DEPARTMENT OF
COMPUTER SCIENCE

JOANA FALCÃO DE MOURA
BsC in Computer Science

IOC: INTERNET OF COWS

COWS WIRELESS TRACKING

Dissertation Plan
MASTER IN COMPUTER SCIENCE AND ENGINEERING

NOVA University Lisbon
Draft: *February 10, 2023*

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JOANA FALCÃO DE MOURA
BsC in Computer Science

Adviser: João Carlos Antunes Leitão
Assistant Professor, NOVA University Lisbon

Co-adviser: João Nuno de Oliveira e Silva
Assistant Professor, University Lisbon

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Abstract

There have been enormous developments in IoT (Internet of Things) over the past few years, creating the opportunity to connect multiple devices with each other in diverse conditions. This thesis focuses on creating an innovative way of connecting cattle and their owners using wireless ad hoc networks. This will make possible the information collected with a collar to be transmission in the most remote areas, as it is the case of the Coitadinha Farm.

For farm owners it is of the upmost importance to be able to know the whereabouts and health of their cattle throughout all day, as well as maintain the cows separated into herds and away from dangerous situations.

During this work we plan on building a wireless sensor network using a gossip-based protocol to disseminate the cattle's localization and other relevant information back to the farm owners. This information should be relayed using peer-to-peer communication, without the need for an infrastructure available in the area. We also plan to be able to maintain the cows inside a virtual fence created by the farm owners. This virtual fence should be easy to create and relocate as needed.

At the end of our work, we expect to obtain a totally functional collar prototype with an overall good performance, low cost and low power consumption, able to connect with other collars, within the same network, without the need of infrastructures available.

Keywords: Wireless sensor networks, gossip-based protocols, cattle, sensors, wireless technologies, wireless ad hoc networks

Resumo

Durante os últimos anos tem havido grandes desenvolvimentos na área da IoT (Internet of Things), criando a oportunidade de conectar múltiplos dispositivos uns com os outros, nas mais diversas condições. Esta dissertação irá se focar na criação de uma forma inovadora de conectar gado e os seus donos usando redes ad hoc. O que fará possível as informações recolhidas através de uma coleira serem transmitidas nas áreas mais remotas, como é o caso da Herdade da Coitadinha.

Para donos de quintas é deveras importante saber a localização e estado de saúde de todas as suas vacas em qualquer altura do dia, tal como mantê-las separadas em rebanhos e longe de situações perigosas.

Durante este trabalho planeamos construir uma rede de sensores sem fios utilizando um protocolo de rumor para a disseminação das localizações dos animais, tal como qualquer outras informações pertinentes de volta para os donos da quinta. Esta informação deverá ser transmitida utilizando comunicação peer-to-peer, sem a necessidade de existir uma infraestrutura na área. Também planeamos ser possível manter as vacas dentro de uma cerca virtual criada pelos donos da quinta. Esta cerca deverá ser fácil de criação e utilizar, podendo realoca-la conforme a necessidade.

No final do nosso trabalho é expectável obter um protótipo totalmente funcional de uma coleira com bons valores de performance, preço reduzido e baixo consumo de energia, capaz de conectar-se com outras coleiras, dentro da mesma rede, sem a necessidade de infraestruturas disponíveis.

Palavras-chave: redes de sensores sem fios, protocolos de rumor, gado, sensores, tecnologias sem fios, redes ad hoc sem fios

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Acronyms

D-BPSK	Differential Binary Phase-Shift Keying *(p. 16)*
DA	Duty-cycled Activation *(p. 20)*
DAT	Deviation Avoidance Tree *(p. 19)*
DCAT	Dynamic Clustering for Acoustic Tracking *(p. 20)*
DCTC	Dynamic Convoy Tree-Based Collaboration *(p. 19)*
DOT	Dynamic Object Tracking *(p. 19)*
DPT	Distributed Predictive Tracking *(p. 20)*
DSTC	Dynamic Space-Time Clustering *(p. 20)*
GPS	Global Positioning System *(pp. 2, 18, 28)*
HEAP	HEterogeneity-Aware gossip Protocol *(p. 8)*
HPS	Hierarchical prediction strategy *(p. 20)*
LoRa	Long Range *(pp. 15, 16)*
LoRaWAN	Long Range Wide Area Network *(pp. 15, 16)*
LPWAN	Low-Power Wide Area Networks *(pp. vi, 15–17)*
LTE	Long Term Evolution *(pp. 15, 16)*
MAC	Media Access Control *(pp. 12, 15)*
MiRAge	Multi Root Aggregation *(p. 21)*
NB-IoT	Narrow Band Internet of Things Network *(pp. 15, 16)*
NeEM	Network Friendly Epidemic Multicast *(p. 8)*
OCO	Optimized Communication & Organization *(p. 19)*
Plumtree	push-lazy-push multicast tree *(p. 6)*

RF	Radio Frequency *(pp. 14, 22)*
STUN	Scalable Tracking Using Networked Sensors *(p. 19)*
TCP	Transmission Control Protocol *(pp. 7, 8)*
UDP	User Datagram Protocol *(p. 8)*
Wi-Fi	Wireless Fidelity *(pp. 13, 14, 16)*
WLAN	Wireless Local Area Network *(p. 13)*
WPAN	Wireless Personal Area Network *(p. 14)*
WSN	Wireless Sensor Networks *(pp. vi, 10, 11, 14, 17, 19, 20, 22, 23, 26)*

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 perspective from ecology and conservation, the aforementioned data is also relevant to understand the impact of cows' behaviour on the ecosystem, 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 due 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 tackle 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 ability 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 Contributions

This works expects to accomplish the following contributions:

1. The integration of a gossip protocol in a wireless sensor network, such as to make possible the communication between the nodes without the necessity of infrastructures.

