REPUBLIC OF TURKEY

ALTINBAS UNIVERSITY

Institute of Graduate Studies

Electrical and Computer Engineering

EFFICIENT NODE DEPLOYMENT IN WSN UISNG LEACH GUIDED ACO

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Master's Thesis

Supervisor

Asst. Prof. Dr. Abdullahi Abdu IBRAHIM

Istanbul, 2022

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I hereby declare that all information and data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Hussein ALSHUWAILI

Signature

PREFACE

This thesis would not have been feasible without the assistance of several individuals. My multiple edits were reviewed by my advisor, who helped me make sense of the confusion. Also, thanks to my committee members for their advice and assistance.

DEDICATION

For my dearest friends and nearest relatives, I offer this effort. Without the help of many people, my thesis would not have been possible. My professor examined my several revisions and helped me make sense of the chaos. Additionally, I appreciate the help and guidance of the members of my committee.

ABSTRACT

EFFICIENT NODE DEPLOYMENT IN WSN UISNG LEACH GUIDED ACO

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Date: 08/2022

Pages: 62

Microprocessors, novel sensing materials and micro electro-mechanical systems (MEMS) and wireless communication have fuelled the development and application of "smart" sensors in a variety of fields, including physical and chemical processes. This kind of sensor has an integrated circuit logic controller and a wireless communication interface, which is commonplace. If a chip comprises one or more sensors capable of processing data signals, the phrase "intelligent sensor" is usually used. More and more sensors are being manufactured, which lowers their cost and encourages further technological development of these devices, leading to new improvements and capabilities. of energy; they must have mechanisms for self-configuration to deal with problems such as communication failures or the loss of nodes. By using fault-tolerant hierarchical routing protocols like LEACH [8] and applying them to industrial WSNs based on the IEEE 802.15.4 standard, this research hopes to develop a new clustering scheme for WSNs that reduces energy consumption without compromising communication or data dissemination between sensor nodes. As much since feasible, prevent routing failures in WSNs, as a damaged route might disrupt a significant number of data flows [10]. Researchers are driven to design and enhance routing protocols for efficient industrial WSNs because of the difficulties in retaining the qualities of energy savings, cheap costs, low communication latency, dependability, and availability.

Keywords: WSN, LEACH, MEMS, EMS.

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ABBREVIATIONS

AI	:	Artificial Intelligence
WSN	:	Wireless Sensor Network
LEACH	:	Low-energy adaptive clustering hierarchy
MEMS	:	micro electro-mechanical systems
ML	:	Machine Learning
ACO	:	Ant Colony Optimization

1. INTRODUCTION

1.1 BACKGROUND

Microprocessors, new sensing materials, micro electro-mechanical systems (MEMS), and wireless communication have all led to the development and implementation of "smart" sensors in scientific fields such as physics and chemistry. The development of wireless communication interfaces on single-chip sensors that function as controllers as a result of integrated circuit logic is increasingly commonplace in the current technological environment. Frequently, the term "intelligent sensor" refers to a chip that contains one or more sensors and can process data signals. In order to reduce the price of these sensors and invest further in their technological development, both of which will bring new possibilities, mass production is becoming the standard. Even though the majority of WSNs are self-sufficient, they rely greatly on the aid of their peers to complete their tasks. In light of this new environment, traditional techniques of animal distribution, such as those requiring dog protocols and the election of a leader, will need to be reexamined. Problems and obstacles related with the design of WSNs are far more complex than those of conventional networks. Each node in these networks is equipped with an array of sensors, including acoustic, seismic, infrared, video camera, heat, and pressure detectors. Each member of the cluster is able to notice events locally, process them, and decide whether or not to broadcast their findings to the rest of the cluster. From this perspective, wireless sensor networks are not only realizable, but also readily accessible [2]:

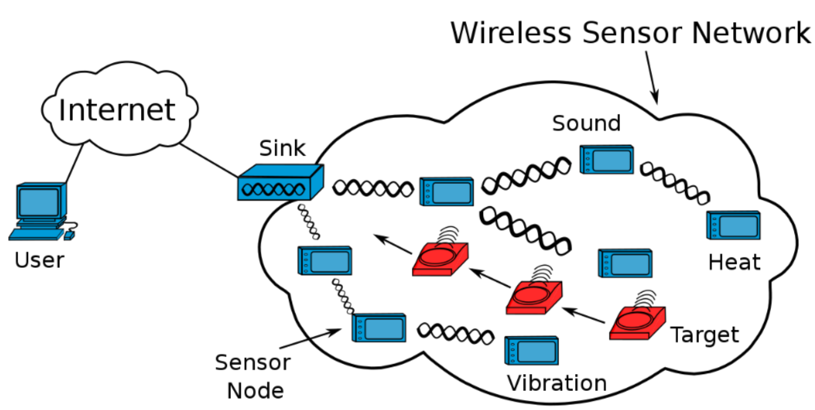

Figure 1.1: Basic WSN structure [1]

1.2 PLANNING THE PROBLEM

Wireless Sensor Networks (WSN) consist of small embedded units, having characteristics such as low cost, low latency and low power consumption. This brings as a consequence strong hardware and software restrictions in terms of memory capacity and processing power. These devices, called “sensor nodes” or motes, are powered by a set of batteries and inserted into an environment to perform instrumentation through a wireless network, forwarding the data resulting from these measurements to a central node (network coordinator). WSNs allow a wide variety of applications, gathering data from multiple sensors without the high cost of wired networks, including allowing the sensing and control of hostile environments or difficult access to wired networks. Some WSN applications include, for example, environment monitoring and surveillance [3], of the conditions of industrial equipment for maintenance [4], of the effort in large construction structures, such as bridges and buildings [5], of the supply chain for shipping containers [5], from the oil and gas industry [6] and many other applications [7]. Some of these applications require a large number of devices, on the order of tens to hundreds of nodes.

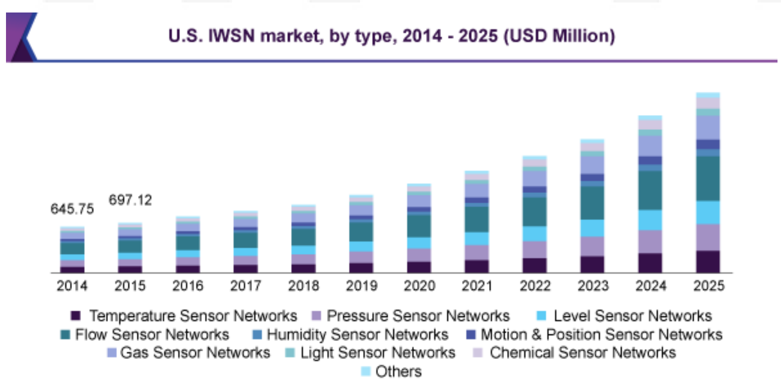

Figure 1.2: Energy consumption in WSN by 2025 [5]

1.3 THESIS OBJECTIVES

The main objective of this work is the creation of a new clustering scheme for WSNs, a fault-tolerant hierarchical routing protocol based on LEACH [8] and applied to industrial WSNs that use the IEEE 802.15.4 standard, reducing energy consumption as much as possible without harming communication and data dissemination between sensor nodes. The concepts to be covered in this thesis include:

A. The goals and motivations behind the clustering in WSN
B. The implementation strategy and associated benefits of using Metaheuristics
C. The structures, methods and other development tools in use
D. The relative strengths and weaknesses of the different WSN models and structures:

1.4 THESIS CONTRIBUTION

A WSN uses a time-varying communication channel, which can only be characterized by probabilistic models, because the environmental conditions that affect such a communication channel are difficult to measure properly. This is a general problem in wireless communications and, as a result, one can only have probabilistic guarantees of the performance of this network. In fact, many WSNs built today (and many communication systems) use the "least effort" technique, meaning that designers give many "guarantees" of reliability, low latency, and high data transfer rates in communication [7]. What happens, however, is that systems are built first and tested later, making such networks inefficient as the number of sensor nodes grows or when a WSN is integrated into more complex systems [8]. This leads to potentially harmful failures, which can compromise the entire WSN structure [9]. In routing protocols in particular, communication errors lead to failures, such as broken routes. When this failure is detected, the routing protocol must be responsible for identifying an alternative route, allowing the traffic between the nodes to be re-established. Routing failures in WSNs should be avoided as much as possible, since a damaged route can affect a large number of data flows that travel in this network [10]. The challenges of maintaining the characteristics of energy saving, low cost, low communication latency, reliability and availability motivate researchers to seek to develop and improve routing protocols for efficient industrial WSN, thus ensuring the longest network lifetime...

1.5 THESIS ORGANIZATION

I will summarize the thesis so that you can better comprehend it. In the part that follows, we will examine some of the previous research and applications conducted on the issue of smart grids. In Section 3, we provide an overview of each component's context. The description and implementation of our model can be found in Section 4, while the simulation results and analysis can be found in Section 5. In the last segment, we will review everything discussed thus far and set the stage for what is to come.

2. LITERATURE REVIEW

The following is a list of different works that are relevant to our work and how they explain the principles of wireless sensor network computing.:

Siani Pearson and her coworkers are among the many individuals who have contributed to this initiative. (2010) [4] I submitted an essay that required grading by my professor. Within the field of large-scale infrastructure, WSN represents a paradigm shift that is gaining rapid acceptance. By allowing several customers to share computer and storage resources concurrently, on-demand provisioning and the pay-as-you-go pricing model are two techniques that can reduce costs associated with their utilization. There is a direct correlation between the emergence of these new characteristics and the need to reevaluate conventional security measures, such as those concerning trust and privacy. This is due to the fact that these new qualities are a direct outcome of the introduction of the preceding ones. Due to the paradigm change, it will be important to reevaluate many of these diverse systems. In this essay, the author examines some of the issues raised about the privacy and security of wireless sensor networks. They also discussed potential solutions to these issues and how to locate them.

To wit: Dlamini, M. T., et al (2011) [5] According to the authors of this study, WSN is a new paradigm for the production, distribution, and consumption of information technology resources and services via the Internet. Adopting this new computing paradigm offers a wealth of benefits, including cost reductions, increased service availability, improved IT operations efficiency and flexibility, and many others. According to the investigation's findings, maintaining proper levels of security is a top priority for many of these businesses. There has been a great lot of confusion surrounding the threats that "WSN" poses to network security, and the moment has come to set the record straight. Before we can determine what is fact and what is fiction, additional research must be conducted. This study aims to distinguish between actual concerns regarding the safety of WSN and the hype, uncertainty, and lack of understanding around WSN. This study attempts to go deeper into the recent discussions on WSN security in an effort to dispel any misconceptions induced by the addition of "wireless sensor networkgy sensors" to the conversation. It is essential that persons in positions of authority are made aware of the threats posed by WSN so they can make decisions based on correct data.

