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Hybrid Energy-efficient Routing Protocol based on Firefly and Simulated Annealing algorithms

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ملاحظة :لاتقبل أي شهادة بدون التوقيع والمصادقة.

Abstract

Recently, researchers have focused heavily on the development of wireless sensor networks. These networks are an effective way to study most phenomena in various difficult places. The WSNs consist of a large number of sensor nodes. Each node has a battery of limited capacity. The WSNs are affected by the lifetime of their nodes. The power savings of nodes and the good aggregation of data are two of the main factors in increasing the efficiency of wireless sensor networks. In this research, we hybridized Firefly algorithm and simulated the annealing. We combined them to create an effective protocol that conserves the nodes' energy, thus optimizing the overall network lifetime. This protocol is for achieving optimal cluster heads selection. The role of this hybrid protocol is twofold, improving the global search behavior (exploration) and accepting worst solutions (exploitation) with some probability (avoid getting trapped in local minima). Thus, finding the best cluster head's positioning (which is the ideal choice for the cluster head). In terms of energy consumption and the amount of data packets delivered to the base station, the effectiveness of our proposed protocol is demonstrated by comparing it to the two hierarchical routing protocols, LAECH and LEACH-C.

Key words: WSNs, energy consumption, Firefly algorithm, simulated annealing, clustering, LEACH, LEACH-C

Résumé

Récemment, les chercheurs se sont beaucoup concentrés sur le développement de réseaux de capteurs sans fil. Ces réseaux sont un moyen efficace d'étudier la plupart des phénomènes dans divers endroits difficiles. Les RCSFs se composent d'un grand nombre de nœuds de capteurs. Chaque nœud a une batterie de capacité limitée. Les **RCSFs** sont affectés par la durée de vie de leurs nœuds. Les économies de puissance des nœuds et la bonne agrégation des données sont deux des principaux facteurs d'augmentation de l'efficacité des réseaux de capteurs sans fil. Dans cette recherche, nous avons hybride l'algorithme **Firefly** et simulé le recuit. Nous les avons combinés pour créer un protocole efficace qui conserve l'énergie des nœuds, optimisant ainsi la durée de vie globale du réseau. Ce protocole permet d'obtenir une sélection optimale des chefs des clusters. Le rôle de ce protocole hybride est double : améliorer le comportement global de recherche (exploration) et accepter les pires solutions (exploitation) avec une certaine probabilité (éviter d'être piégé dans les minima locaux). Ainsi, trouver le meilleur positionnement de chef de cluster (qui est le choix idéal pour la tête de cluster). En termes de consommation d'énergie et de quantité de paquets de données livrés à la station de base, l'efficacité de notre protocole proposé est démontrée en le comparant aux deux protocoles de routage hiérarchiques, LAECH et LEACH-C

.**Mots clés:** RCSFs, consommation d'énergie, algorithme de luciole, recuit simulé, clusters, LEACH, LEACH-C.

Dedicates

قال الله تعالى "لَا تَعْبُدُونَ إِلَّا اللَّهَ وَ بِالْوَالِدَيْنِ إِحْسَانًا ." البقرة -83-

My Dear Parents

My father & my mother, you were the perfect support for me throughout my scientific career. My success was due to your endless sacrifice. You have all the appreciation, thanks and gratitude.

My Lovely Family

*My brothers & my sisters; thank you for all what you did for me, your efforts, supports and your prayers. Also I don't forget my sisters in law "**Aisha & Hassina**" thank you too.*

To all my relatives and friends

*Dear **Karima BASSOUDI,** you were the perfect friend for me. I will never forget all the support and encouragement you gave me.*

Thanks to everyone who helped me or prayed for me during all my scientific career.

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All praise and thanks to you, **O Allah**, for your grace to us, lighting the way for us, and giving us patience to complete this humble work and achieve success Thank God ever and forever.

"Get up for the teacher and reverence him." The teacher is almost a messenger."

Mr. Mohammed DEMRI

My respected teacher I forward to you all the meanings of thanks, appreciation, and gratitude for your efforts made with us throughout the completion of our work. You were truly the best role model for hard and pious work. Thank you all for your support and guidance. We also apologise if we have missed or delayed the completion of the work. Thank you, our teacher. I have the honor of your supervision of our work.

I forward my thanks and respect to the members of the jury, who always guided us and corrected our mistakes in order to produce a neat work without scientific or linguistic errors.

I didn't forget to give my special thanks to my colleague **DIARA Hamadoun** for helping and guidance.

In the end, my thanks and appreciation to all of our professors and colleagues who supported us inside and outside the university.

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List of Acronyms

ACQUIRE	ACtiveQUery forwarding In sensoR nEtworks
ADC	Analog to Digital Converters
BS	Base Station
CH	Cluster Head
CSMA	Carrier–Sense Multiple Access
DC	Data-Centric
DD	Directed Diffusion
FA	Firefly Algorithm
GPS	Global Positioning System
GUIs	Graphical User Interfaces
HEED	Hybrid Energy Efficient Distributed
HRP-FASA	Hybrid routing protocol based on firefly and Simulated Annealing
LEACH	Low Energy Adaptive Clustering Hierarchy
LEACH-C	Low Energy Adaptive Clustering Hierarchy Centralized
MAC	Medium Access Control
MWE	Multiple Winner Algorithm
PEGASIS	Power Efficient GAthering in Sensor Information Systems
Qos	Quality of System
RAM	Random Access Memory
RR	Rumor Routing
RUGGED	RoUting on finGerprint Gradient in sEnsor networks
SA	Simulated Annealing
SAR	Sequential Assignment Routing
SPEED	Stateless Protocol for Real-Time Communication in Sensor Networks
SPIN	Sensor Protocol for Information via Negotiation
STCP	Sensor Transfer Control Protocol
SWE	Single Winner Algorithm
TDMA	Time Division Multiple Access
TEEN	Threshold Sensitive Energy Efficient Sensor Network
TORA	Temporarily Ordered Routing Algorithm
WRP	Wireless Routing Protocol
WSN	Wireless Sensor Network
ZRP	Zone Routing Protocol

General Introduction

Due to the importance of wireless sensor networks in many fields, such as control operations and monitoring applications, these networks have achieved great development in various aspects. Sensor nodes are one of the main components of these networks. Wireless sensor nodes have been greatly developed to contribute to the process of transmitting sensor information from various difficult places. For example, they are distributed in the mountains, in the forests, and in the seas. They are also deployed underground for specific purposes depending on their location.