2. Creation of a virtual fence with the usage of sound and electric outputs to contain animals inside a boundary defined by a user. Being the user able to reset this boundary in a easy manner.

3. Development and experimental evaluation of a collar prototype for cattle.

1.5 Research Context

The current work is part of a collaboration with the Herdade da Coitadinha, the Ecology of Environmental Change - eChanges, a research group from Faculty of Sciences from the Lisbon University (FCUL), and the Department of Electrical and Computer Engineering from the Instituto Superior Técnico (IST).

1.6 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, the **??**, where it is discussed some of the existing collars with similar purpose as the proposed to be develop during this dissertation, 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

Gossip protocols [17], also known as epidemic protocols, were first proposed as highly scalable and resilient approaches to implement reliable dissemination of information [6, 21, 27]. For a protocol to be considered reliable it must deliver the messages to all the nodes in the network, even if there are network omissions or node failures [34].

Subsequentially these protocols were used to resolve many other problems, such as failure detection, data aggregation, overlay topology construction and many more[42].

2.1.1 History and Overview

Gossip protocols, as the name indicates, were created based on how rumors are propagated in social groups [33]. 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.

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 making 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 avoid messages 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 [34]:

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

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 trade-off 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 negatively impact 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 [25]:

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 explicitly 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 [34].

By combining the approaches studied above, we can get better results, obtaining a better latency/bandwidth trade-off. This are two of the studied combined approaches [10]:

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 straight 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 low message complexity, however, they are not particularly resilient to faults. On the other hand, gossip protocols, as mentioned earlier in Section 2.1, are known for their resilience, but have a high message complexity [35].

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 push-lazy-push multicast tree (Plumtree) protocol.

Plumtree protocol

The plumtree protocol [35] uses eager push and lazy push gossip, previously explained in the Section 2.1.2. Every node maintains two separate sets of nodes, the *eagerPushPeers*, to whom the node disseminates its messages using eager push gossiping, and the *lazyPushPeers*, to whom the node disseminates its messages using lazy push gossiping. The links that the eager push method uses to propagate the messages are chosen in a way to create a spanning tree over the unstructured overlay network. 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.

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.

This protocol has two main operations:

- Tree construction: the protocol starts with a node using uniquely the eager push gossip to disseminate a message to t randomly selected nodes, the nodes in his *eagerPushPeers* set. When a node receives for the first time a message it includes its sender in the *eagerPushPeers* set. If the node receives the same message once more, it will include its sender in the *lazyPushPeers* set and it will inform the sender that he already received that message so that he can also allocate this node in his *lazyPushPeers* set.

  Once the broadcast is terminated, a spanning tree is created with the overlay defined by the *eagerPushPeers* set.

  The nodes will start sending messages using both the eager push and the lazy push methods. However, the messages sent to the *lazyPushPeers* set will only have the broadcast ID.

- Tree repair: When a node receives a message via lazy push gossiping with a broadcast ID it does not recognize, it waits a predefined time for the full payload of the message to arrive via eager push gossiping. If the message does not arrive within the predefined time period, the node sends a message to the node that firstly send him the message containing the broadcast ID, as a mean to receive the payload of the missing message, as well as, to add the corresponding link between these nodes to the broadcast tree, and heal it.

2.1.4 Examples

Throughout the last years there have been proposed numerous gossip-based protocols. During this Section we will discuss some gossip-based dissemination examples.

2.1.4.1 Network Friendly Epidemic Multicast (NeEM)

One of the biggest problems in most gossip-based protocols is when the network gets congested and, subsequentially, messages are discarded. This occurs due to the usage of connectionless transport protocols, such as User Datagram Protocol (UDP), that do not retain information about the channel state or controls the flow of information between two nodes, leading to potential congestion in these channels [40].

NeEM [49] uses connection-oriented transport connections, TCP, to support the communication between nodes. In periods of network congestion, it retains the messages at the network border instead of inject them immediately into the network, which will eventually lead to low bandwidth usage.

To deal with the bandwidth problem created by the usage of TCP connections, NeEM uses a buffer management technique that utilizes a combination of different selection techniques, that decide which messages are important and which can be discarded, when faced with network congestion. These selection techniques depend on the systems preferences. They can either select messages based on their age, randomly or based on semantics. Age-based exclusion will discard the messages that have been propagated more times, the randomly selection will choose a message at random to discard when a new message arrives, and, lastly, the semantics option depends on the understanding if a message is still necessary to the network. For example, in a system that the information propagated is the nodes positions, there might already be another message with a more current position of the same node, which will make the first message obsolete and should be discarded by the protocol as to reduce the bandwidth consumption.

2.1.4.2 HEterogeneity-Aware gossip Protocol (HEAP)

Gossip-based protocols are usually load balanced, meaning that the dissemination work is done uniformly between all nodes. However, large scale distributed systems are heterogeneous, meaning that they have different network capabilities, such as bandwidth.

The HEAP [20] is a gossip protocol where each node contributes to the dissemination of information based on their bandwidth capability. This protocol implements an aggregation protocol to relay the nodes relative bandwidth capability. Each node periodically gossips its own capability as well as the newst capabilities of the rest of the nodes that have been in contact with him. He also calculates the overall average capability and regulates its fanout. This way each node will decrease their fanout if they have low bandwidth capability or, otherwise, increasing their fanout.

Taking into account the heterogenity between the nodes was proved in [20] that leads to more efficient dissemination.