The authors of the paper are Stolfo, Salvatore J., et al. (2012) [6]. Their research led them to the conclusion that "WSN has the ability to completely transform how we use computers and how we access and store personal and business information." This was one of the findings that their inquiry uncovered. As a direct result of the increasing adoption of advanced computing and communication technologies, the level of worry surrounding the security of sensitive data has increased. It has been established that encrypted data is effective at preventing data theft, especially when the data is targeted by employees of sensors service providers. Utilizing technology that generates offensive dummies, they devise an ingenious approach for preserving sensor data. Due to this monitoring, they were able to identify any unusual data access trends. When we identify an unauthorized user, we initiate a deception operation by providing him a substantial amount of false data. This will continue until the unauthorized user has been removed from the system. As a direct result of this, the user's legitimate information is protected. Based on the results of these tests conducted in a local file context, it appears that this approach, when applied to a scenario involving sensors, may provide unparalleled levels of safety for user data.

Henrik Madsen et al. (2013) [7]. In this field of study, new computer paradigms and the factors that significantly contribute to these paradigms' dependability are examined. In addition to investigating the reliability of smart device networks, researchers are investigating wireless sensor network computing as a nontrivial extension of Sensors. By merging grid computing and wireless sensor networks (WSN) with the dependability requirements for sensor and actuator networks in a distributed computing environment, it is possible to establish a dependable computing platform for wireless sensor networks.

Listed below should be cited: Hong, Kirak, et al. (2013) [8] They claim that "the Internet of Things (IoT) is establishing a new environment, particularly the widespread deployment of wireless and sensor devices." In the future, this will enable a vast array of new internet applications. They argue as follows in their defense. In this research project, a high-level programming paradigm known as Mobile Wireless sensor networks was presented as a possible solution to the challenge of how to develop massive, decentralized, and latency-aware Web applications in the near future. Mobile wireless sensor networks constitute a distributed, scalable, and delay-sensitive programming paradigm. It is feasible that Internet applications of the future will utilize these networks. To demonstrate the efficacy of the technique, researchers studied a variety of Mobile Wireless sensor network programming paradigm applications. Among these applications were camera networks and linked vehicles. In addition, simulation was employed in order to analyze the program's overall performance.

In a 2013 published article [9] Chou, Te-Shun, et al.

According to the research reported in this paper, WSN can serve as a dependable infrastructure for a wide range of consumer- and enterprise-level operations. These tasks include the storage and retrieval of data, the deployment of commercial programs, the creation of custom software, and the simulation of network circumstances, among others. The inherent properties of each of the three studied sensor service models were utilized to establish whether or not the WSN was at risk. This hacker group displayed their proficiency by targeting real-world sensor networks. In addition, we address potential safety risks associated with the usage of sensors.

Authors Modi, Chirag, and others (2013) [10] According to the author, WSN consumers receive scalable on-demand services that are also more flexible and require less infrastructure investment. In addition to the threats created by more modern architectural designs, the fact that Sensors services are delivered over the internet using obsolete network protocols and file formats has led to the rise of new problems around data privacy and security. Concerning their personal privacy and safety, practically all individuals who are contemplating the usage of WSN have a variety of queries and concerns. This essay is primarily concerned with the mechanisms that lead to the establishment of these vulnerabilities and the various steps that can be taken to strengthen the system's resistance to attack.

Shankarwar, Mahesh U., et al. (2014) [12] WSN is always growing and displaying continual progress in the realm of computing," he wrote. A wide range of computing services, including sensors storage, sensors hosting, and sensors servers, are making it a popular choice for businesses and academics alike. On the other hand, there are a number of sensors security and privacy concerns to be addressed. The WSN paradigm still faces a significant hurdle in terms of security. Data leakage and the disclosure of personal data privacy are among these issues. There are several hazards to the user's sensitive data on sensors storage because of the sensors's security and privacy. Security and privacy concerns and solutions are examined in this study. In addition, WSN offers a wide range of security and privacy options.

Firdhous, Mohamed et al. (2014) [13] It represents the utility-based WSN" paradigm, which is a new computer paradigm in which computing resources are made available over the Internet at a cost-per-use basis. WSN offers various advantages to users, including decreased costs, the elimination of system management responsibilities, more flexibility, greater reliability, and the ability to operate from any location. WSN is becoming increasingly popular. Even while WSN has many advantages, it also has certain limitations that must be considered. The same reason that is considered a benefit is also responsible for the emergence of these limits. By putting sensors data centers on the Internet, a third party has gained access to sensitive information, resulting in significant and unanticipated network delay as well as unknown security issues. There are certain networks, such as sensor networks and the Internet of Things, where it may not be desirable to have location independence of processing in the sensors. They are referred to as location aware services since they need speedy processing depending on the user's location. For these reasons, sensors researchers have developed a new sort of WSN called wireless sensor network computing, which puts the sensors system either on the edge of or very close to a private network as a workaround for the problems mentioned above.

Loke, Seng W, and others did research in 2015 [14] on the provision of services and applications to mobile consumers via an airborne computing infrastructure. The usage of drones as a service or as a fly-in, fly-out infrastructure may cause substantial data management and computer system architectural issues. It is crucial to ensure the safe and efficient use of these applications in order to optimize the airborne and ground infrastructure for the highest possible quality of service and quality of experience, as well as to have situational awareness, scalability, reliability, efficient scheduling, and interaction between users and drones via physical annotations. It is essential to optimize the ground and air infrastructure in order to provide clients with the best possible service and experience.

Specifically, Bitam, Salim, and others' (2015) [15] investigation. According to the author, "WSN" is a network access architecture that enables "open and ubiquitous sharing of a massive number of computer resources" Customers that frequently utilize digital products can rent them online from a service provider. In light of the increasing number of traffic accidents and the public's rising discontent with vehicle networks, the solutions being examined for intelligent transportation systems aim to improve road safety and maintain passenger comfort. As researchers continue to learn more about the transportation services offered by VANET-many Sensors, a number of issues will require additional study. Data aggregation, energy efficiency, interoperability, resource management, and data and privacy protection are among these subjects.

Rodrigo Roman et al (2016) [16] According to the research findings, "WSN is incapable of meeting essential criteria," such as "low latency and jitter, context awareness, and mobility assistance." These specifications are required for a vast array of applications (e.g. vehicular networks, augmented reality). In order to meet these needs, a variety of computing paradigms, including computing in wireless sensor networks and at the network's edge, have arisen in recent years. Even though these cutting-edge paradigms possess a large number of characteristics, the potential for synergy has gotten little attention in the existing research. Despite the fact that many of these features are similar, this is the case. This is especially true due to the peculiar nature of the subject, as the vast majority of security evaluations fail to account for every conceivable edge case. This is particularly true considering the topic matter. This research will investigate the inherent security threats, issues, and processes prevalent in all edge models. This research is primarily concerned with the prospect of synergy and collaboration. According to our findings, developing cutting-edge paradigms should account for the maturity of previous cutting-edge paradigms

3. MATERIALS AND METHODS

In this chapter we review some of the essential components that we used to implement our model, we give a brief introduction to the component, and then we show how we simulate that component inside MATLAB environment.

3.1 WSN

is based on providing each node with low power radio links, so that the coverage area is relatively small. In this way, it is possible to significantly save power consumption, while, on the other hand, it is necessary to provide routing mechanisms with multiple hops, which allow communication with the farthest nodes. Another advantage is the reuse of frequencies, since two nodes with disjoint coverage areas will be able to use the same transmission band. If the node density is large enough, this mechanism allows establishing multiple routes for each possible destination, allowing the implementation of fault tolerance techniques, considering redundant routes - and global energy management - using alternative routes to balance consumption between nodes.

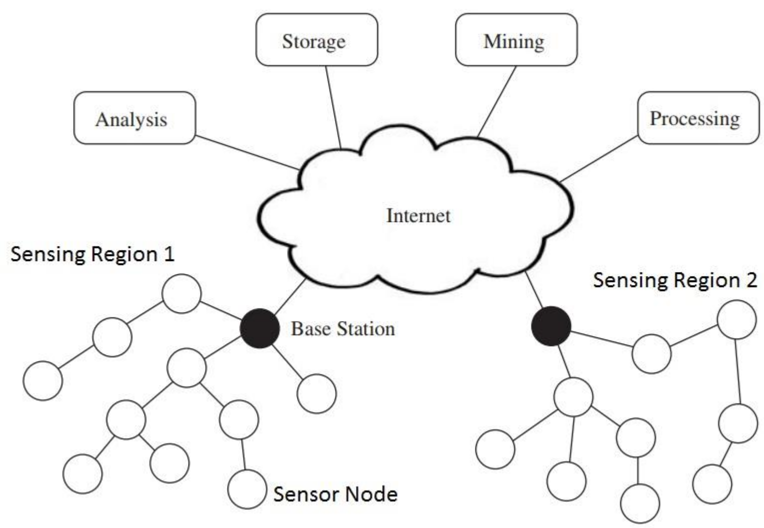

Figure 3.1: WSN basic scheme [11]

Another significant advantage is the possibility of proposing cooperation mechanisms between nodes, either through the distribution of functions, for example, by carrying out each node a complementary task to its neighbors, or through redundant processes where each node supervises the behavior of the neighbor.

However, these capabilities are limited by two fundamental factors: cost and consumption. Thus, in most applications, the nodes are intended to require no maintenance, exploiting the concept of “use and throw” nodes, since once deployed they are not recoverable. This requires that their cost

One of the aspects that has the greatest impact on the performance of wireless sensor networks is the set of protocols used at each of its levels. For this reason, this is a still open research front: despite the existence of standard protocols (IEEE 802.15.4), other more efficient proposals for many applications in which a long period of operation with very limited energy (low cost of nodes), therefore energy efficiency being one of the main objectives of this thesis. However, this work does not neglect other features that are increasingly demanded in new applications of WSN such as scalability, flexibility, fault tolerance, security and time constraints in communications.

Regarding technologies for the implementation of WSN, at this time the following are contemplated:

A. WiFi: The IEEE 802.11 [WIFI09] communications standard is widely used in communication between computers. It is a high bandwidth technology.

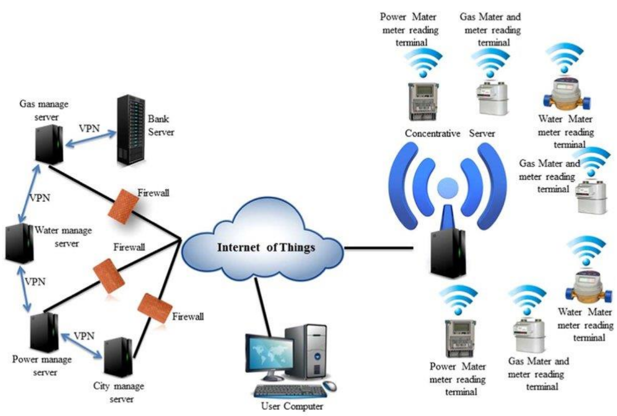

Figure 3.2: WIFI \WSN coverage [12]

B. BlueTooth: The Bluetooth standard [BLUET09] enables the transmission of voice and data between different equipment through a radio frequency link. It is a widely used standard in mobile telephony. 802.15.4 / Zigbee: 802.15.4 [IEEE15.4-06] has been specifically designed for the development of wireless sensor networks. Zigbee [ZIGBEE07] is aimed at providing low cost devices, as well as reduced power consumption and great hardware and software simplicity.