There is no doubt that the development in wireless sensor networks is not just in the physical aspect ; it is in the strategy of gathering information from the nodes to the base station that follows the phenomenon. There are many obstacles that face wireless communication networks. These networks may be exposed to battery damage due to their limited capacity, high power consumption, and the problem of routing and data collection as well.

Scientists and researchers have focused a lot on solving the problem of energy consumption due to the nature of the node batteries, which are not changeable or rechargeable and limited in capacity. Therefore, several solutions have been proposed to save node energy and thus extend the network lifetime.

One of the energy-saving and efficient methods is the cluster-based hierarchical approach. In this approach, the network is divided into groups. Each group is headed by a leader, or what is known as the "cluster head". The primary role of the cluster head **(CH)** is to collect sensor data from the nodes and send it to the base station. It is maintaining a balance of energy consumption within its group and extending the battery level of each node. The aggregation process helps reduce the amount of energy consumed.

The main objective of this study is to create a strategy to improve the process of aggregation and routing in wireless sensor networks to achieve a more efficient and energy-saving architecture.

In this study, we propose a series of improvements based on the creation of a hybrid protocol inspired from the nature. The proposed protocol includes both the firefly and the simulated annealing algorithms. The hybrid protocol is based on the hierarchical routing strategy.

This study is built on four consecutive chapters to achieve the desired objective.

In the first chapter, we focus in general on defining wireless sensor networks. Describe WSNs' characteristics, their applications in various fields, and the challenges that they face.

In the second chapter, we will look at several routing protocols used in wireless sensor networks to provide sensor power. This chapter contains the routing protocols' classifications and the principles of each protocol separately. Like LEACH, LEACH-C and so on.

The third chapter is related to the presentation and explanation of our proposed protocol. We have devoted the first part of it to explaining both the firefly and the simulated annealing algorithms. In the second part, we present in detail the methodology of the proposed hybrid routing protocol, which is a combination of the two algorithms (**FA** and **SA**).

The fourth chapter. This chapter is devoted to simulation, presentation, and analysis of results. We start first with an overview of the simulation platform used, which is the **Matlab** program on which we implemented the simulation. Then, we present the different results of the comparison between our **hybrid protocol (FA-SA)** and the **Leach** and **Leach-C** routing protocols.

Finally, we conclude our study with the most important results and problems that we have solved. And how we contributed to achieving the desired goal and the improvement that we gave to this network.

CHAPTER I:

General overview of Wireless Sensor Networks

I.1. Background

Wireless sensor networks have witnessed a great development in recent years due to the increase in scientific researches and the great support for these researches. But it still faces several limitations, such as the limited power of wireless sensors. The applications of WSNs are many and various. As wireless sensor networks are one of the most important technologies used in the transmission of information

In this chapter, we will discuss the basics and the most important concepts of this study, beginning with the architecture of sensor nodes and wireless sensor networks, followed by the most important difficulties facing wireless sensor networks, and finally, we present the various areas of application of these networks.

I.2. Sensor Node Architecture

I.2.1. Definition:

Sensor nodes are one of the components of sensor networks that are used to locally carry out simple computations and transmit the required data, which are randomly deployed either inside the phenomenon or very close to it, and inaccessible terrain **[1].**

Figure 1.1: Sensor Node

I.2.2. Sensor Node Structure

There are four essential components to each sensor node, which are shown in the figure below.

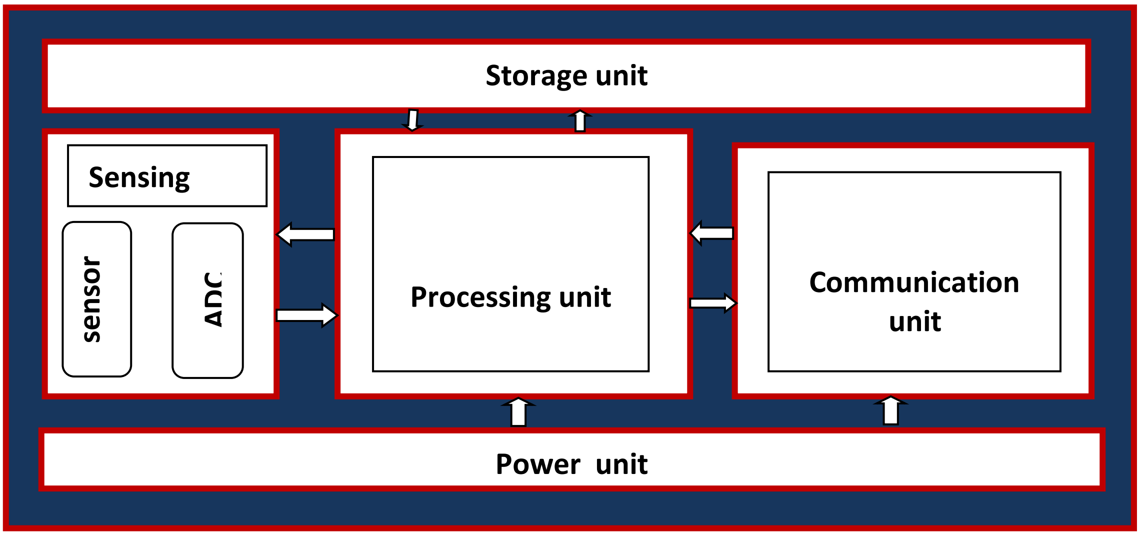

Figure 1.2: Sensor Node Structure [2].

I.2.2.1. Sensing Unit

The sensor generally consists of two main components:

- **Receiver:** recognize the analysis.
- **Transducer:** converts the signal from the receiver into an electrical signal.

The sensor provides analog signals to the converter after observing the phenomenon. These signals are converted by the converter into a digital signal and sent to the processing unit **[2].**

I.2.2.2. Processing Unit

The processing unit features a microprocessor and storage memory. Through it, binary computation and storage are performed. In addition, it contains communication protocols for cooperation with other network parts. It can also analyze sensor data to facilitate base station missions **[2].**

I.2.2.3. Power Unit

The power source for holding the sensor is in the form of a battery of small size and limited life. It is responsible for providing the necessary energy to all sensor node cells **[2].**

I.2.2.4. Communication unit

This unit includes two parts: a radio and an antenna. Its aim is to send and receive data over a wireless medium. Either the optical type or the radio frequency type **[2].**

I.2.2.5. The Memory/storage unit

The quantities of memory and storage on board a **WSN** device are limited primarily by economic considerations, and are also likely to improve over time. Memory and storage in the form of random access and read-only memory include both programme memory and data storage. Data storage includes raw and processed sensor measurements and other local information **[2].**