2.1.4.3 JetStream

The gossip principle of dissemination leads to random overhead of messages, this is, some nodes may receive tirty copies of the same message, while others receive three.

JetStream [47] uses social network principles to select the gossip targets and then reducing the randomness overhead previously mentioned. This protocol foucuses in two particular social network principles, the reciprocity and the structural holes.

The reciprocity theory declares that individuals tend to reciprocate the affection provided by others, creating relationships. In the Section 2.4 it is discussed how cows also create this kinds of relationships with each other.

The structural holes theory declares that there are individuals that place themselves in advantageous positions, this is, positions where they can connect two disconnected individuals are. This is an advantage since he can consume higher amount and quality of information from these two previously disconnected individuals, as well as control them.

The JetStream algorithm pursues the augmentation of a node's utility value. This value increases based on the number of reciprocated relationships that the node has or if said node forms a relationships with disconnected nodes. This way, the protocol will lead to nodes creating connections to specific nodes and communicating with these nodes that provide higher utility. It will eventually lead to the network stabilization, reducing the amount of messages overhead.

This protocol's evaluation [47] showed that it lowered messages overhead by half, gossip latency by a quarter percentage and lower the traffic by half, however it requires the knowledge of the network state which makes it not ideal for large scale networks.

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 [8]:

1. Saturation - if the rate of events increase there may occur saturation in the communication channel, and the protocol may eventually malfunction. The same might happen if the size of the events increases, since each node can only gossip a certain amount of information per time unit (occasionally named round). This will lead to an increase in 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 protocols are particularly interesting since they require very little or no structure to operate, which will be helpful when dealing with the propagation of the data provided by the herds 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 via ad hoc 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 carried by the cows will necessarily communicate via wireless, potentially in an infrastructure-less network (ad hoc network) which discussed in the next Section 2.2.

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, by multi-hopping, transmits it back to the sink, a node that has the capacity to communicate with external devices, such as phones, laptops, base stations, among other. It eventually reaches the end users via internet or a satellite from the sink node[3].

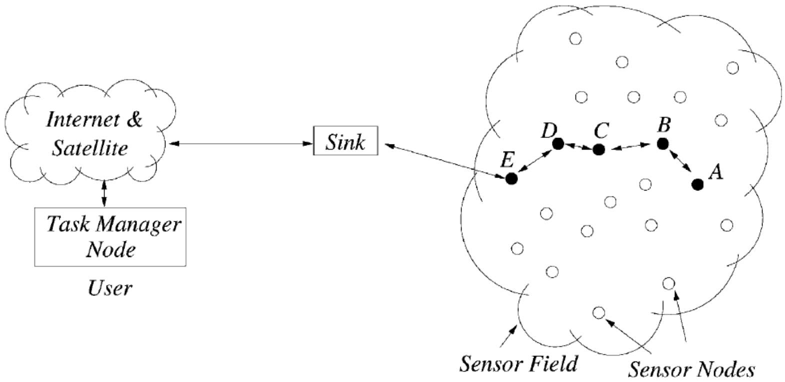

Figure 2.1: Sensor nodes in a sensor field [3]

2.2.2 Communication Architecture

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

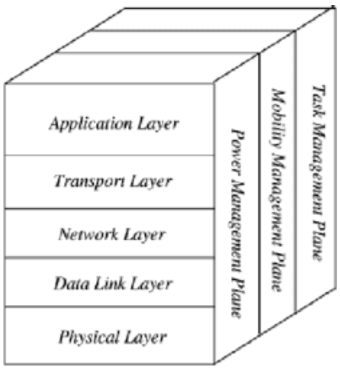

Figure 2.2: WSN Communication Architecture [3]

The five layers above mentioned work together to ensure the data is properly transmitted to the network, each with a specific functionality [3, 39]:

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 [3]:

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 [36, 65] regarding the connection between nodes and their message exchange routes. In the Figure 2.3 it is possible to observe representations to the following topologies:

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 [55]. 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.

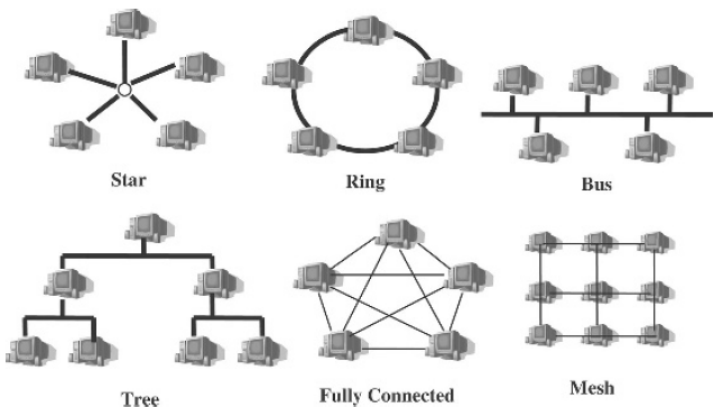

Figure 2.3: Network Topologies [36]

2.2.4 Wireless Technologies

To build a wireless network we need to consider the usage of wireless technologies, and their characteristics and limitations. There are a multitude of technology alternatives available, we will briefly examine six possibilities and later compare them in the Table 2.1

WiFi - Wireless Fidelity (Wi-Fi) is a highly popular technology used to implement Wireless Local Area Network (WLAN), most commonly known for connecting smartphones and portable computers to the Internet without the usage of a physical connection [56]. It uses RF to rapidly transmit data over short distances [28]. However, for this technology to function it is necessary to already exist a Wi-Fi network at its location [43].