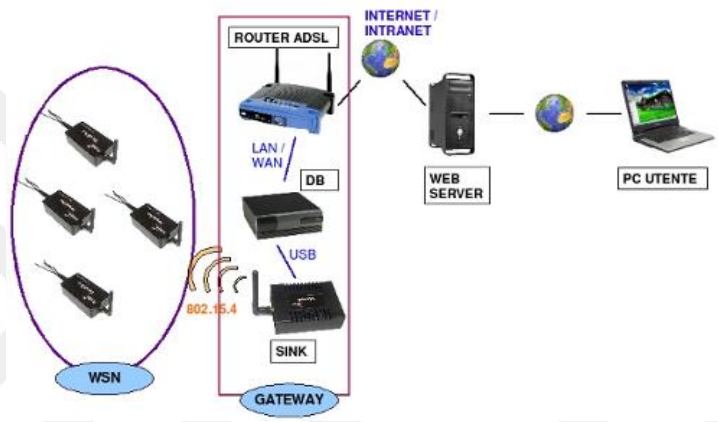

Figure 3.3: Bluetooth \WSN coverage [13]

C. Sub-Ghz wireless technologies: these are technologies also specifically designed for sensor networks, operating in bands below GHz, typically over four hundred and eight hundred megahertz, and whose primary objective is low consumption in both transmission and reception. The great advantage of these technologies compared to those located in the 2.4Ghz is that they have a greater radio range, they are less affected by inclement weather, and they generally have less interference from other wireless devices in these bands than in the 2.4Ghz band.

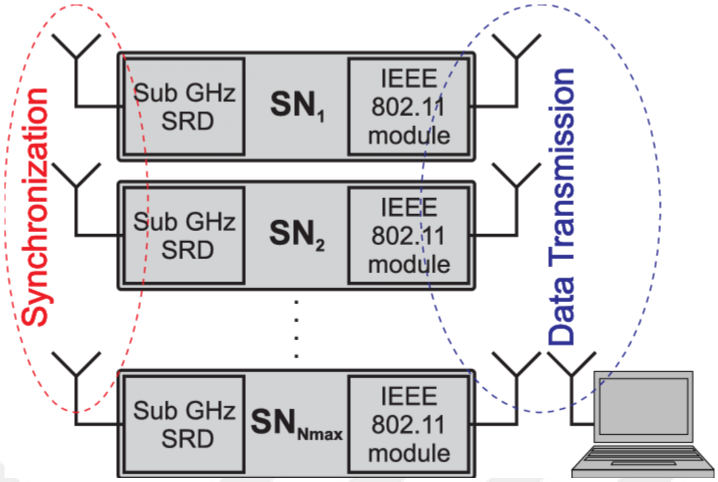

Figure 3.4: SubGhz \WSN coverage [14]

3.1.1 WSN Applications

In this thesis, the previous technologies have been evaluated, the balance shifting towards sub-Ghz and 802.15.4 technologies, mainly for reasons of energy consumption, as stated in Chapter 2 (State of the art). Regarding fields of application, the use of WSN-based technologies is currently contemplated in:

A. Environmental applications: Habitat monitoring, detection of floods, fires, etc.

B. Buildings: more efficient air conditioning systems, location of people or objects, home automation and security applications, etc.

C. Emergency systems.

D. Health Sciences: Follow-up and monitoring of biomedical constants.

E. Home: technical and security alarms (flood, gas, fire, intrusion), home automation applications, etc.

F. Scientific exploration: Environments places with inaccessible or dangerous (oceanic abysses, volcanoes, etc.).

A multitude of researchers focus their efforts on this promising field. As an example, some of the most representative research projects carried out in the European Union can be cited:

A. Awake (EU) [AWAKE]: It is a system for monitoring vehicle drivers in traffic: tiredness, inattention, etc.
B. WiSeNts (UE) [WISENTS]: Cooperation of embedded systems of wireless sensor networks.
C. EYES (EU) [EYES]: Self-configuring, collaborative and energy efficient sensor networks.
D. Hogthrob (Denmark) [HOGTHRO]: Sensor Networks for monitoring the snow conditions.
E. CSOnet Project (France) [CSONET]: Wireless sensor networks for monitoring and controlling sewers in the metropolitan area.
F. RUNES (UE) [RUNES]: Self-configuring Sensor Networks.
G. SECURE TIME SYNCHRONIZATION IN SENSOR NETWORKS (Denmark) [SECURET]: Research project focused on the synchronization of sensor networks.
H. SPOT (Denmark) [SPOT]: Location of nodes in wireless sensor networks.

3.2 ROUTING STRATEGIES IN WSN

The great rise of wireless sensor networks has its basic pillars in its wide range of possibilities, due, among other factors, to the low cost and miniaturization of current microcontroller-based sensors and systems. A sensor node is generally a microcontroller-based system that incorporates a Radio Frequency (RF) module, a sensor unit responsible for collecting data from the environment, all powered by a battery. As seen in detail in figure 2.1, these nodes can be improved with positioning hardware (for example, GPS) or by providing them with movement capacity, all at the cost of greater consumption.

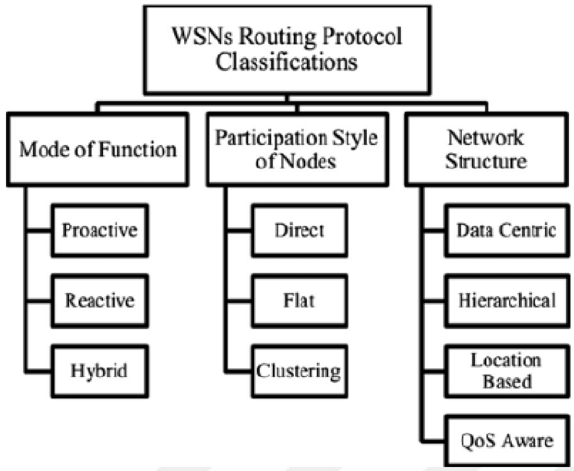

Figure 3.5: WSN routing protocols [15]

In spite of the fact that it endows the node with a great deal of variety, the strategy of constructing advanced sensors with additional hardware to carry out a myriad of different functions is counterproductive. This is due to the fact that it includes a greater level of consumption. If we continue along this path, the sensors that we produce will be expensive, they will call for ongoing maintenance (for instance, to replace the batteries), or they will need for continuous power, which will demand the installation of more wire. The use of wireless communications is not warranted in this scenario, with a few notable exceptions, despite the fact that these sensors have the potential to be useful in some settings. On the other hand, these sensors do come with a number of evident drawbacks.

However, the current trend is to replace these expensive sensors with a myriad of little sensors that are relatively simple. This is done in accordance with the overarching goal of lowering expenses. The deployment of low-cost nodes, which are also likely to be straightforward, is the first factor of economy, and the removal of maintenance, along with the personnel expenses that are linked with it, is the second factor that is crucial. Because of this strategy, maintenance is simplified to the process of repopulating the monitored area with new nodes that are integrated into the existing network to replace those that have stopped functioning, either as a result of failure, accident, or other causes as well as from exhaustion of their batteries.

In order to accomplish this goal, it is vital to carefully manage in order to maintain a balance between the performance and consumption of the sensors. The utilization of a certain routing algorithm is one of the variables that has the greatest impact on the consumption limits. In recent years, a multitude of techniques have been developed in this direction, proposing various alternatives on which type of network topology is optimal to decrease energy consumption and, as a result, increase the life time of the network. These techniques have been developed in this direction for a variety of reasons. Alongside these recommendations, a plethora of protocols have emerged, each of which is focused on optimizing a distinct set of network parameters. [Here] is a classification that is presented, at the level of network structure and protocol operation, which gives a global picture of the various routing approaches that are now being discussed.

On the basis of the operation of the protocol, the following five types are differentiated:

a. Based on Negotiation (Negotiation Based), in which the use of a series of negotiation messages is intended to eliminate duplicates of information and prevent redundant data from being sent to the next node or sink. 2. Based on a Priori (Priority Based), in which the use of a priori information is intended to eliminate duplicates of information and prevent

b. Multi-Path Based, an approach that utilizes a number of different paths as opposed to just one in order to boost overall performance.

c. Based on Queries (Query Based), in which the recipient nodes propagate the information query (sensorization task) from a node to the network, and when a node that possesses the said information is found, it responds to the query by sending the data to the that started the query. This is done when a node that possesses the said information is located.

d. Based on Quality of Service (QoS Based), in which the network must satisfy certain Quality of Service metrics, such as delay, energy, and bandwidth, when sending data to the sink. This helps to keep the network balanced in terms of the amount of energy it consumes and the quality of the information it provides.

e. Based on Coherence (Coherent Based), in which the information is transmitted to the nodes in charge of the aggregation after a minimum amount of processing has been performed on it. The use of consistency processing is a common tactic for designing routing algorithms that are efficient in terms of energy consumption.

There are primarily three categories of networks, and they are classified according to the following criteria:

a. Flat Networks, in which each node in the network performs the same function. In this kind of network, the process of sensing is one that is carried out jointly by its participants.

b. Hierarchical Networks, which have nodes that play a variety of roles depending on the hierarchy of the network. Here, different levels of the network are built, each of which is determined by the function of the nodes.

c. Location-based routing, in which each node possesses a system that enables it to know the precise location of the other nodes in the network, and uses this information for the transmission of data.

3.2.1 Flat nets

When it comes to the functioning of the protocol, the underlying network topology can potentially play a very significant influence. When creating routing protocols, the first step is to start with the presumption that all of the nodes in the network are identical in every way, with no distinctions made between them and the expectation that they will all carry out the same activities. This strategy results in the formation of flat networks, in which all of the nodes carry out the same activities of routing and processing. Different roles are not assigned to the sensors, and they do not cooperate together to carry out the sensorization responsibilities.

In this scenario, it is not appropriate to assign a global identity to each node in many of the systems because there are so many of these in the network. This is because of the enormous number of nodes. Because of this concern, centralized routing has been implemented, in which the Base Station or the Sink sends requests to specific locations and then waits for the data that is sent by the sensors. Because the data is negotiated through queries, you will almost certainly need some kind of addressing scheme that makes use of attributes in order to express the qualities of this data.

The SPIN and Direct Diffusion protocols maintained energy savings through negotiation and the deletion of superfluous data at the beginning of the study on centralized routing. These two protocols, which will be addressed more below, served as inspiration for the design of a great number of others that adhere to a like principle.