I.3. Wireless Sensor Network

I.3.1. Definition

The random deployment of a large number of wireless sensors in a geographical area creates a network of wireless sensors. These networks help to monitor different physical events. For example, monitoring earthquakes, weather changes in terms of temperature or humidity, and many other physical phenomena **[3].**

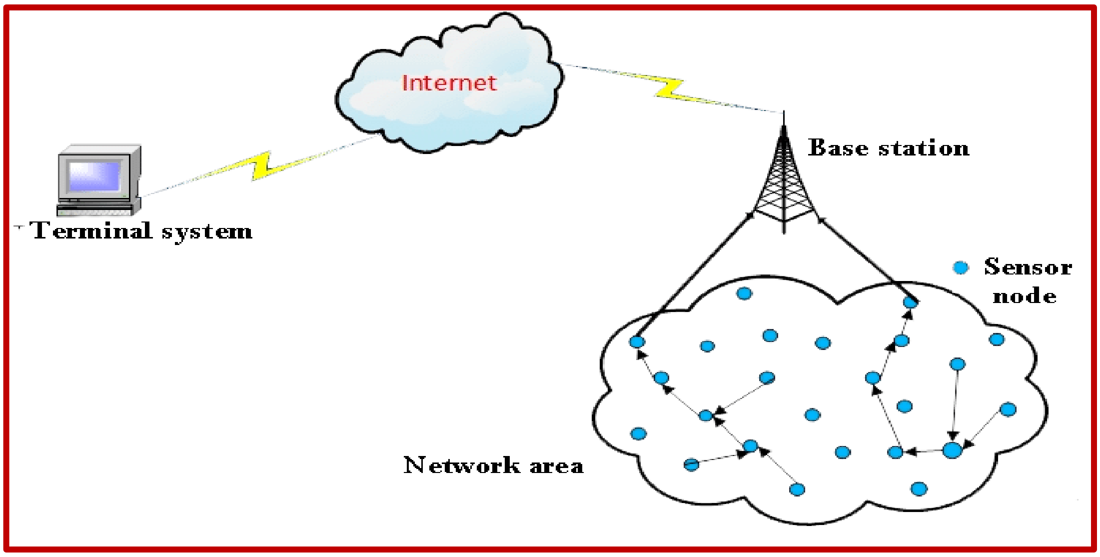

Figure 1.3: Wireless Sensor Network.

I.4. Characteristics of Wireless Sensor Networks

I.4.1.1. Power efficiency

The process of supplying energy to the nodes through the battery is one of the most commonly used methods, but the battery is liable to damage due to its limited energy and the inability to change it, which causes a decrease in the life of the wireless sensor network in general **[4].**

I.4.1.2. Fault tolerance

When some nodes become damaged, it may cause the network to become defective. So the wireless sensor network should be able to hold out against this problem by enabling fault tolerance while not increasing the cost of the overhead connection **[5]**.

I.4.1.3. Mobility of nodes

Due to the contract's limited power problem, the mobility feature reduces the energy consumed by the knot, thus delays its death. This makes the network's lifetime longer **[6].**

I.4.1.4. Heterogeneity of nodes

The role of heterogeneous wireless sensors that have a variety of purposes contributes to increasing the accuracy of the cooperation between the parts of the wireless network. This helps reduce errors that may be encountered on this network **[7].**

I.4.1.5. Scalability

In a wireless network, no matter how large the nodes are spread, the network has to maintain the self-adaptation of these nodes. It thus provides high flexibility in the system, which imparts robustness in the network**[8].**

I.4.1.6. Responsiveness

As the sensing nodes connectivity structure changes, the wireless sensor network must quickly adapt to this change **[9].**

I.4.1.7. Communication failures

Certainly, any wireless sensor network has too many problems, such as the death of the nodes, for example, which causes the transmission to fail over. Therefore, the system must identify the fault and fix it in order to continue the network's tasks and achieve its goal **[10].**

I.5. Challenges of Wireless Sensor Networks

Despite the important and effective role played by wireless sensor networks in monitoring physical phenomena in various fields, which avoid many problems in life. With all these advantages and the great developments in this field, **WSNs** still suffer from many obstacles on their way, which they must look over to solve the problems. To gain a better effectiveness.

I.5.1. Energy

The power consumption depends on the battery level. The nodes used in wireless sensor networks are equipped with limited energy and unchanging batteries, which leads to the depletion of their energy stocks. The number of active nodes determines the lifetime of the network. Therefore, energy must be saved and reasonably used to maintain network connectivity **[4].**

I.5.2. Limited memory and storage Space

Limited memory is a major restriction. The memory capacity can be improved, but the network cost will increase, especially for those that need a large number of nodes [12]. Find the most effective solution to this limitation. It also depends on the limited battery capacity of the nodes, which are responsible for feeding all the sensor elements **[11].**

I.5.2.1. Deployment

The difference in geographical areas causes a great obstacle for the designers. There is no doubt that the nodes are deployed in the area to be monitored by aircraft, which increases the cost of work, especially in rugged areas, so special systems must be used to solve this problem **[13].**

I.5.2.2. Fault Tolerance

Even if one of the nodes in the sensor network fails, the network should continue to function. In the event of a failure, the network should be able to react by altering its connectivity. In that instance, a highly efficient routing algorithm is used to alter the network's overall design **[14].**

I.5.2.3. Design Constraints

The size and cost of the sensor are two important factors in the design of these elements. The main goal is not only to study the phenomena, but to increase the efficiency of the sensor to increase the positive results. Wireless sensor networks are still having challenges with the software and hardware used in these networks **[15].**

I.5.2.4. Limited bandwidth

In wireless sensor networks, sending data does not consume a lot of energy compared to processing it. Bandwidth constraints have an impact on sensor communication. Message exchange is a prerequisite for network synchronization. In wireless communications, a multi-hop medium is often used with limited performance and bandwidth for sensor networks **[16].**

I.6. Protocol Stack of Wireless Sensor Networks

The wireless sensor network architecture allows nodes to communicate with each other under certain conditions. Whether in terms of power, bandwidth, or protocol, the protocol is a communication strategy used by the base station with all network sensors. These protocols are summarized in the so-called protocol stack, which contains several layers as shown in the figure below. We will discuss them in detail.