Bluetooth - Bluetooth is a technology used to implement Wireless Personal Area Network (WPAN), widely recognized for connecting multiple devices with each other, such as wireless computer mouses, headphones, computers and other [63]. Similarly to Wi-Fi, it transmits data over short distances, however the speed of these transmissions is very low. The most commonly network topology of Bluetooth is the piconet, where a Bluetooth device acts as the master and up to seven active devices act as slaves. The slaves can only communicate with the master, with point-to-point communication [13, 32].

ZigBee - ZigBee is a technology used to implement WPAN. Its name came from the way bees fly in zigzag, which is similar to the way nodes communicate in a mesh network. This technology is low cost, low complexity and low power, which makes it ideal for WSN. It has two different methods for access, the beacon enabled, that allows every node to send messages to the network whenever the channel is unoccupied, and the non beacon enabled, that only allows sending and receiving messages on a predefined time period [26]. A ZigBee network has three types of devices: the coordinator, that creates and adjusts the network; the routers, that forward the data between the nodes; and the end devices, which cannot forward data from other nodes, only produce or consume it [14, 52]. Besides the mesh topology, it is also ZigBee also supports the star and the tree topologies, as demonstrated in the Figure 2.4, where the red nodes represent the coordinators, the blue nodes represent the routers and the orange nodes represent the end devices.

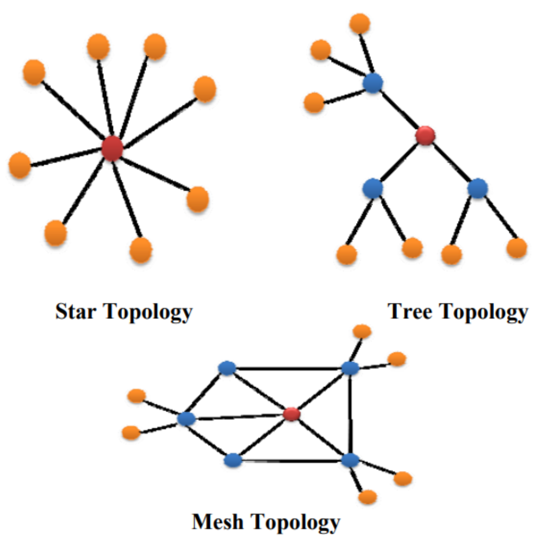

Figure 2.4: ZigBee Topologies [26]

NB-IoT - Narrow Band Internet of Things Network (NB-IoT) is part of the Low-Power Wide Area Networks (LPWAN) class of technologies. It is a type of cellular network developed to support low power and low cost devices in a long range area [7]. NB-IoT uses the Long Term Evolution (LTE) communication protocol, reducing some of its functionalities to minimize the power consumption, such small and infrequent message transmissions, as well as not implement features not needed for this types of networks [41], like radio quality measures.

LoRa - Long Range (LoRa) is part of the LPWAN class of technologies. It is a low power, long range and low data rate technology, which makes it a great choice for applications such as environmental monitoring, smart healthcare, industry, among others. This technology has been standardized by adding a MAC layer protocol, the Long Range Wide Area Network (LoRaWAN). The LoRa network has four basic elements: the LoRa nodes or end devices, the gateways, the network server and the application servers. The LoRa nodes or end devices are all the sensor nodes in the network. The gateways create the connection between end nodes and the network server. The data transmitted from each end node to each gateway is propagated using LoRa and LoRaWAN technologies, while the data propagated from the gateways to the network server uses Ethernet, cellular, satellite or Wi-Fi technologies. Then, the network server filters the data received from the gateways, perform security checks, adaptive data rates, and so forth, and, finally, sends an acknowledge back to the gateway and decides which application server receives that specific data and sends it. Lastly, the application server receive the data from the network server[11, 18]. LoRaWAN is based on the star topology, shown in the Figure 2.5, a topology that consumes a significant lower amount of power than other types of topologies, namely the mesh topology. The typical network consists of a star-of-stars topology, where the network is divided into cluster, each cluster containing multiple end devices and a gateway [5].

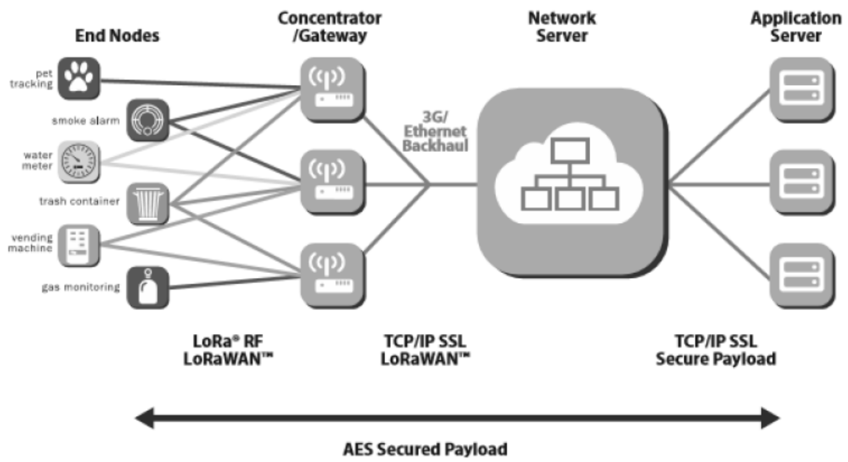

Figure 2.5: LoRa Topology [18]

Sigfox - Sigfox, like LoRa, is part of the LPWAN class of technologies. It is also a low power, long range and low data rate technology. In Sigfox the network elements are equal to the ones of LoRa, however, the topology employed is a simple star topology, represent in the Figure 2.6. Contrarily to LoRa, Sigfox uses Differential Binary Phase-Shift Keying (D-BPSK) modulation, which only allows for the transmission of 4, 8 or 12 bytes messages with a bandwidth of 100Hz and speed of 100bps in Europe and it also only lets the transmission of 140 messages per day.