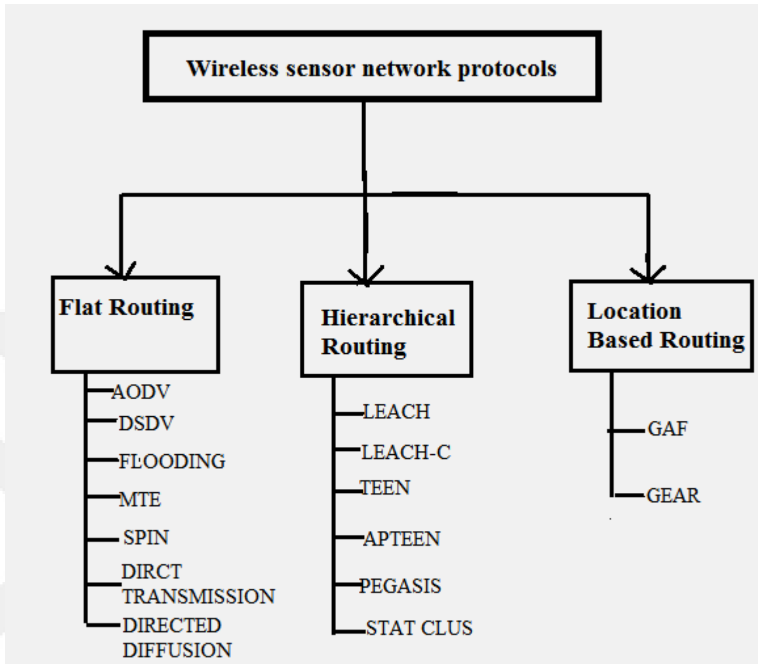

Figure 3.6: WSN routing [16]

3.3 ROUTING SCHEMES

3.3.1 Sensor Protocols for Information via Negotiation (SPIN)

In SPIN [KULIK99], all of the information collected at each node is sent to the rest of the network nodes. Because of this, the system operates under the assumption that all of the nodes have the capability of functioning as base stations. The end user is able to make questions and receive the information instantly as a result of this. The protocols that belong to this family make use of the fact that nodes that are geographically close to one another have data that is comparable to one another; as a result, it is only necessary to communicate information that the other nodes do not already know.

The idea of flooding, as well as flooding itself, is plagued by two significant issues: the implosion problem, which results in the transmission of multiple copies of the data to the nodes, which wastes resources; and the overlap problem, which is brought on by the fact that neighboring areas are covered by different nodes, which in turn transmits replicated information about these zones to the other nodes. Both of these issues are caused by flooding. In general, the protocols that make up the SPIN family are founded on two primary concepts, which are as follows:

A. Sensors are able to work more effectively and preserve energy more effectively when they provide descriptive information about the data that they sense rather than delivering the data itself.

B. Traditional flooding is inefficient because it sends excessive copies of data, which is a result of poor management of overlapping sensors. This wastes a lot of energy and bandwidth. By choosing a random node within the network to send the information to instead of broadcasting it throughout the network, the issue can be resolved in the first instance; however, this results in a significant increase in the amount of time it takes for the information to spread throughout the network.

One of the benefits of SPIN is that changes in the topology are localized. This means that a node only needs to know the position of its immediate neighbor in single-hop for a change to take place, making the process of changing the topology very inexpensive. When compared to traditional flooding, there is a significant reduction in the amount of energy used. Nevertheless, there are a few drawbacks to think about when using SPIN: The shipping warnings that are provided by SPIN do not guarantee the delivery of the information. Consider, for the sake of illustration, an application for intrusion detection in which data must be given in a dependable manner at predetermined intervals of time. If it is assumed that the nodes interested in the information are located far from the source node and that the nodes between the source and destination are not interested in the information, then the information will never be delivered to its recipient, which causes a deficiency in the diffusion capacity (QoS) from SPIN. A substantial overload is imposed on the shipments as a result of the previous negotiation carried out by the nodes, and as a result, this affects the lifetime of a network that, although competent in comparison to classic flooding, is not competitive in the terms on which this work is based. This was a forced decision to apply negotiation in order to avoid the classic flooding and overlap problems. If efficiency mechanisms are not imposed in the sending of the algorithm's messages, then the algorithm will not be scalable. This is because the number of neighbors per network node, and consequently the number of messages, will multiply as the number of network nodes increases, which will exacerbate the problem. Furthermore, such negotiation will cause the algorithm to lack scalability.

3.3.2 Direct Diffusion

Direct Diffusion is a data-centric and application-oriented paradigm, and it names all of the information that is created by the sensors using attribute-value pair combinations. The sensor network will broadcast a sensorization task if it determines that a certain set of specified data is of "interest." This interest explains the task that is to be completed in the network and is broadcast by the same hop by hop, with each node broadcasting to its neighbors in order to spread the information throughout the network. Because of this dispersion, gradients in the network are configured, and these gradients identify an event scheme, also known as an interest-data agreement. A gradient, in its most basic sense, denotes the value of a property as well as the direction in which it moves. As a result of the fact that the intensity of the gradient might vary depending on the neighbors, there is the potential for information flows to be distinct from one another. This technique also has some obvious drawbacks, including the following:

 Because Direct Diffusion uses a model that is based on queries on demand, it cannot be used for applications that require continuous data delivery to the sink. This is because the model does not help achieve this goal. The constant flooding that the network would be subjected to would result in an overload that would be more noticeable than average. Since there are no mechanisms to avoid overload due to flooding and therefore increase the life time of the network by delaying the exhaustion of the battery, the authors of the referenced research work actually achieve the results in environments that are far removed from high loads. This means that the environments must be devoid of congestion and have a low frequency of consultations. Because of this flood, the protocol is not scalable, which eliminates its viability when it is essential to take control of networks that contain a high number of nodes. Because of the use of flooding in the network, it is not possible to guarantee any kind of quality in the delivery service because both latency and packet losses are uncontrollable. This is another result of the use of flooding in the network. As a result, the author is of the opinion that the quality of service is not improved by using this protocol.

In addition, the choice of pathways is done in a manner that is not well optimized, and the diffusion is stable in just a subset of possible scenarios; as a result, this is in no way an effective solution.

3.3.3 Energy Aware Routing

The majority of strategies that have the overarching goal of maximizing the amount of time that sensors are able to function properly focus on minimizing the amount of energy that is expended by each node. The authors of this protocol propose that not always using the path with the lowest energy consumption is the optimal path from the point of view of network life time and long-term connectivity [SHAH02]. This is because not using the path with the lowest energy consumption ensures that the network is always connected. The potential problem that typically arises in protocols that always apply the path with the lowest energy cost for their transmissions is that the nodes involved in this path end up draining their battery much earlier than the rest of the nodes in the network, which causes the network to partition. This can be avoided by always applying the path with the highest energy cost, but this approach does not eliminate the possibility of it happening. As a result, the purpose of this protocol is to locate suboptimal paths that will enable the nodes to save energy and, as a result, distribute the consumption of resources in a more equitable manner.

This protocol may have some similarities to Direct Broadcast, but it is distinct from Direct Broadcast in that it maintains a set of routes rather than a single way that is considered to be best. The fundamental concept behind this strategy is to lengthen the lifespan of the network by not incessantly choosing the best path, but rather by rotating between those two options at regular intervals. Because of this, it is ensured that the nodes that are part of the optimal path will not become depleted too quickly, and that the network will gradually lose its energy in a manner that is more evenly distributed, rather than dividing as a result of the loss of nodes. These non-optimal routes have a greater chance of being taken depending on their energy meter, which refers to the amount of resources that are expended while traveling along that route. When different courses within this set of paths are taken, the energy of each of the paths does not end up getting depleted. As a result, the network is able to maintain its average life span for a significantly longer period of time. The capacity to select numerous paths from among a group of sub-optimal paths, on the other hand, contributes to the fault tolerance of the sensor network.

Table 3.1: WSN protocols compared to each other [17]

Routing Protocols	Classification	Mobility	Power Usage	Scalability	Multi path
SPIN	Flat	Possible	Ltd	Ltd	Yes
DD	Flat	Ltd	Ltd	Ltd	Yes
RR	Flat	Very Ltd	N/A	Good	No
COUGAR	Flat	No	Ltd	Ltd	No
ACQUIRE	Flat	Ltd	N/A	Ltd	No
DRUG	Flat/Hierarchical	Ltd	Ltd	Good	No

3.4 ANT COLONY OPTIMIZATION ALGORITHM

Bio-inspired multi-target optimization algorithms have been shown to be a good tool for solving problems with different target functions [1]. The most representative algorithms are those that rely on evolution and also on swarms of particles. Specifically, algorithms based on the concept of evolution achieve a good approach to the Pareto front, however they require many generations.

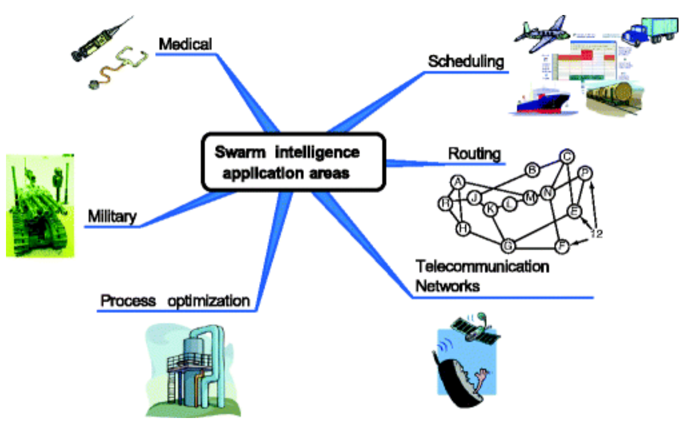

Figure 3.7: Applications of swarm algorithms [20]

Public WSN, in a period of growing attention to environmental issues and coexistence with a permanent state of congested traffic, sees its importance grow daily as a means of satisfying the demand for mobility in cities, especially in metropolises. The choice that brings people all the use of a bus or an underground subway line is tied to a series of factors such as comfort, speed, distance from one's position and from that of arrival. On the other side of the service there are those who want the WSN system to direct it and who, in best satisfying users, must seek a balance with the economic sustainability and practical needs of daily management.

The purpose of this thesis is to manage the public WSN network. Specifically, it studies and applies an approach that allows to redesign the WSN lines currently varying the route to allow more people to use the public service without forcing it to move to reach the stops. At the same time, the study aims to limit the image of the kilometric length of the lines to avoid, on the one hand, the expansion of travel times and, on the other, to ensure a balance between the increase in users and the change in fixed costs. Redesigning a WSN system focusing on improving certain parameters is an operation that falls within a large set of methods and techniques known as network optimization. In fact, the name "public WSN network" is commonly used to indicate the whole complex system of routes, means, frequencies. Over the years the optimization of networks has become one of the most important topics on which all operational research has focused most, that of the branch of mathematical logic developed in the second half of the last century in the wake of the studies of pioneers such as Turing, Minsky, Dijkstra. It is no coincidence that with the term "routing problem", which today indicates a generic routing problem in a network, it has become of common meaning: satellite navigators that solve road networks and computer routers that solve computer networks are objects with which we have more or less direct daily relationships on a professional, recreational, domestic level.