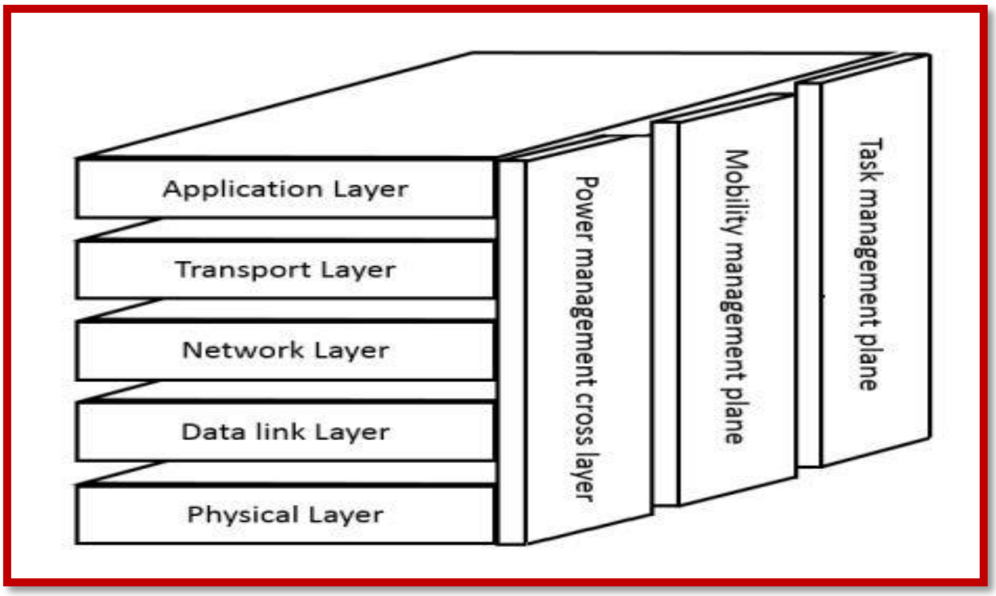

Figure 1.4: Protocol Stack of Wireless Sensor Networks [23].

I.6.1. Physical layer

The physical layer must be designed with WSN requirements in mind. Material layer needs: Bandwidth: Narrow Band, Spread Spectrum, and Ultra Wide Band. Radio architecture; The reason for the power consumption in the physical layer is due to the power of both the circuits and the transmission.

Modulation schemes; The power consumption is due to the modulation scheme that the radio uses for the node. Therefore, adjustments must be made to reduce it. Binary modulation and M-ary; M-ary modulation transmits symbols from a group of distinct M waveforms during binary modulation**. [15]**

I.6.2. Data link layer

The role of this layer, for two nodes that have the same connection, is to transfer data between them. This is due to the characteristics of the medium access protocol that distinguish it. For example, bandwidth utilization, error control during the communication process, scalability, and frame synchronization **[15].**

I.6.3. Network layer

The network layer defines the path of information from the source to the destination. The **IP** based routing protocol cannot be used in WSNs because the sensors do not have **IP** addresses. These protocols must also be distinguished for their scalability. as well as the ease of communication between the sensors and the base station. It also considers network resources, including bandwidth, limited memory, and energy.

Essentially, the protocol has to address the problems of fault tolerance, efficiency, security, and other network limitations **[15].**

I.6.4. Transport layer

The transport layer is responsible for the quality and reliability of the information in the sink and source as well as for addressing design problems. The Sensor Transfer Control Protocol (**STCP**) provides reliability and the ability to monitor congestion before it occurs, thus conserving power. Before sending data from the sending node to the base station, a packet containing information about the number of streams, type, reliability, and transmission rate is sent from the source node to the base station **[15]**.

I.6.5. Application layer

The application layer provides the technology to connect the user to the network for the purpose of interaction using system-wide interfaces (internet). It also allows sending requests and analyzing the results received from the network **[17].**

I.6.6. Power, Mobility, and Task Management Plane

The energy consumption of the network is controlled by task management, power levels, and mobility. In addition, the division of functions and the functionality of each node are controlled by all the layers of the protocol. It also helps coordinate the tasks of the sensor nodes **[18].**

I.7. Application of Wireless Sensor Networks

I.7.1. Military applications

The important role that the wireless sensor network provides in serving the military sector solves many problems. The rapid distribution and low cost of the contract greatly facilitated the work of military applications in terms of monitoring the enemy, tracking the locations of soldiers, or even studying the geographical condition of the area before sending soldiers. In addition, for protection against any counter-attacks and for danger predictions **[19].**

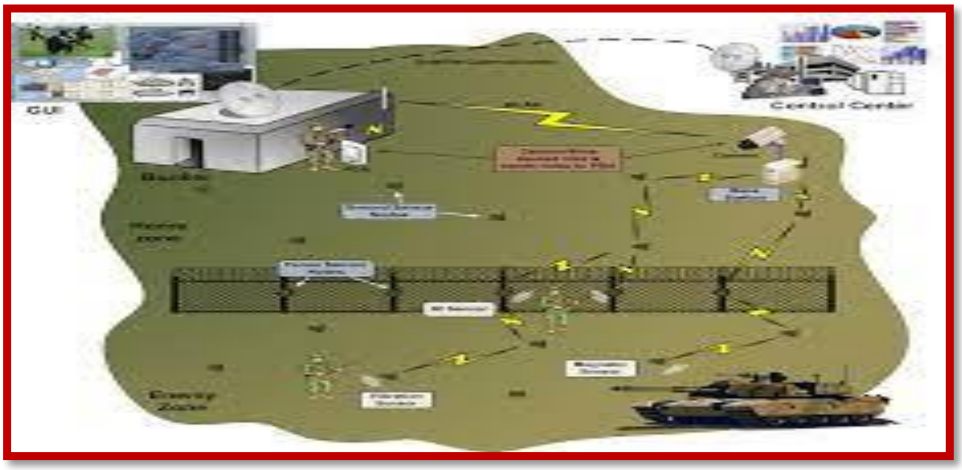

Figure 1.5: Military applications of WSN

I.7.2. Area monitoring

Wireless sensor networks can be used to monitor changes in buildings. In addition, the state of public facilities after natural phenomena such as earthquakes. It is also used as a warning in cases of intrusion. This reduces the security cost of human beings and places **[19]**.

