DEPARTMENT OF
COMPUTER SCIENCE

NOVA SCHOOL OF
SCIENCE & TECHNOLOGY

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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
Draft: *January 20, 2023*

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Abstract

Resumo

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Acronyms

CREW Concurrent Random Expanding Walkers *(p. 6)*

GPS Global Positioning System *(p. 2)*

NeEM Network Friendly Epidemic Multicast *(p. 6)*

Scamp Scalable Membership Protocol *(p. 6)*

TCP Transmission Control Protocol *(p. 6)*

WSN Wireless Sensor Networks *(p. 7)*

1 Introduction

This chapter will explore the motivations for this thesis development, the underlying problem that provoked it, the objectives expected to achieve during its development and finish with the current document structure.

1.1 Motivations

In the xxx Farm, located in xxx, they have over 150 cows, alongside many other animals, spread throughout xxx acres. Controlling that many animals in such a vast terrain is quite a difficult task. Furthermore, the region lacks cellular service, which complicates this mission even more.

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 follow.

The xxx Farm currently has physical fences in place to maintain the multiple herds separated from each other and protected. However, these fences are not very persistent, which lead to an often replacement and potential danger for the cows. In addition, since the farm has 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 xxx Farm. Mainly because of the lack of cellular service available, but also do to the immensely amount of cattle at this location.

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.

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 towers. This creates obstacles to propagate messages from the fields to user.

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.

1.3 Objectives

During this dissertation it is expected to be developed a fully functional 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.

1.4 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

Within this chapter it is examined some topics and techniques that are vital for my future work. These topics are the Gossip Protocol, a dissemination method, the Wireless Sensor Networks and particularly interesting applications on tracking animals, the Cows, section that explains how the cows behave in herds, their diet, and its consequence to the plant communities, and finally, the Existing Collars, where it is discussed some of the existing collars with similar purpose as the proposed to be develop during this dissertation.

2.1 Gossip Protocol

2.1.1 History and Overview

The gossip protocol, also known as epidemic protocol, as the name indicates, was created based on how gossips 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 gossip is spread between members in a social group [12].

The gossip protocol is known as a highly scalable and resilient approach to implement reliable broadcast. This protocol is based on every participant propagating their messages collaboratively with 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 subsection 2.1.1.1). When the receiving nodes obtain the message for the first time, they will do the same as the previous node had done 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 redundancy.

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 he has already received.

2.1.1.1 Parameters

The gossip protocols have parameters that should be taken in consideration when using this technique. The most relevant ones are the [13]:

Fanout: represents the number of nodes that each node will propagate its message to, in every round.

Maximum Rounds: represents how many times a message can be retransmitted. Each message has a value of rounds it endured, starting with zero and adding one value every time a node resends the message to a neighbour. This round value cannot exceed the maximum round value.

Both these parameters create a clear tradeoff between reliability and redundancy. If the fanout or the maximum rounds values is elevated so it will be the reliability of the protocol, however, the amount of redundancy will also be quite elevated, potencially creating memory problems. The opposite will occur for low values of each of the parameters.

2.1.2 Strategies

The Gossip Protocol may be executed 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. This approach consumes a great amount of bandwidth, considering it leads to multiple copies of the same messages are delivered to each target node.

Pull approach: Regularly, nodes inquire each other on new messages they've recently receive. If they acquire information about a message they haven't receive yet, they will request it expecifically from that node. This approach leads to higher values of latency, derived from the extra round trip needed to obtain the messages.

Lazy push approach: When a node receives a message for the first time, it will only broadcast to its neighbours a small fraction of the message, an identifier, per example a hash of the message. If the neighbour never receives the given identifier, it will request the rest of the message. As in the pull approach, there will be a higher value of latency.

Besides the differences in latency and bandwidth previously mentioned, 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 [13].

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 lacunas that might have occurred during the first phase of this method. This approach reduces the amount of redundancy in comparison with the eager push approach, without decreasing its performance. It will, however, endure a higher level of latency due to the pull phase.