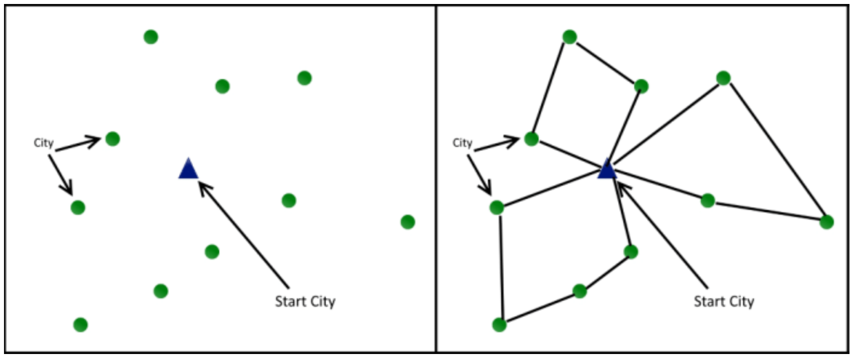

Figure 3.8: ACO applied to a node problem [18]

Understanding how to move in a network of points such as cities, stations, stops along routes such as roads, routes, paths trying to optimize travel in the best possible way has been a theme since the 1950s on which the sensitivity of public opinion first and of scientists then it was more pronounced mainly due to the exponential increase in post-war network.

Studies relating to the optimization of WSN networks have focused on two fundamental aspects: minimizing the length required for movement and maximizing the flow of goods or people on a commercial journey. Studies among others by Dijkstra, FordFulkerson and more recently by Orlin and Ahuja, have led over time to the formulation and subsequent improvements of algorithms capable of searching for minimum paths and maximum flow paths of extremely extensive and complex networks. An important result was the formulation of procedures for obtaining the so-called "maximum flow - minimum cost" paths, that is, those capable of guaranteeing a maximum flow of goods / people to commercial routes, even with the shortest journey possible. The main limits of these algorithms were the high computing power required and the resolution times proportional to the complexity of the problem. In the last quarter of the last century, simultaneously with the formulation of the last generation of deterministic algorithms for optimizing nets, the observation and study of the social behavior of some species of insects inspired the work of some researchers such as Gerardo Beni and led to the definition of the concept of swarm intelligence. The ability to communicate with the rest of their community by subjects fundamentally lacking the ability to make complex decisions has proved to be the basis thanks to which species such as termites are able to build nests, with an extremely elaborate structure, tens of meters high. The process by which the banal choice of the single element of the swarm becomes the means by which much more complex community behavior is produced and developed starts with the use of space as a means of communication. A set of volatile signals emitted by each individual based on the elementary choice made (which could be, for example, that of passing over or under an obstacle) conditions the decisions of the other members of the swarm who behave accordingly, bringing the whole group to follow only the most favorable choice, letting the signals of individuals, who get lost or die, disappear over time. Insects, birds, fish are just a few examples of species specialized in stigmergic forms, the ability to make decisions based on the signs present in the environment, present in nature. Based on these studies, Marco Dorigo in the early 90s developed an algorithm based on swarm intelligence and capable of solving network optimization problems. Specifically, the algorithm refers to the behavior of ants and has been called ACO, Ant Colony Optimization, an optimization algorithm based on ant colonies. The search for this dissertation is based on the application of this algorithm, specifically the evolution called ACS or Ant Colony System.

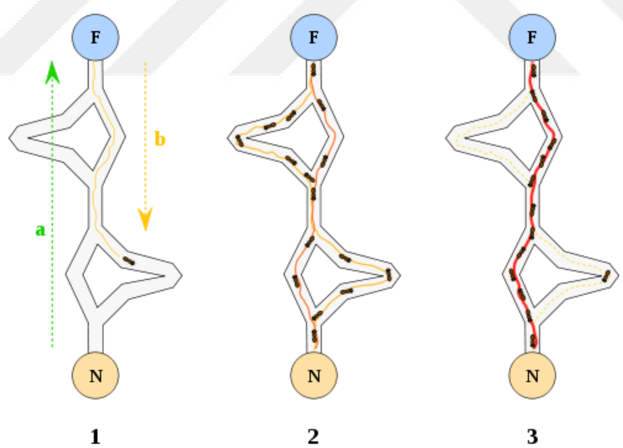

Figure 3.9: ACO explained [19]

If it is true that ACO first and ACS then were initially written to solve mainly minimal path problems, their formulation inspired the work of this thesis thanks to their generality. The algorithm is based on the idea that ants follow, in the medium-long term, the most convenient route to reach their goal, whether it is food or the entrance to the nest. Ants that undertake a suboptimal path see their choice discarded in a short time thanks to a volatility mechanism of hormonal messages with which insects communicate and this guarantees convergence towards an optimal solution in a short time. The path that the original formulation of the search algorithm is the shortest able to connect the starting and finishing points.

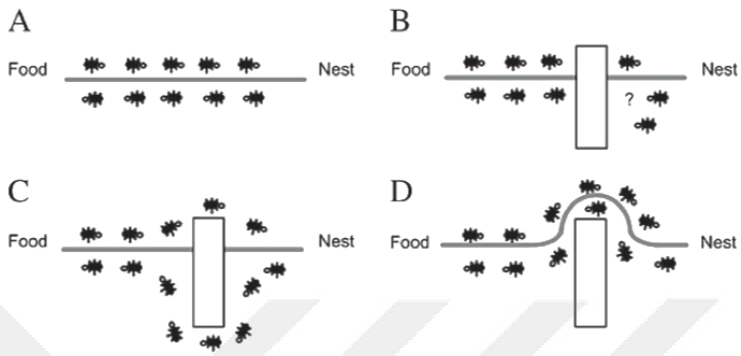

Figure 3.10: ACO work flow [22]

Utilizing the public WSN network and the ACS algorithm, our optimization generates shorter routes that collect more passengers while still meeting demand. The combination of these two elements makes this possible. Our digital ants must be able to forage and travel in an environment that, despite being governed by rigorous mathematical principles, closely mirrors the actual world in terms of the existing lines and the necessity for mobility. Before any more action can be taken, the node must be turned into a colossal chessboard. This would entail creating metropolitan regions with specified boundaries within the chessboard's cells, as if a grid with predetermined dimensions had been placed on top of the node. The routes and associated motions must then be converted into transitions between the cells that comprise this board. This necessitates a reconfiguration of the current public WSN lines positioned atop this network. Once we have transmitted information in the form of a virtual hormone to the cells on the request for mobility in the various portions of the node, we will be able to dispatch our ants to examine the nests represented by the terminal node in search of the most efficient pathways. This will enable the algorithm to be told to find a path that connects the user's starting location and final destination via intermediate nodes whose attractiveness is proportional to the user's need for movement. This will enable the algorithm to locate a path between the origin and the destination. After a network containing new paths has been generated, the level of optimization from both the network administrator's and the user's perspectives must be evaluated by applying an appropriate algorithm to the network's performance and observing the results. Given the increased interest in WSNs for practical, social, and notably environmental concerns, it is essential to assess the practicality of optimization with a wider user base. This necessitates considering the likelihood that the WSN system will evolve in a manner that replicates growing consumption. It is crucial to analyze the possibility of optimization with a bigger user base in light of the increased interest in WSNs for these reasons.

The structure of the dissertation which aims to illustrate the theoretical bases and the practical realization of what has been said provides: a first chapter in which traditional approaches to routing algorithms are discussed; a second chapter in which the Ant Colony System algorithm is illustrated in detail; a third chapter in which the current situation of public WSN is analyzed and its translation into a form that can be used to optimize the WSN network; a fourth chapter centered on the practical implementation of the algorithm in computer language; a fifth chapter with the results of the one-day simulation of traditional lines compared with the lines resulting from the implementation of the ACO algorithm.

3.5 K-MEANS CLUSTERING

K-means is a method for clustering data that seeks to divide a dataset with N observations into K clusters, with each observation being assigned to the cluster with the most similar mean value. K-means is an illustration of a hierarchical clustering technique. The criterion consists of assigning the N observations to the K clusters in a manner that minimizes the average of the disparities between each observation and the cluster mean, which is supplied by the cluster points. This can be achieved by allocating the observations such that N observations are allocated to K clusters.

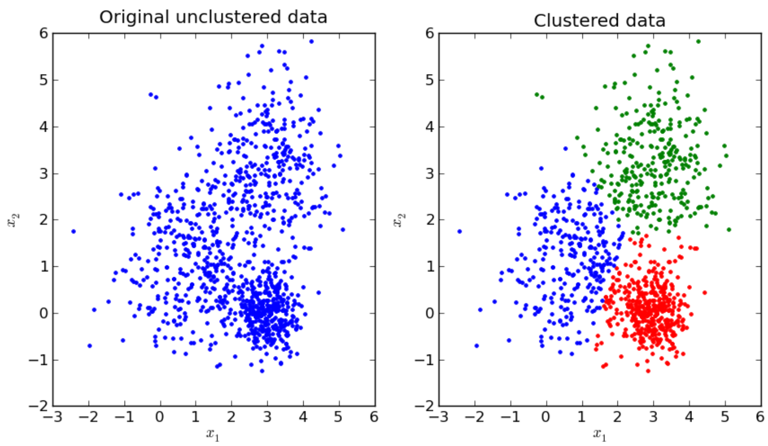

Figure 3.11: K-means clustering [20]

The best-known measures of similarity are those of distance. For two vectors

$$\|\bar{x} - \bar{y}\| = \sqrt[p]{\sum_{i=1}^{n} |x_i - y_i|^p} \tag{1}$$

Depending on the value of p, the following particular cases are generated that will be used in this research work: - For p = 1 Distance from Manhattan (block):

$$\|\bar{x} - \bar{y}\| = \sum_{i=1}^{n} |x_i - y_i| \tag{2}$$

- For p = 2 Eucledian Distance:

$$\|\bar{x} - \bar{y}\| = \sqrt{\sum_{i=1}^{n} |x_i - y_i|^2} \tag{3}$$

- p-> infinite Schebyshev distance:

$$\|\bar{x} - \bar{y}\| = \max_{i=1,2\ldots n} |x_i - y_i| \tag{4}$$

<u>Hamming distance:</u>

If the attributes are categorical, then Hamming distance proposes a distance between two strings: the distance is 1 for each different element and 0 for each identical element in the chain, example:

The distance from "toned" to "roses" is 3.

The distance from 1011101 to 1001001 is 2.

4. PROPOSED METHODS

4.1 CHAPTER OVERVIEW

Current applications increasingly require the integration of tracking into sensor network deployment decisions. We can take the example of GPS allowing you to find your way around road networks, but also mobile applications refining their results or their services by exploiting the position of the user. Here we are interested in localization inside buildings such as hospitals and museums in order to guide visitors and allow them to move around more easily. Although localization techniques using WSN signals have been known for a long time, their use inside buildings, especially hospitals, is prohibited for several reasons. First of all, the health effect of exposure to WSN signals is still little known, which has the consequence of causing some mistrust on the part of users. In addition, coverage inside buildings is sometimes patchy, depending on the frequencies used by telephone operators. For these reasons, we favor technologies that are already ubiquitous in buildings, and more specifically WiFi signals. Triangulation is one of the most widely used methods for estimating target position. However, this technique is inefficient when using an unstable signal. In the previous chapter, we gave an overview of the different topics addressed in the optimization of sensor network deployments, and in particular the application of multi-objective optimization in this field. If the fact of providing coverage represents the first step allowing the estimation of position, a significant modification of the models presented previously is necessary in order to take into account the precision of the localization.