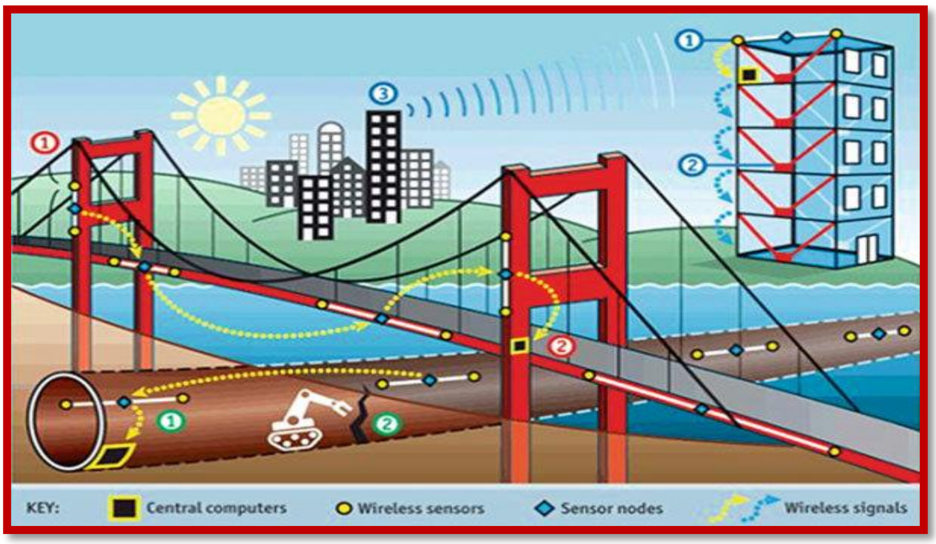

Figure 1.5: Area monitoring **of WSN**

I.7.3. Health applications

Due to accurate and highly efficient sensors that allow monitoring of human vital organs, it has helped a lot in the field of medicine. In monitoring, the development of most human diseases, the diagnosis of diseases and the detection of dangerous epidemics, with the help of special mission sensors And more than that, monitoring the patient's position, such as the crying of the infant, for example, or the fall from the bed for the handicapped person. **[19]**

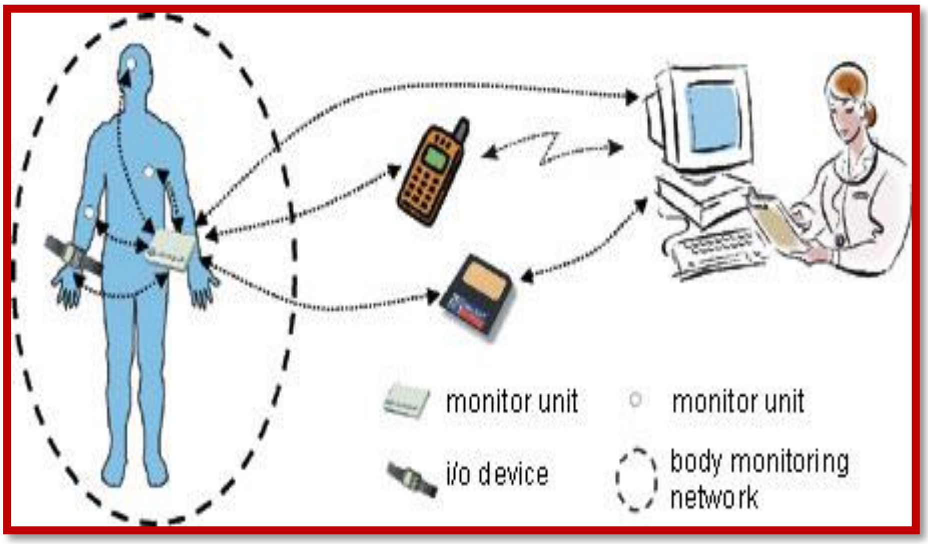

Figure 1.6: Health application **of WSN**

I.7.4. Environmental applications

Applications of wireless sensors allow for the control of various environmental parameters, for example, the detection of fires in forests due to thermal sensors, which helps to speed up the process of putting out fires and reduce losses. As for the chemical field, the sensors helped a lot in knowing the degree of pure air pollution. And that sends alerts in the event that there is a leakage of toxic substances into the atmosphere. In addition, the role of sensors has been crucial in the development of modern agriculture in the processes of irrigation, soil dryness, and climate change, which makes it easier for engineers to provide the necessary conditions for obtaining abundant and good products **[19]**.

Figure 1.7: Environmental applications

I.8. Types of Wireless Sensor Networks

The differences in the environment and geography have contributed to the diversity of sensor networks, which are used in various areas of life. Despite the **WSNs** challenges, they are still used in many fields. There are five types of wireless sensor networks: Terrestrial **WSN**, Underground **WSN**, Underwater **WSN**, Multi-media **WSN**, and Mobile **WSN**.

I.8.1. **Terrestrial WSNs**

For the deployment of sensors in the target area, nodes are distributed either by planes at random or in pre-planned ways, for example, a three-dimensional placement. Effective communication between the nodes and the base station must be considered. This network is characterized by the ability to supply the nodes with solar cells to recharge their batteries, which increases the power of the system. There are other methods that help to conserve energy, such as choosing the best routing for multi-hops, collecting data, implementing a short transmission system, etc **[20]**.

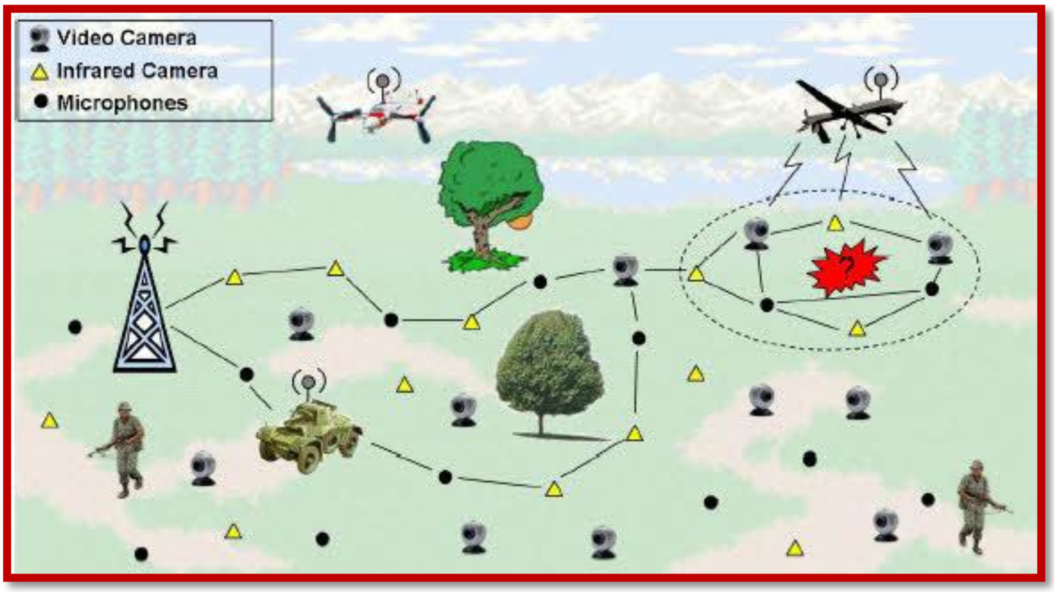

Figure 1.8: Terrestrial WSNs.