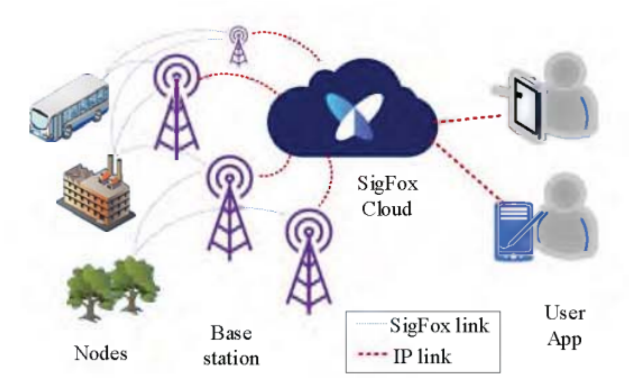

Figure 2.6: Sigfox Topology [50]

	Wi-Fi 6	Bluetooth 5.2	ZigBee	NB-IoT	LoRaWAN	Sigfox
Frequency Band	2.4GHz, 5GHz, 6 GHz	2.4GHz	2.4GHz (global), 868MHz (Europe), 915MHz (America)	Licensed LTE frequency bands	Unlicensed ISM bands	Unlicensed ISM bands
Max Data Rate	9.6Gbps	3Mbps	250kbps at 2.4GHz, 20kbps at 868MHz, 40kbps at 915MHz	200kbps	290bps-50kbps	100 bps
Range	max 300m	10m	10-100m	1.5km urban - 20-40km rural	2-5km urban 15km suburban 45km rural	3-10km urban - 30-50km rural
Bandwidth	20-160MHz	1MHz	2MHz	200khz	125KHz-250KHz	100Hz
Power Consumption	High	Low	Low	Low	Low	Low
Network Topology	Infrastructure (ad hoc also available)	Piconet	Mesh, Star, Tree (peer-to-peer)	Star	Star-of-stars	Star

Table 2.1: Wireless Technologies Comparison [1, 11, 28, 29, 45, 52, 69]

The six above described wireless technologies have different strengths and limitations, which makes them more suitable for diverse types of applications. Since this work's problem is related to multiple sensor nodes dispersed in a vast area, it is important to use a technology with low power consumption and wide range, such as the LPWAN technologies. In the Figure 2.7 it is possible to observe the key advantages of each of these technologies.

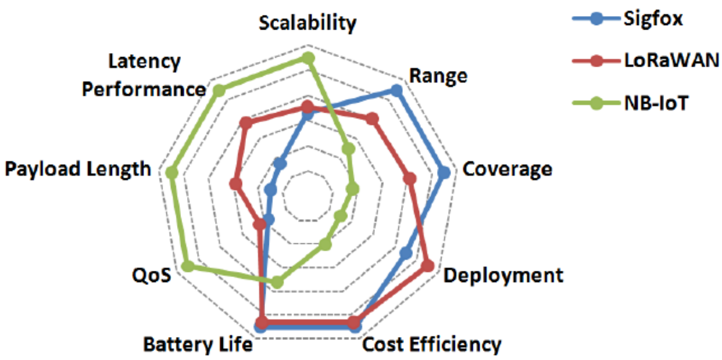

Figure 2.7: LPWAN Comparison [41]

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 [2] to understand which of these would better conduct this task.

As presented previously, in the Section 2.1, 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, this is, the nodes receiving the same information twice [2]. 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[24], 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.

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.

This project was developed in a wide area, with hundreds or thousands of square kilometres, and lasted a year without direct human interaction. It used GPS technology to obtain the position of the animals every three minutes, and also collected detailed activity logs every hour during three minutes. Considering there is no fixed antennas or cellular telephone service, the system used an ad hoc peer-to-peer routing to transport the data from one animal to the next towards a mobile base station, when it was in close proximity.

During the development of this project there were some design limitations to consider, 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 [70]. 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 was 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 and the amount of storage available to keep the activity logs. During the course of years there were developed many hardware alternatives [70].

The first protocol contemplated to undertake the ZebraNet communication between the nodes and the base station was flooding. The flooding protocol disseminates the data to all nodes available, which will eventually lead to a high percentage of the information to reach the base station even if it is only in contact with a few of the nodes. While flooding has high reliability, it also has high overhead, which increases the need for a larger amount of storage and will eventually tend to a higher network bandwidth and therefore energy required.

It was then considered a protocol that took in consideration the previously used communication patterns. It associates a hierarchy level to every node based on his past success in delivering data to the base station. If a node had a high level it is probable that he is still in range of the base station or of another node close to it. Every node has to have knowledge of his own hierarchy level and when he scans for neighbours it requests their hierarchy levels. The nodes send their collected data to the neighbour with the highest hierarchy level. The hierarchy level increases when a node is in range of the base station and decreases when it is not in range for a period of D scans, this means that if D is three and the node is not in range of the base station during three consecutive scans his level will decrease. Initially all nodes start with the lowest hierarchy level, zero. The overall success of this protocol vastly depends on the mobility of the nodes and the base station. Since it is based on previously acquired data, with rapid changes of locations on either the base station or the nodes the success rate will be low.

2.2.6.2 Wireless Tracking

Wireless tracking is an application of WSN widely used for wildlife monitoring, 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 [68].

To conserve energy it is common to keep only the sensor nodes closest to the target in active mode, while the other nodes remain inactive until the target approaches them

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 [30].