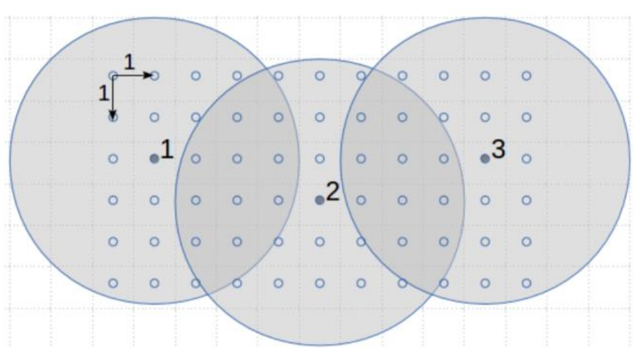

Figure 4.1: WSN deployment

4.2 PROPOSED METHOD

We seek to propose a deployment of sensors in an area optimizing the precision of the localization. Let P be the set of positions resulting from the discretization of the area to be covered, and |P| the number of positions in the zone. Each position can accommodate one sensor, and each position must be covered by at least one sensor. Figure 4.1 shows an example deployment on 6 rows by 11 columns grid. Dark colored positions represent deployed sensors, which cover all positions. For each sensor, the corresponding coverage is represented by a binary disc. Any point inside the disc is covered by the sensor. In this chapter, we are interested in modeling the error of the localization of an event in the grid. If an event is detected by a sensor, we can say with certainty that it is in the detection set corresponding to the sensor. In other words, the event is in the corresponding disk. It is possible to refine the detection by linking the information provided by all the sensors. Indeed, it is possible to dissociate the detection sets provided by the different combinations of sensors. In the previous example, three sensors are deployed, which corresponds to the 2 |P| − 1 Figure 4.2 represents the appearance of a target in the zone at coordinates (4, 4). The corresponding position is represented by a square. It can be seen that the target is detected by the first and the second sensor, the position of the target belonging to the two corresponding cover discs.

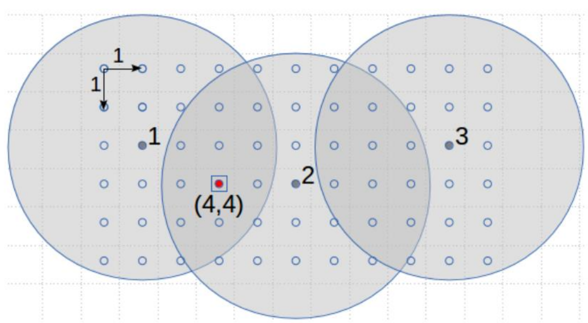

Figure 4.2: setting up the cluster heads

Figure 4.3 represents the estimation of the position of the target by the network of sensors. In the case of a binary coverage model, the only information available is the binary detection, i.e., one can only determine which sensors detect the target. From this information, as well as the sets covered by each cover disc, the sensor network locates the target in a set of 10 positions represented by the diamonds. This size corresponds to the size of the search area following the detection of an event by the combination of sensors concerned. It is therefore important to minimize the size of this set-in order to refine the localization and thus facilitate the search for an event following a detection.

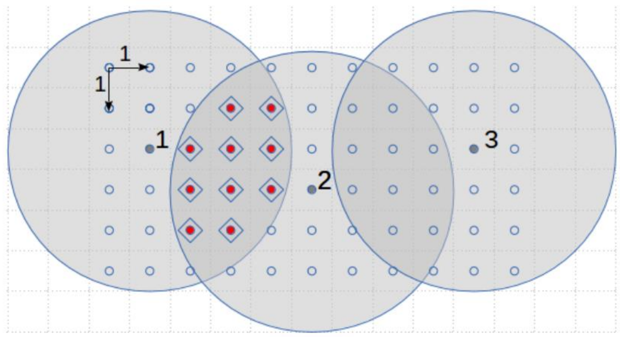

Figure 4.3: clustering the nodes according to the CH

We address here a bi-objective problem: the first criterion is the minimization of the number of sensors to be deployed, which is a common objective in deployment issues. Indeed, this objective is of major interest from several points of view. First, a smaller number of sensors induces a lower deployment cost, in terms of the purchase of the units to be deployed and the workforce to be employed for the deployment (time or number of employees). Reducing this number is also important from an invasive point of view. Indeed, reducing the visibility of the sensor network may be desirable in terms of the aesthetics of the building to be covered. The second criterion is the maximization of the localization precision. The interest of this new objective focuses on localization applications, and it will be represented here as a quality of service.

4.3 MULTI OBJECTIVE ACO

To deal with this problem, we will adapt the LEACH and MO-ACO methods whose general algorithms have been described in the state of the art. The advantage of the first three algorithms is the ease of implementation for binary problems. Indeed, the evolutionary principle is based on genetics and adapts to both combinatorial and continuous optimization problems. The main difficulty is the creation of appropriate operators allowing the efficiency of these methods for the problem. The first step is the representation of the solution by a chromosome. Here the decision variables are the positions of the sensors. Two solutions are available to us: the first is to store the positions (rows and columns) of the sensors in the grid in a vector of variable size. The second inherits directly from the mathematical modeling described above: the chromosome is then represented by a vector of fixed size, corresponding to the number of positions in the grid, each element of which is a Boolean representing the presence of a sensor deployed in the corresponding position. If the first is more compact from a computer point of view, and causes an acceleration from an algorithmic point of view, in particular for the procedures of copying individuals, the second is more natural and facilitates the creation of the operators of crossing and of mutation. We will therefore favor the latter: Let X be a proposed solution to the problem, N = |P|:

$$X = \{X_1, ..., X_N\},$$
$$\forall i \in \{1, .., N\}, X_i \in \{0, 1\}$$

The first step is the initialization of the population, making it possible to create a starting set for optimization. Then reproduction operators are applied to simulate the natural evolution. A repair operator is sometimes necessary in order to guarantee the feasibility of the proposed solutions for the problem. It is also possible to integrate an optimization method into this cycle in order to increase the performance of the solutions generated at each iteration. This last step, present in the so-called "hybrid" algorithms, used in part 3.6, allows an acceleration of the convergence, but however consumes more time.

4.3.1 Population initialization

Population initialization is the first step of most evolutionary algorithms. The goal of this procedure is to create a large number of feasible solutions for the problem, while keeping some diversity. The two initialization operators we will use are: (i) random and (ii) SCP-guided.

4.3.1.1 Random initialization

The random initialization operator makes it possible to obtain a population with very high diversity to the detriment of the objective values of the individuals. The creation of an individual is as follows: as long as all the positions are not covered, a sensor is randomly added covering at least one position. This last condition is desirable, especially when running on large instances, to avoid consuming too much time when creating the population.

4.3.1.2 LEACH-guided initialization

We present here an initialization operator allowing to create individuals heuristically by considering a variable weighting of the objectives. This operator takes into account three cases: the first is the creation of the extreme point considering the minimization of the number of sensors by taking into account only the coverage constraints. The second extreme point is obtained in the case where the constraint $z2 = 1$ does not make the instance of the problem infeasible. In both cases, a greedy heuristic dedicated to the resulting LEACH is used. The intermediate points are obtained by carrying out a weighting of the objectives, via the coefficients α and β which make it possible to obtain a solution representative of a particular zone of the Pareto front (i.e. $z = \alpha z1 + \beta z2$). Each variable is associated with a weight calculated according to the coefficients. This procedure allows the creation of a feasible solution for the problem whose construction of the solution ends when each covering constraint is satisfied.

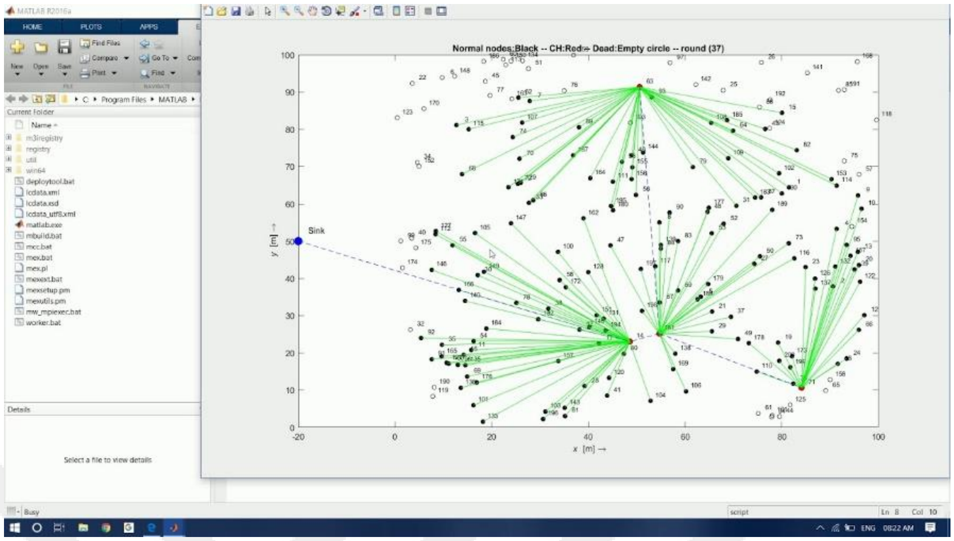

Figure 4.4: MATLAB implementation of the deployment scheme

4.3.2 Crossover operator

The crossover operator is used to intensify the population within a genetic algorithm. This procedure allows the mixing of information from two given configurations, resulting from one or more solutions depending on the chosen operator. For our problem, we are interested in three operators widely used in the literature: the one-point crossover, the multi-point crossover and the uniform crossover.

5. RESULTS DISCUSSION

In order to compare the proposed ACO algorithm with other metaheuristic algorithms, a fourth scenario has been added in which the number of iterations is set large enough to allow nodes to die when consuming their total energy and therefore, packets of information do not reach the base station. With this scenario, it should be observed that the energy consumption indicator is not directly proportional to the latency indicator. Table 5.1 shows the characteristics of scenario four. Table 5.1: Scenario four. Characteristics All nodes start with the same energy level, the source node changes randomly in each iteration and the destination node sb is fixed. The number of iterations is large enough to allow sensor nodes to die. The values of the initial parameters are the same for the three algorithms to be compared, Results The results obtained for both energy consumption, energy efficiency, and latency (for the 30 experiments performed) for each of the four scenarios are presented below.