I.8.2. Underwater WSNs

To study any underwater phenomenon, sensor nodes are deployed in the water. Compare to terrestrial wireless sensor networks underwater wireless sensor networks use a small number of sensor nodes due to their high cost. It collects data from sensors by using autonomous vehicles. The communication process is done by sound waves. Environmental conditions, limited bandwidth, and limited batteries that aren't charged or replaced all affect the quality of the network result **[15]**.

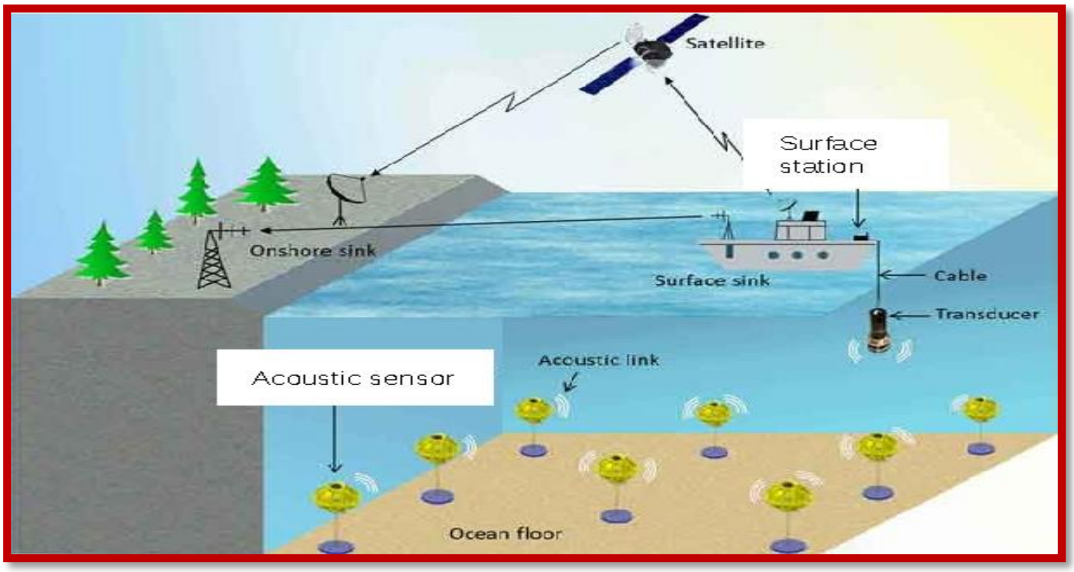

Figure 1.9: Underwater WSNs.

I.8.3. Underground WSNs

Underground wireless sensor networks have been used for several purposes. It has helped to reduce and control the risks that may affect the mines, thus saving on operating expenses. Several sensor nodes are deployed underground at different levels. Each node is able to communicate with more than one node. Therefore, a good distribution of nodes increases the transmission efficiency and security of the network. It is still suffering from the cost of transferring data from the nodes to the server **[20]**.

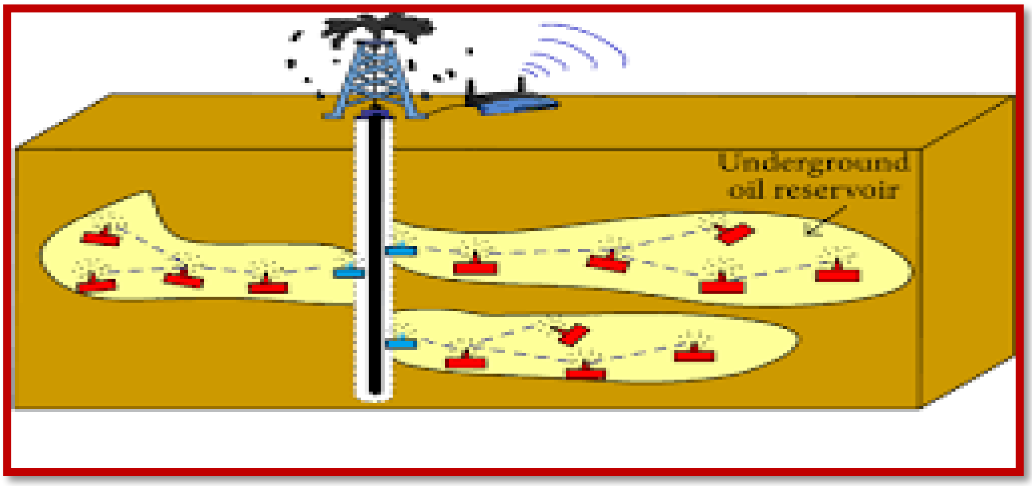

Figure 1.10: Underground WSNs.

I.8.4. Mobile WSNs

Mobile wireless sensor networks are a very effective system for area monitoring or studying phenomena. Nodes in this network are equipped with platforms that allow them to move after the distribution process. Mobile wireless sensor networks help a lot in rugged and dangerous areas. It also has a good coverage area. Taking into account the limitations and improvements in technologies, mobile networks are always evolving **[21]**.

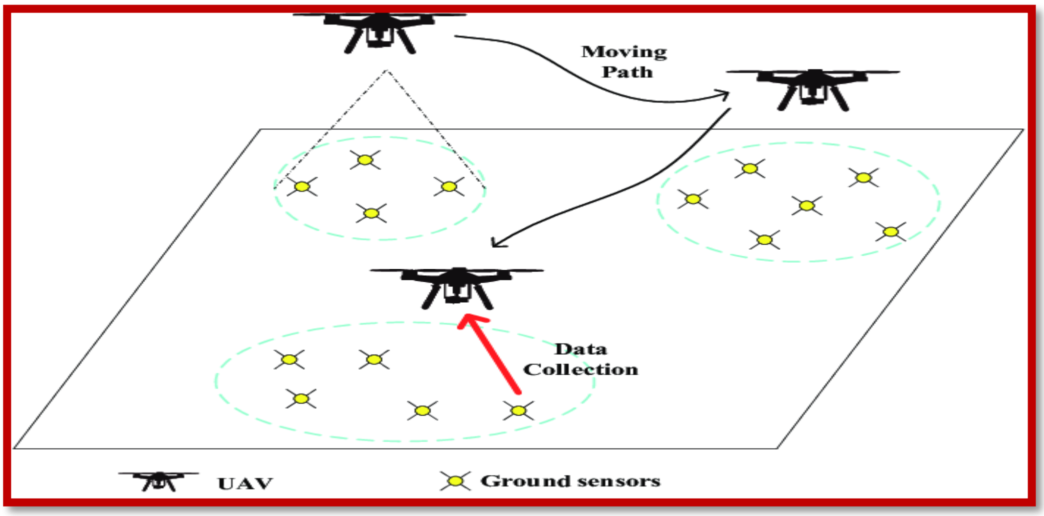

Figure 1.11: Mobile WSNs.

