp. 96–107 (cit. on p. 13).

[11] R. Karp et al. “Randomized rumor spreading”. In: *Proceedings 41st Annual Symposium on Foundations of Computer Science*. IEEE. 2000, pp. 565–574 (cit. on p. 5).

[12] S. Kumar and R. M. Hegde. “A review of localization and tracking algorithms in wireless sensor networks”. In: *arXiv preprint arXiv:1701.02080* (2017) (cit. on p. 13).

[13] J. Leitao. “Gossip-based broadcast protocols”. MA thesis. Master’s thesis, University of Lisbon, 2007 (cit. on p. 4).

[14] J. Leitao. “Topology Management for Unstructured Overlay Networks”. In: *Technical University of Lisbon* (2012) (cit. on pp. 5, 6).

[15] J. Leitao, J. Pereira, and L. Rodrigues. “Epidemic broadcast trees”. In: *2007 26th IEEE International Symposium on Reliable Distributed Systems (SRDS 2007)*. IEEE. 2007, pp. 301–310 (cit. on p. 6).

[16] F. L. Lewis. “Wireless sensor networks”. In: *Smart environments: technologies, protocols, and applications* (2004), pp. 11–46 (cit. on pp. 11, 12).

[17] M. A. Matin and M. Islam. “Overview of wireless sensor network”. In: *Wireless sensor networks-technology and protocols* 1.3 (2012) (cit. on pp. 10, 14).

[18] J. Pereira et al. “Neem: Network-friendly epidemic multicast”. In: *22nd International Symposium on Reliable Distributed Systems, 2003. Proceedings.* IEEE. 2003, pp. 15–24 (cit. on p. 7).

[19] K. Ramya, K. P. Kumar, and V. S. Rao. “A survey on target tracking techniques in wireless sensor networks”. In: *International Journal of Computer Science and Engineering Survey* 3.4 (2012), p. 93 (cit. on p. 13).

[20] R. Šárová et al. “Graded leadership by dominant animals in a herd of female beef cattle on pasture”. In: *Animal Behaviour* 79.5 (2010), pp. 1037–1045 (cit. on p. 16).

[21] A. Shrestha and L. Xing. “A performance comparison of different topologies for wireless sensor networks”. In: *2007 IEEE Conference on Technologies for Homeland Security*. IEEE. 2007, pp. 280–285 (cit. on p. 11).

[22] W. Teague et al. “Grazing management impacts on vegetation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie”. In: *Agriculture, ecosystems & environment* 141.3-4 (2011), pp. 310–322 (cit. on p. 16).

[23] S. Yadav and A. Chitra. “Wireless sensor networks-architectures, protocols, simulators and applications: a survey”. In: *International Journal of Electronics and Computer Science Engineering* 1.4 (2012), pp. 1941–1953 (cit. on p. 11).

[24] A. Ez-Zaidi and S. Rakrak. “A comparative study of target tracking approaches in wireless sensor networks”. In: *Journal of Sensors* 2016 (2016) (cit. on p. 13).

[25] P. Zhang et al. “Hardware design experiences in ZebraNet”. In: *Proceedings of the 2nd international conference on Embedded networked sensor systems*. 2004, pp. 227–238 (cit. on p. 13).