Table 5.1: Network Parameters in Four Scenarios

Parameter	Description	Setting
iMaxX	Network X-axis	50
iMaxY	Network Y-axis	50
Sink Node	Destination Node	(0, 0)
iNetworkDensity	Total Nodes/iMaxX × iMaxY	0.3, 0.5, 0.7
iSourceDensity	Source Nodes/ Total Nodes	0.004 – 0.01
iTransmissionRadius	Transmission Range	5, 6, 7, 10, 15, 20
iTransmissionRadius/iMaxX	Relative transmission range	0.1, 0.12, 0.14, 0.2, 0.3, 0.4

5.1 FIRST SCENARIO

Figures 5.1, 5.2 and 5.3 show the results obtained for the indicators of energy consumption, energy efficiency and latency for the compared algorithms ACO, Other algorithms. The results of the DFRF algorithm are not shown in the Figures, because they do not allow us to observe the true difference between the other three compared algorithms, since the values obtained are in comparison, much higher than those obtained by ACO, Other algorithms. In this first scenario where the source node is fixed, the ACO algorithm in terms of energy consumption was much better than the Metaheuristic algorithms, in all the 30 experiments, with almost the same values as the algorithm FACO, which in this case is the best in this indicator.

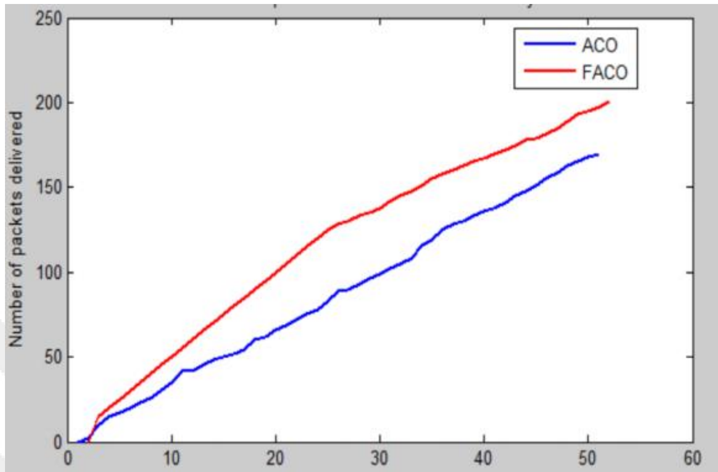

Figure 5.1: Latency in the 1st scenario

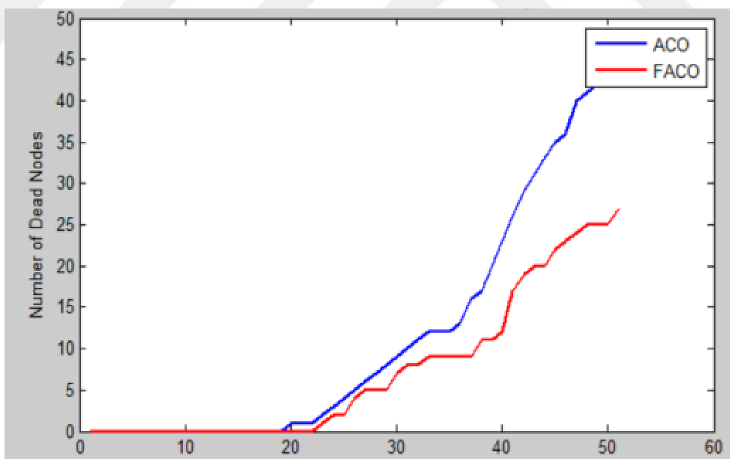

Figure 5.2: Energy efficiency in the 1st scenario

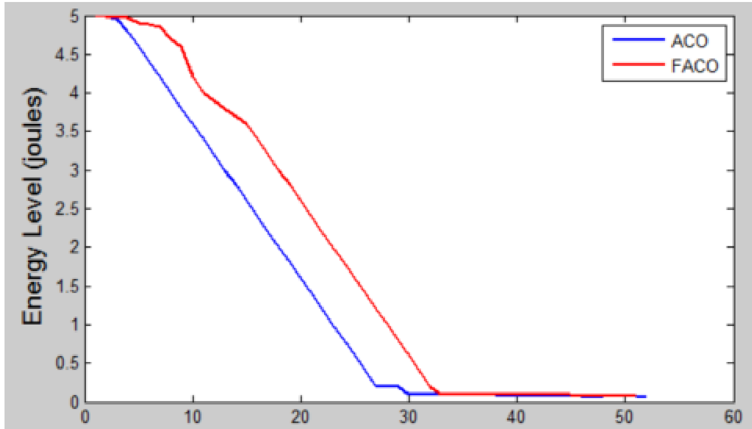

Figure 5.3: Energy consumption in the 1st scenario

The foregoing indicates that the type of administration performed by the nodes regarding the flow of ants proposed by FACO greatly helps the ACO algorithm. In terms of latency, ACO is better than FACO, on average two or three nodes smaller per path, while the ACLR algorithm is the best, although with values very close to those obtained by the ACO proposal, with a difference of one node per path on average. DFRF is the worst in this area, finding on average routes of over 400 nodes. Although the main parts of each algorithm compared were taken, ACO does not improve the performance of its counterparts in the indicators of energy consumption and latency, however in the indicator of energy efficiency, the proposed ACO algorithm it performs better than ACLR and even FACO, with results almost twice the difference with ACLR and a little less than one point with its similar FACO. The results obtained by DFRF are much lower than those of ACO, Other algorithms, since the redundancy of information in this algorithm causes a very low energy efficiency. With the above, it is established that the proposed algorithm is very close to the performance of the ACLR when finding short routes and, regarding energy consumption, it is considerably close to the FACO algorithm, so it is established that the ACO algorithm is the one that best works for when the WSN life span is required to be maximized.

5.2 SECOND SCENARIO

The results of the second scenario for both energy consumption and latency and energy efficiency are shown in Figures 5.4, 5.6 and 5.5 respectively for the compared algorithms ACO, Other algorithms. The results obtained by the DFRF algorithm are in much higher ranges than the other three algorithms, so they are not presented in the Figures. In this scenario, the performance of the proposed ACO algorithm exceeds both the ACLR algorithm and the FACO. In energy consumption, of the 30 ACO experiments improved Metaheuristic in all, and FACO in 24, recalling that the best in this indicator in the past scenario was FACO. The above indicates that the proposed algorithm works in a more outstanding way when the WSN is not in initial operating conditions (all nodes with full batteries). The flooding used by DFRF causes the energy consumptions in the experiments carried out to be very large. In the latency indicator ACO found on average the lowest routes, since of the 30 experiments in 19 it has been better than the ACLR. Regarding the FACO algorithm, ACO performed better in most of the experiments (with only four where the FACO was better). DFRF obtained the worst results, on average routes of 276 nodes. The energy efficiency indicator is won by the proposal in 24 of the 30 experiments.

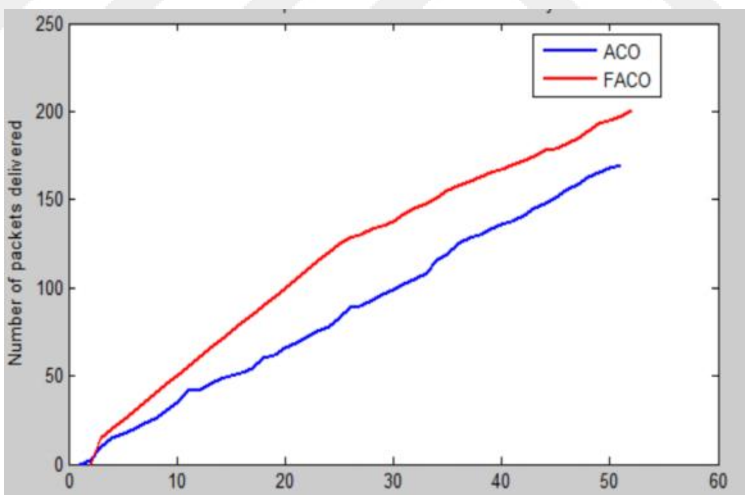

Figure 5.4: Latency in the 2nd scenario

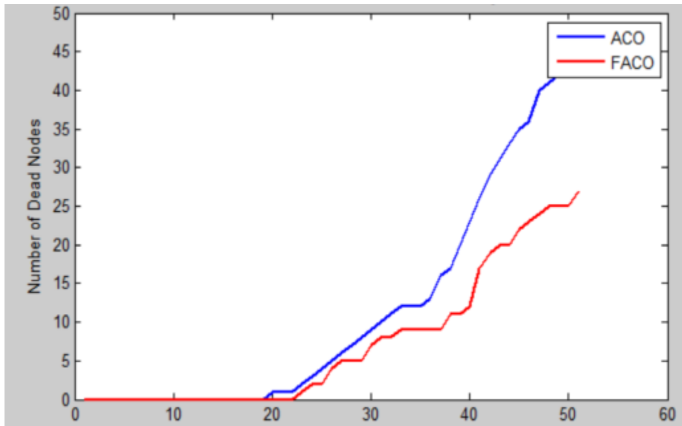

Figure 5.5: Energy efficiency in the 2nd scenario

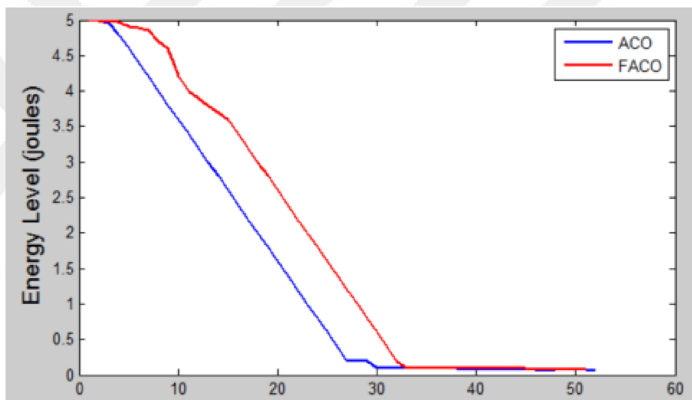

Figure 5.6: Energy consumption in the 2nd scenario

5.3 THIRD SCENARIO

The results obtained from the ACO, Other algorithms are shown in Figures 5.7, 5.9 and 5.8, of the indicators of energy consumption, latency and energy efficiency respectively. As in the previous scenarios, the results of the DFRF algorithm are not shown in the Figures because they are in proportion much greater than those obtained by ACO, ACLR y FACO. For this scenario, the results show an interesting phenomenon in the energy consumption indicator, it seems that the ACO algorithm improves with respect to the previous scenario, since in the previous scenario its results were closer to those of the FACO algorithm However, it is not true, since ACO has remained at the same levels obtained in the previous scenario and FACO has been the one that has obtained higher values than those obtained in the second scenario. ACLR is the algorithm that performs the worst with almost the same values as it obtained in the previous scenario. In this case, ACO obtained better results in 24 of the 30 experiments compared to Other algorithms. As in the previous scenarios, the DFRF algorithm achieved the worst results. In the case of latency, it is observed that the proposed algorithm has matched the ACLR, where the smallest routes on average are very even with each other. In this area, the FACO algorithm falls far short of the performance of both ACLR and ACO. In energy efficiency, ACO remains the leader, even in some experiments its performance is twice the ACLR algorithm.