There are two main types of target tracking approaches according to [53] authors:

1. Hierarchical Networks - the nodes communication follows a mesh based topology, thoroughly explain in the Section 2.2.3, using multi hop 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. There are four methods of tracking belonging to the these networks: Tree-Based Target Tracking, Cluster Based Target Tracking, Hybrid method and Activation method.

   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 that find the target communicate with all the rest of the nodes in the network and collectively select one node to be the root. The root node will gather the information from all other nodes via a distributed spanning tree. If the root gets far away from the target, the spanning tree will have to be reconstructed, leading higher energy consumption. For this reason there were proposed several algorithms, such as STUN [31], DCTC [70], DAT [37], DOT [61], OCO [60].

   b) Cluster Based Target Tracking - the network is organized into clusters, and each cluster is composed by a cluster head and members nodes. In this type of target tracking, the nodes, usually, surround the target and collaborate to estimate its location.

      There are three types of cluster based approaches, the static clustering, the dynamic clustering and the space-time clustering.

i. In static clustering, the attributes of each cluster are defined once, when the network is deployed. This may lead to some disadvantages, since the nodes cannot change clusters as needed. For example, if a cluster head node fails, the entirety of that cluster becomes useless. Also nodes from different clusters cannot communicate or collaborate in data processing.

ii. In dynamic, contrarily to static clustering, nodes do not statically belong to a specific cluster, removing some of the previous limitations of static clustering. In dynamic clustering when a node detects the target, and it has enough battery and computational power, it volunteers to act as cluster head. The cluster head will be the only node active in close proximity with the target.

iii. In space-time clustering, uses algorithms such as the closest point of approach, to declare which node is the cluster head. In DSTC [51] it is declared that the cluster head is the node that is in close proximity with the most other nodes.

c) Hybrid Method - Hybrid methods are tracking algorithms that provide solutions for multiple types of target tracking, some examples of these methods are DPT [66], DCAT [12] and HPS [53].

d) Activation Based Method - In this methods, it is considered which nodes should be active and which can be asleep, if they are far from the target, for example. Some of these methods are the Naive activation based tracking [48], the Randomized activation [9], the Selective activation based on prediction [53] and the DA [67]

2. Peer-to-peer Networks - in tree and cluster-based target tracking there is a lack of robustness to failures, since if the root or cluster head fail the whole system might fail as well. In peer-to-peer WSN, since it relies on single hop communications, this problem does not occur.

2.2.6.3 Yggdrasil

Wireless ad hoc networks often use cloud-based solutions to process and storage the data collected by the sensor nodes, however, for large scale networks this implies a large volume of data being relayed and processed, leading to potential delays. An approach to resolve this situation is to process and storage the collected data directly in the edge nodes. The edge nodes should also be able to connect with each other, sharing the data. To implement a system with these characteristics it was developed Yggdrasil.

Yggdrasil [14] is framework and middleware that provides support for developing and executing distributed protocols and applications in wireless ad hoc settings. It combines an event-driven programming model and a multi-threaded execution environment to deal with possible concurrency issues derived from the distributed protocol.

In Yggdrasil each protocol has its own internal state that can change as events occur. Each protocol can generate events to process himself or to deliver to another protocol (or application). There are four types of events that change the execution of the protocols: messages, that can be transported between processes; timers, that serve to inform about the execution of a time-driven task or that a local timeout occured; requests/replies, enables direct one-to-one interaction between protocols in the local process; and notifications, enables indirect one-to-many interaction between protocols in the local process. Each protocol (and application) has an event queue with the events created by them and the ones created by other protocols, to easly relay events from the protocol that created them to the protocol (or application) to which they should be delivered to.

2.2.6.4 Multi Root Aggregation (MiRAge)

MiRAge [14] is a protocol that employes a self-healing spanning tree to efficiently support aggregation.

In MiRAge all nodes compete to be the root of the tree. This competition uses an assigned identifier for each node and a sequence number, timestamp, maintained by the root node. If the sequence number does not increase, this means that the root node suffered a fault, making the tree incorrect. A tree is considered correct if the root is non-faulty. When dealing with two correct tree, the winner will be the one who's root identifier is lower. While constructing the spanning tree the goal is to obtain a dominating tree, this is, a single spanning tree that covers the whole network to provide an efficient and reliable form to aggregate values. This dominating tree will be the correct tree with the lowest identifier.

In MiRAge the nodes are unware of who are their children or parent in the tree, since they relay to their neighbours alike the resulting aggregated value, not taking into consideration their contribution. They need, however, to remeber the links of the tree they belong to. This is obtained by keeping the node's identifier and a status, active for nodes in the same tree and passive for nodes in other trees.

Each node also keeps a local aggregation value and its current estimation of the aggregation result. The estimated result is constantly being updated with an aggregation function that uses the nodes received estimations performed by the neighbours belonging to the same tree. After this update, the node sends a message, through one hop broadcast, containing a reversed calculation of the estimated result, by removing the contribution of a neighbour. This calculation will be tagged alongside the neighbours identifier, forming a tuple for each neighbour. When a node receives one of these messages it updates the information of the sender. If it is the first message received by this sender it sets his status to passive.

When propagating aggregation information the nodes also relay some information about the tree that they belong to as well as their position on it. With this information it is possible to ensure that the dominating tree covers all nodes, that the tree is healed if there are failures and that a node is not permited to connect to a tree whose root has failed.

2.2.7 Limitations

There are multiple limitations that need to be considered while creating a WSN [3, 39]:

- **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 Constraints** - a sensor node is usually constituted by a sensing unit, a processing unit, a transmission unit and a power supply, as represented in Figure 2.8. 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.