I.8.5. Multimedia WSNs

Wireless multimedia sensor networks have been used in many fields, such as monitoring systems, the environment, and others. Technology development helped these networks increase data efficiency and accuracy. Through this network, images are captured in real time, as well as audio and video. WSN multimedia can analyze data in more detail, and it has been used to monitor roads, health systems, and traffic. Energy is consumed more. This limitation must be overcome by optimizing the algorithms **[22]**.

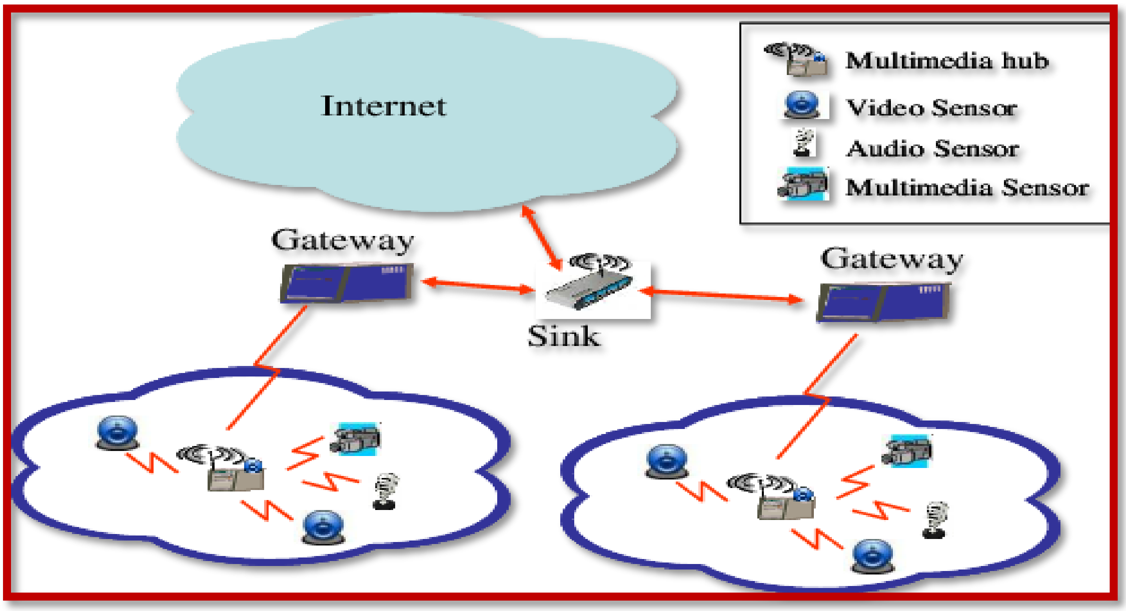

Figure 1.12: Multimedia WSNs.

I.9. Conclusion

Wireless sensor networks have made great progress in various fields. They can hardly be dispensed with in light of this great technological development. In scientific research or even in everyday applications. Despite all the limitations they face, wireless sensor networks have made several improvements in their application area.

In the next chapter, we will discuss the main hierarchical routing protocol in wireless sensor networks.

CHAPTER II:

HIERCHICAL ROUTING PROTOCOLS IN WSNs

II.1. Background

The main components of wireless sensor networks are the sensor nodes. The limited capacity of the node batteries creates a major problem and a challenge for this type of wireless network. Several solutions have been proposed to save sensor power. Among the proposed solutions are designing protocols that help extend the life time of the nodes, thus increasing the life of the network.

In this chapter, we will look at a tutorial on routing protocols used in wireless sensor networks.

II.2. Classification of Routing Protocols in WSN

Regardless of the challenges facing wireless sensor networks, there are many protocols that have greatly contributed to the improvement of WSNs. These protocols are categorized according to certain criteria and the services they provide.

In the diagram below, we'll show some of the commonly used protocols **[24]**.

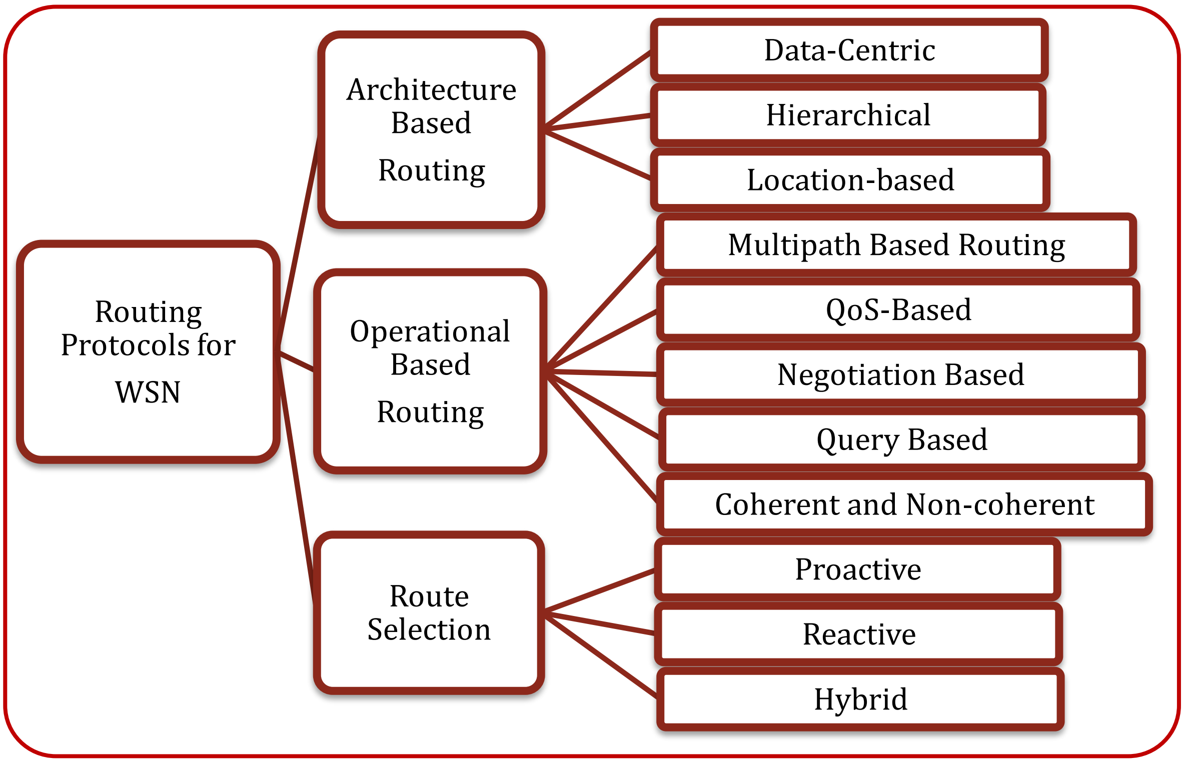

Figure 2.1: WSNs Routing Protocols [24].