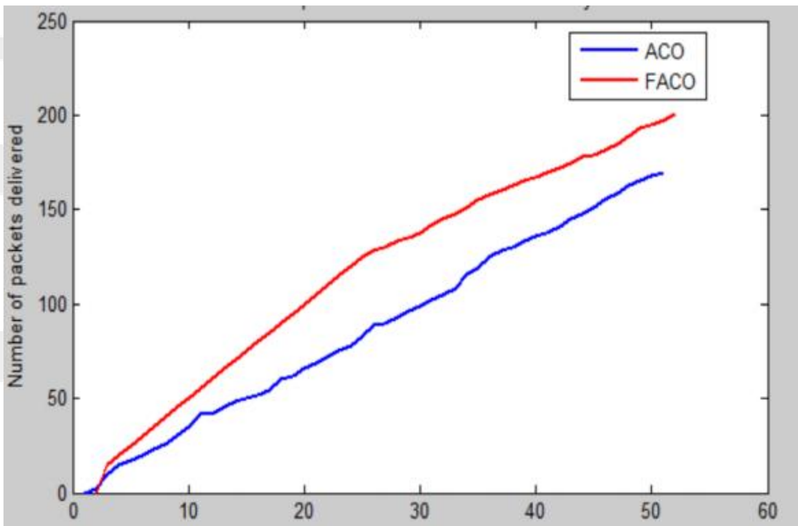

Figure 5.7: Latency in the 3rd scenario

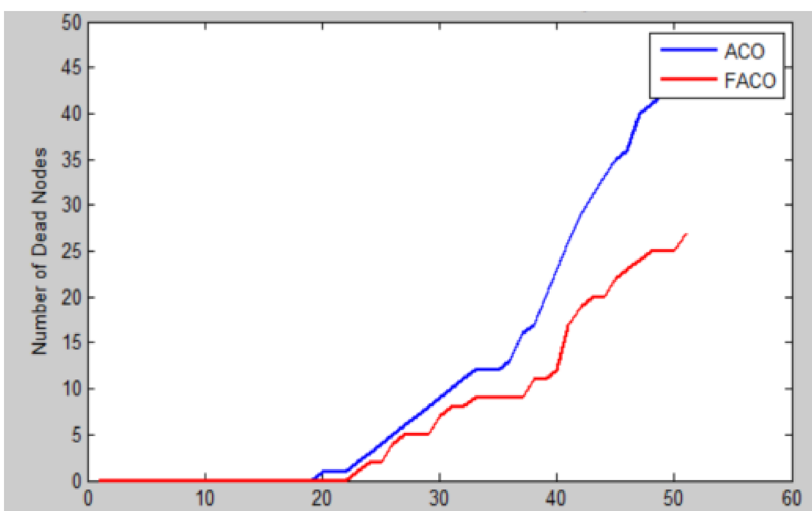

Figure 5.8: Energy efficiency in the 3rd scenario

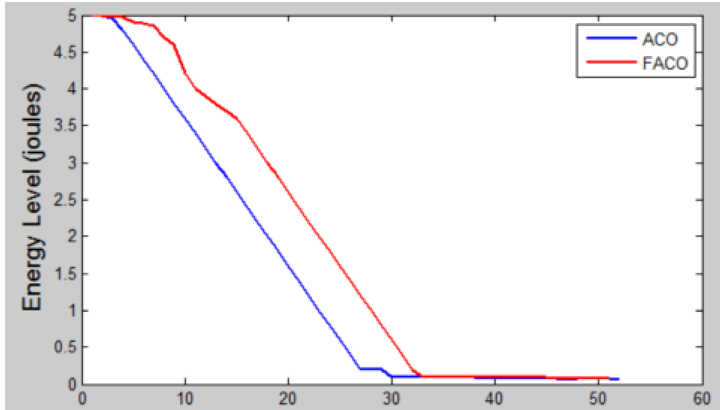

Figure 5.9: Energy consumption in the 3rd scenario

5.4 FOURTH SCENARIO

Figures 5.10, 5.12 and 5.11 show the results obtained for the indicators of energy consumption, latency and energy efficiency respectively for the fourth scenario. The results obtained by the DFRF algorithm are not shown in the Figures, for the same reason as in the previous scenarios. DFRF had the worst results for both power consumption, latency, and power efficiency. Due to the characteristics of scenario four, the energy consumption spiked to much higher amounts than in the previous scenarios. ACO obtained the best results in 22 of the 30 experiments carried out. However, what is important in this scenario is that a direct proportion is not observed between the values of the energy consumption and latency indicators, mainly due to the fact that not all the packets that were created in the WSN were received by the base station, since several WSN nodes died. In terms of latency, in this scenario it is observed that ACLR is the one that obtained the worst results, while ACO improved significantly when obtaining better values in 29 of the 30 experiments. In the energy efficiency indicator ACO was better than Other algorithms in 23 of the 30 experiments performed. Similarly, the correlation that was observed between the energy efficiency indicator and energy consumption in the previous scenarios no longer appears in this one, for the same reason that not all packages created in the WSN arrive at their destination.

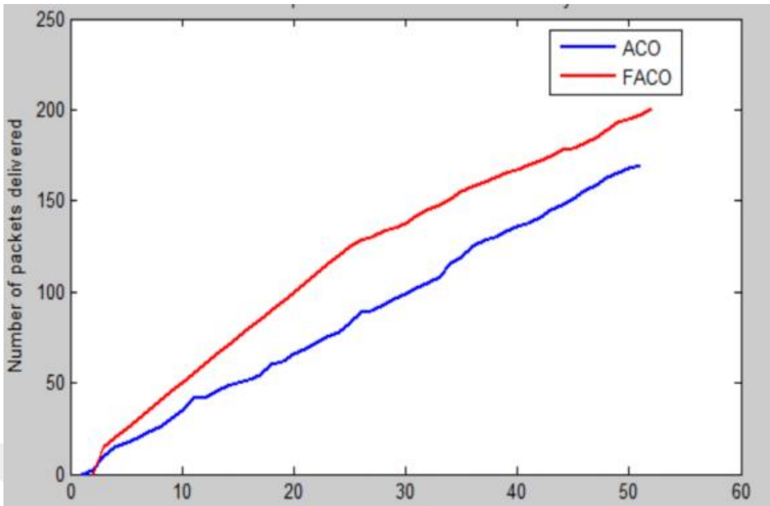

Figure 5.10: Latency in the 4th scenario

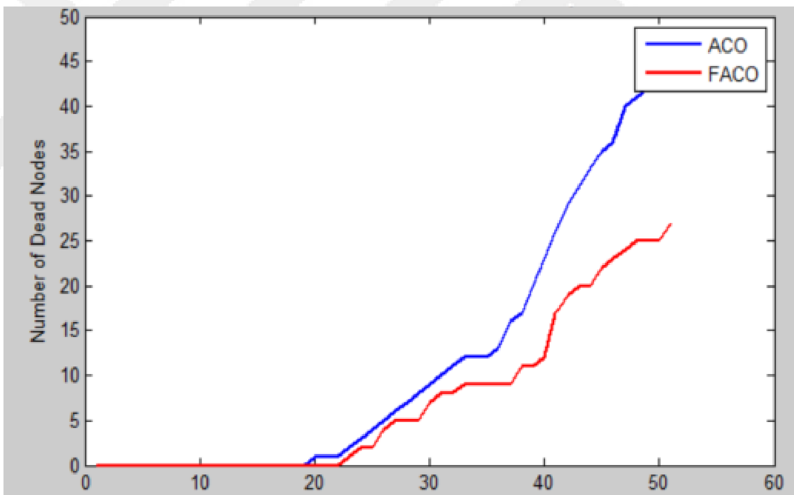

Figure 5.11: Energy efficiency in the 4th scenario

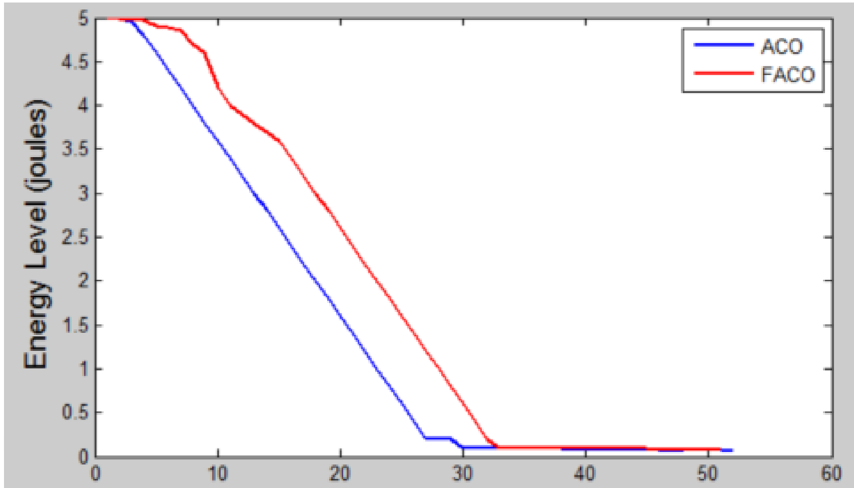

Figure 5.12: Energy consumption in the 4th scenario

6. CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The area of WSNs has received a lot of attention from the research community as it poses new challenges and opportunities in different areas of knowledge. In the future, remote sensing will become part of our lives and will be used in a variety of applications. ˜ WSNs are application dependent. Thus, the design and development of WSN components is directly linked to the application to be developed. There are sensors that, given their dimensions, transmission rate and range, for example, are ideal for one application and totally unsuitable for others. In other cases, we seem to be suitable for a type of application in terms of hardware, but have limitations in terms of the software we want to use. This chapter presented the different protocols for WSNs proposed in the literature and some of the main projects of sensor platforms. Analyzing the platforms, we observe that many of the existing works have not yet actually managed to compose protocol stacks. So far, the 802.11 scheme has prevailed due to its popularity achieved and routing simplified by the tree scheme, although it proves to be efficient in WSNs for simple activities of disseminating data to a sink. Thus, new platforms are expected to benefit from TDMA MAC schemes and routing schemes that allow cooperation between nodes, such as distributed data processing. It is worth mentioning that the protocols to be used must “fit” in the formation of stacks to meet applications with specific requirements, mainly in the data collection scheme, such as event-based.

6.2 FUTURE WORK

There is still a lot of work to be done to incorporate improvements in routing protocols designed for industrial WSN Allied to the aspects of increasing the lifetime of the network, information security is an area of vital importance in preventing malicious attacks that lead to theft, modification or loss of information The challenge is to design secure systems that do not degrade the overall performance of the network, since the devices designed for monitoring industrial plants are mostly lacking robust hardware.

This is the price paid to keep the network operating properly in environments without permanent energy resources that feed the network nodes. Information security techniques must also ensure the maintenance of low latency and high throughput, necessary for industrial WSNs. It is intended, in the future, to physically implement the FTE-LEACH in an industrial WSN that has characteristics similar to the models presented here, where comparative performance studies with the simulations of this Thesis will corroborate in the proof of the efficiency of FTE-LEACH as a hierarchical routing protocol, in the functions for which it was designed to perform.

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