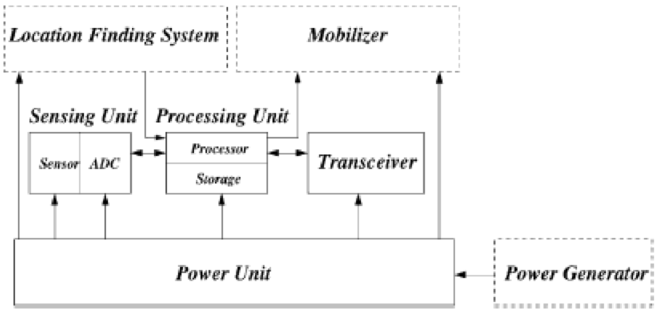

Figure 2.8: Sensor node typical architecture [3]

- **Sensor Network Topology** - energy consumption is the main obstacle regarding WSN performance and efficiency. To combat 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 electronic 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

Throughout this Section it has been discussed how WSN generally work, some of the different wireless technology available, some examples of how to operate gossip protocols in WSN, a few of this type of networks applications, namely ZebraNet, Wireless Tracking, Mirage and Yggdrasil, and their limitations.

To building a WSN it is of the upmost importance to consider the necessity for low energy consumption devices, which will have a great impact while deciding the hardware and software designs for our sensor nodes. It is essential to have a protocol for the communication between the nodes both reliable and power efficient.

The ZebraNet application is very important for our problem resolution since it deals with the collection of information in a similar situation to the one we encounter in the Coitadinha farm, where there are mobile nodes carried by animals and potentially mobile base stations as well. Just as in ZebraNet, we want to have an infrastructure-less network.

2.3 Existing Commercial Solutions

Throughout the last few years there have been developed diverse solutions for problems similar to ours. Every solution has different characteristics, as represented in the Table 2.2, where it is made a comparison between seven solutions, we found interesting for this work.

There are different applications available in each of these collars, such as:

1. Tracking - provides information on where the cattle has been during a period of time, being this data collected every few minutes or every hour, depending on the collar;

2. Real-time localization - which makes it possible to always know where all cows are at any moment;

		Digital Matter								
		Oyster Edge [46]	Yabby Edge [64]	Digitanimal [38]	Chipfox [57]	IoT Factory [15]	Nofence [44]	Vence [62]	eShepherd [19]	Halter [58]
Applications	Virtual Fence	Alert in App	Alert in App	Alert in App	Alert in App		Audio + Eletric	Audio + Eletric	Audio + Eletric	Audio + Eletric
	Tracking	x	x	x	x		x	x	x	x
	Axis Angles	x								
	Health Issues			x		x		x		x
	Temperature			x					x	x
	Real-time	x	x	x	x	x	x	x	x	x
Technologies	WiFi	x	x							x
	Bluetooth	x		x		x	x			
	Cellular	x					x	x	x	
	LoRaWAN		x			x				x
	Sigfox			x	x					
Backend	Cloud	x	x		x	x		x	x	x
	Private Server			x			x			
Network	Peer-to-peer									
	Infrastructure	x	x	x	x	x	x	x	x	x
Battery	Duration	4.5years	3years	1.5years	3years	1-2years	no data	1-2years	no data	no data
	Solar Painel						x		x	x
Price	Per Collar	189.03€	106.98€	189.95€	143.79€	no data	303€	~33€	60-90€	no data
	Infrastructure	no data	no data	no data	681.51€	no data	no data	no data	5000€	no data

Table 2.2: Commercial Solutions Comparison

3. Virtual fencing - when available it is possible for the user to create a virtual barrier on an mobile application, and when an animal crosses this barrier it can either alert the user on the application, or force the cow to go back inside the fence with the usage of sound triggers first and if the cow continues to leave the enclosed area the collar delivers a low intensity shock to the cow [22]. This technique will teach the cattle to not cross the barrier as soon as they hear the initial sound delivered by the collar, so that they do not receive the shock;

4. Health issues detection - some of these collars have other sensors embedded in them, such as heart rate monitorization, which allows the detection of health issues or imminent birth sooner;

5. Temperature detection - similarly to the detection of health issues, some of the explored solutions are able to detect abnormal temperatures for cattle and report it

to the user;

6. Axis angles detection - the device with this feature allows to detect the angle presented by the device, which may be useful to better understand the cow's behaviour, for example detect if she is eating, drinking, sleeping, among others.

2.3.1 Discussion

The current existent commercial solutions are quite helpful for this work, since they allow us to compare the success and metrics of our future solution with the obtained by these collars, that are already in the market.

However, they are not a perfect solution for our particular problem due to their lack of peer-to-peer options for communication and expensive price.

2.4 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.

2.4.1 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 [23]. 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 [54].

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 [23].

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 [4]. 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 [16]. 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 favourable 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 [59]

2.4.3 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.

2.5 Summary

In this chapter we exposed the already existing protocols and networks available to help us develop our work.

We started by explaining the gossip protocols, as a reliable and scalable solution for the dissemination of information, which is fundamental for our work as we will be using a gossip-based protocol to relay the cows collected sensing information back to the user without the usage of infrastructures.

We then discussed WSN, the way it operates, how to include gossip-based protocols in this kind of networks, some of its applications and lastly the limitations that need to be taken into consideration while dealing with these types of networks, specifically the need for low power consumption options.

Later, we collected some information about the commercial solutions available and their pros and cons and discussed the need for a new solution to resolve this works problem.

Ultimately, we gathered some information regarding cattle production, we researched how they behave when they are in herds and the impact of their diet on the plant communities. This information will be useful for the development of our prototype since it tells that it is probable that cows walk together and that they follow a leader.