Eager push and lazy push approach: It is used the eager push approach to a subset of nodes. Then it uses the lazy push approach on the remaining subset of nodes to recover the lacunas and guarantee the reliability of the method.

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 subsection 2.1.1, are known for their resilience, but have a high message complexity [14].

In order to obtain a small message complexity and high reliability, it was considered combining both these methods.

With this protocol we obtain the nodes organized in a tree structure format, where each node knows to whom forward its messages. To achieve this structure we have many approaches, per example the PlumTree protocols:

PlumTree protocol This protocol uses eager push and lazy push gossip, previously explained in the subsection 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 using 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 [14].

Additionally, in opposition to other gossip protocols, with 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 TCP connections, which will provide extra reliability and failure detection.

2.1.4 Examples

Throughout many 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 Transmission Control Protocol (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 [16].

Concurrent Random Expanding Walkers (CREW): 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 the gossip protocol. Mainly, it was referred the resilience and scalability offered by this method. However, as any other protocol, it has its limitations. A few of this are [4]:

1. Fixed maximum message size - the gossip protocol has a fixed maximum message size which may lead to problems. Per example, if we desire to propagate a message with a greater size than this fixed maximum message size, we will have to divide the message into multiple messages. When this happens, some of these messages may be lost, since each node can only gossip a certain amount of information per round, which will increase the number of rounds to deliver a single message.

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

3. Malicious behaviours and correlated loss patterns - another gossip protocol's limitation is when the nodes behave in a malicious form, intentionally, with disseminating of false information or when nodes malfunction, or unintentionally, when multiple nodes fail or become unavailable at the same time.

2.1.6 Discussion

Throughout this section 2.1 it has been explained the basis of the gossip protocol, its strategies, tree-based approaches, particularly the PlumTree, it was also mentioned some interesting examples of gossip-based methods and finally its limitations.

This protocol is crucial for the development of my dissertation, since it is highly scalable and reliable, which is fundamental for dealing with the messages exchanges between all cows. Every cow will have to be constantly informed on the fence location, since it can potentially change. Using the gossip protocol to disseminate this information seems benefic.

The PlumTree approach is quite interesting for my dilemma considering that every herd has a leader that commands all the other cows in the group. With a tree-based strategy this cow appears to be an obvious choice to be the root and send the information throughout the entire herd.

2.2 Wireless Sensor Networks

2.2.1 Definition

Wireless Sensor Networks (WSN) is an innovative technology with immeasurable applications ranging from remote environmental monitorization to target tracking. This network is composed by multiple small cheap and low-power sensor nodes distributed throughout various locations. Usually, these nodes are scattered in a sensor field, as demonstrated in Fig. 2.1. Individually, each node can perform sensing tasks, which implies:

- collecting data, per example, from its surroundings, such as temperature, light, humidity, and many other types of data, depending on its sensor;
- process it, using its on-board processor;
- and finally, transmit it back to the sink by multi-hopping. It eventually reaches the end users via internet or a satellite [2].

Typically, each node sensor is composed by a radio transceiver, an embedded processor, internal and external memories, a power source and one or more sensors [20]. However, the nodes' design and the WSN itself' must take into account its purpose, the environment where the nodes will operate, the hardware, the cost, along with other restrictions that need to be considered [22].

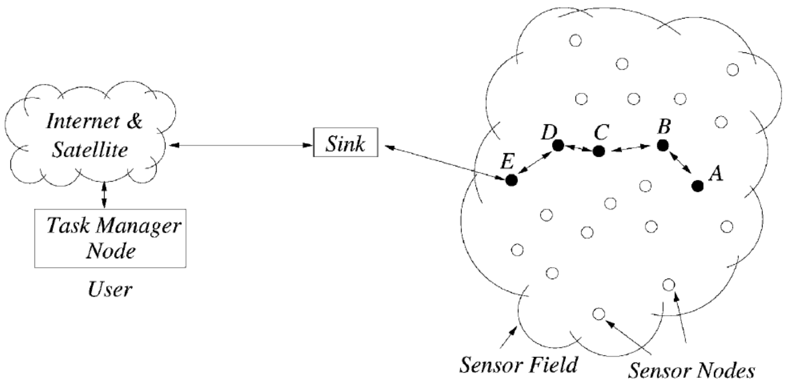

Figure 2.1: Sensor nodes in a sensor field [2]

2.2.2 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 Fig. 2.2.