In the following chapter we will briefly describe the plan for the foreseen chapter of this work and the timeline for it.

3 Work Plan

Nowadays the cattle in the Coitadinha Farm is separated through physical fences. This solution leads to great costs and labour expenses, as the fences do not last long and need to be constantly repaired or replaced. Furthermore, the cows might escape, get lost and potentially get hurt, and the farm owner might only become aware of this situation when it is too late. Furthermore to minimize the respective impact on cows on the vegetation, when they remain too long on the same location, it might useful to change the placement of these fences frequently.

For these reasons we plan to building a collar prototype with the purpose of collecting data, such as the cows locations and movements, directly from them. This way the farm owners will receive up to date information about the whereabouts of each cow. We also propose creating a virtual fence mechanism, where the farm owner can choose the fences locations, as well as easly change them as required. The virtual fence will keep the cattle inside it through the use of sound outputs, when a cow starts to get too close to the virtual fence barrier, to try and change the cows route. If the cow continue to pursue this path the collar will provide a small frequency electric shock to convence her to go back within the fenced area. This way, the cows will learn that if they hear the sound output, they should go back, since if they continue they will receive an electric shock.

When studying the animal social behaviours it was recognized that each herds has at least one leader, which all the other cows in the herd tend to follow. For that reason, we can consider only having GPS on these cows, potentially a few more, but not all the cows in the herd. This way we can reduce overall costs of the system, while still ensuring that we get acurate enough date with a less need for communication.

Additionally, we need to consider the Coitadinha farm's conditions. It is a vast area with low cellular coverage which require us to consider solutions to propagate messages, namely the localization of the virtual fences, from one cow to another until it reaches all of them. This way it is only needed for one cow to receive this information for it to be propagated in a decentralized way through the collars of all cows in the herd. A similar approach must be used to collect the data acquire from each sensor in the collars worn by the cows back to the end user.

At the end of this work plan, we aim at creating a collar prototype that allows the communication from the user to the cows and vice-verse to be conducted in a peer-to-peer approach where each cow propagates the informations from one cow to the next until the information arrives at a mobile base station, without the need for an infrastructure, in a fully decentralized and ad hoc manner.

3.1 Planification

The work to be conducted next is divided into separate tasks until its completion, namely:

1. Research
   a) explore the functionalities of three of the existing commercial solutions: the Digital Matter Oyster Edge collar, the Digital Matter Yabby Edge collar and the Nofence collar, mentioned in the Section 2.3, and better comprehend how these collars work (we have already started this process to buy these collars).
   b) continuously study the way Arduino works during the whole prototype creation process.
2. Built Prototype
   a) creation of a rather simple prototype, with help of infrastructures for the communication between nodes and base stations
   b) explore and create other options for communication, without the need of an infrastructure, leveraging a gossip-based protocol that will be specially tailored for this end.
   c) development of a virtual fence using sound and/or shocks to maintain the cattle inside it, and a mechanism to change the fence location at the user's desire, using a gossip-based protocol to update the configuration in all collars of a herd.
   d) augment prototypes applications by adding new sensors to it, possible motion sensors to understand when cows are eating (which is relevant not only to the managers of Herdade da Coitadinha, but also for our partners from FCUL from an ecology research group).
3. Testing: testing of final prototype and dense improvements based on test results.
4. Evaluation: evaluation of the performance of our prototype, using diverse parameters, against three previously mentioned commercial solutions.
5. Completing final report: during the entirety of this work there will be a development of the final dissertation report.

Figure 3.1 provides a Gantt chart planification of the work plan described above.

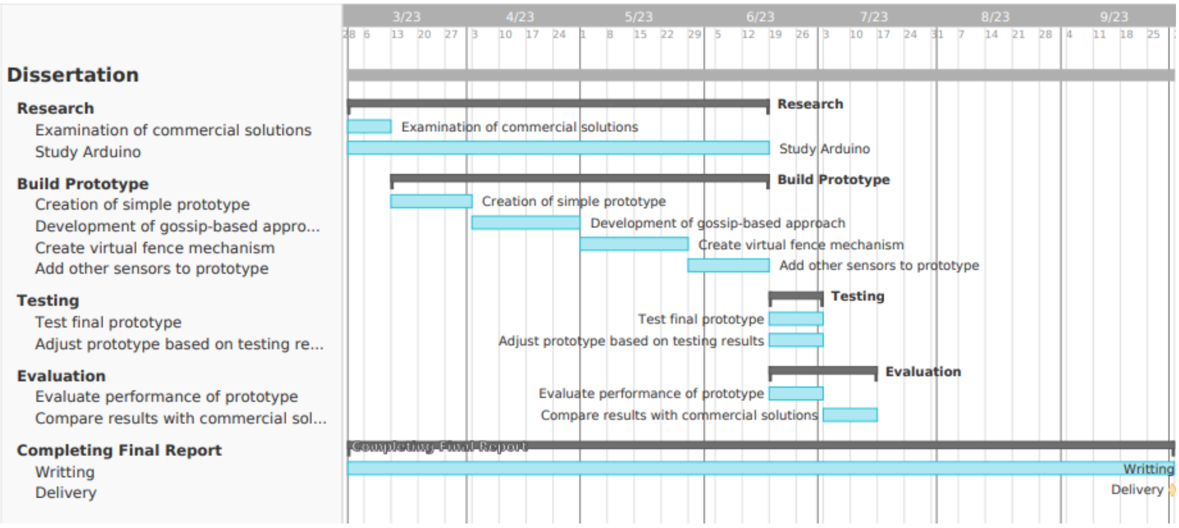

Figure 3.1: Gantt chart of the work plan.

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