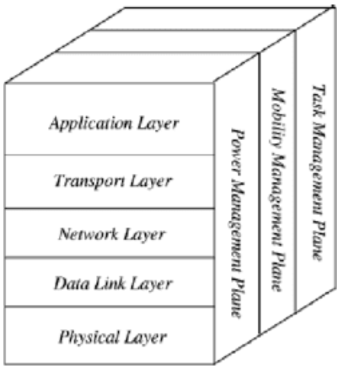

Figure 2.2: WSN Architecture [2]

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

Application Layer

Transport Layer

Network Layer

Data Link Layer

Physical Layer

The management planes' roles are to manage the network and optimize the sensor nodes' performance in order 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.

2.2.3 Network Topologies

There are several different topologies regarding the connection between nodes and their message exchange routes [21, 15]:

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 [18]. 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 and good for large scale networks.

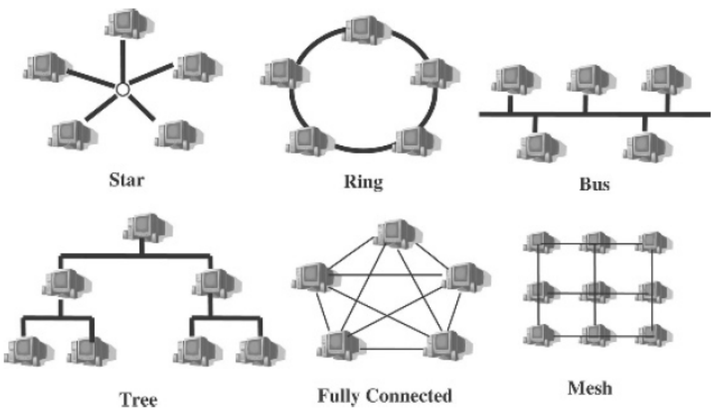

Figure 2.3: Network Topologies [15]

2.2.4 Strategies

The WSN have innumerous applications, this idea will be further discussed in the subsequent subsection 2.2.6, which will lead to different solutions for each of them.

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 is of the most importance, therefore various protocols were studied in [1] to understand which of these would better conduct this task.

As presented previously in the section 2.1, during the 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 in the 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 resolving some of the problems observed from previous studies of collecting data from wildlife tracking. 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 recharge, which would eventually end, and had to be recovered and recharged, losing enormous amounts of data in process [10].

Additional, 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 has to have a durable battery life [23]. Subsequentially, most of the weight would be occupied by the battery and the GPS, leaving a small space for the storage, which means that there is 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 widely common when dealing with wildlife research. Usually, it takes the sensor direct position with the use of GPS to track the node itself. There is, however, another method to obtain this position. It can be estimated using the information from the surrounding nodes. This method is called remote positioning and it is truly relevant when it is necessary to reduce resources consumption. To have a functional wireless tracking it is, nonetheless, vital to have an accurate position.

2.2.7 WSN Challenges

2.2.8 Discussion

2.3 Existing Collars

2.4 Cows

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.

2.4.1 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 [17].

There was conducted a study that observed the interactions of cows during the course of two years. During this research it was 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].

2.4.2 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, it was conducted a study 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 convened 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 [19]

2.4.3 Discussion

It is imperative to understand how cows operate to correctly develop a tracking system that works for them and considers their behaviour.

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.

2.5 Summary

3

Work Plan

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