II.2.1. Architecture Based Routing

The figure shows the classification of some of the routing protocols for wireless sensor networks. The protocols are classified according to their mechanisms. We will discuss each part to understand the role of each protocol separately **[25]**.

II.2.1.1. Data-Centric (DC)

Data-centric routing is an alternative solution to the problem of identifying sensor locations. Hub routing is a query mechanism that helps solve some of WSN's limitations **[25].** There are many protocols of Data-centric routing, for example:

- **ACQUIRE** (ACtiveQUery forwarding In sensoR nEtworks) considers a network as a database distribution. It performs partial query analysis. As well as the possibility of solving complex inquiries, however, it suffers from the problem of energy consumption **[25]**.

- The **RUGGED** (RoUting on finGerprint Gradient in sEnsor networks) protocol is also a type of data-centric routing protocol. It selects a node at random in order to direct the query to the event. Taking into account the natural hierarchy of information, event fingerprints, and action probability. The **RUGGED** protocol is rather efficient, although it consumes energy **[25]**.

II.2.1.2. Hierarchical (Cluster-Based)

Hierarchical protocols have a special structure. The network is divided into groups. Each group is headed by a node called the Cluster Head (CH). CHs are set using specific routing protocols. Each protocol has its own strategy for setting the CH. Each CH takes over the task of communicating either between other CHs or with the base station (BS). As represented in **Figure 2.2**.

One of the most effective ways to increase scalability and network lifetime is through hierarchical routing protocols. There are many hierarchical routing protocols, for example: **LEACH**, **LEACH-C**, **PEGASIS**, **HEED**, and **TEEN**, etc **[25]**.

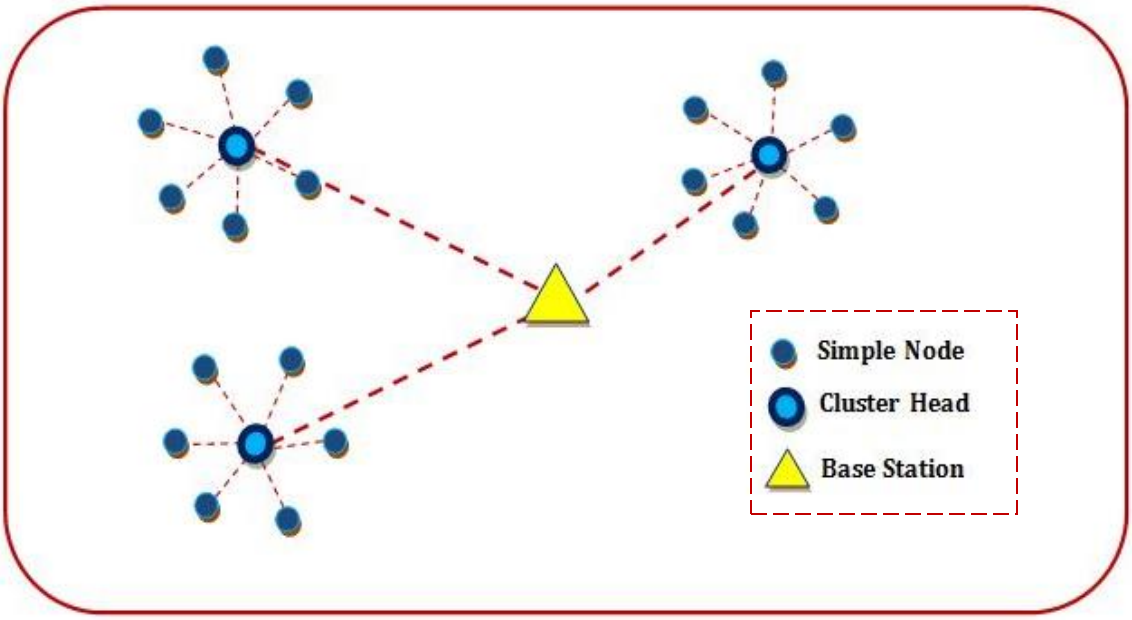

Figure 2.2: Hierarchical routing model [25].

II.2.1.3. Location-based

Via GPS or radio signal strength, the perceived location is used to access location information. This makes it easier to forward queries again. In addition, it reduces communication processes in order to save energy. **[25],** these protocols contain:

- **Min-hop routing protocol:** It depends on the location. Through the initialization and routing phases, it selects the packets that consume the least energy to be routed. With the selection of the shortest paths possible, by creating routing tables for the optimal paths. However, it causes the rapid death of the nodes of those tracks due to their frequent use. **[25]**

- **Path Energy Weight (PEW):** It is also a location-based protocol. It determines the overall power level of the network. It maintains the energy balance in the network through the methods used in rerouting, according to path energy **[25]**.

II.2.2. Operational Based Routing

Routing protocols differ according to the functionality they provide. Each protocol performs specific operations in order to realize the network requirements **[25]**.

II.2.2.1. Multipath-Based Routing

Some routing protocols have multiple data delivery paths. Due to the possibility of path failure, the network must provide alternative paths. These protocols have high reliability. However, it is energy-consuming. There are different types of multipath protocols, such as: Directed Diffusion (DD) **[25]**.

II.2.2.2. Qos-Based

Accuracy of information is certainly a primary goal. However, the energy consumed from the implementation of this protocol must be taken into account. Energy consumption is essential to increasing the quality of service. Of course, taking into account bandwidth and delay, examples: **SAR**, **SPEED [25]**.

II.2.2.3. Negotiation Based

The redundancy in the transmitted data is a concern for the network. Sending redundant data consumes a lot of power and reduces the life of the network. There are protocols that organize and help solve the problem of data redundancy, like SPIN and Sequential Assignment Routing (SAR). As a result, this data is restricted **[25]**.

II.2.2.4. Query-Based

This protocol allows nodes to send a query to find out about a specific event or provide an explanation for it. If the event path is found, the query routing is direct. The query is repeated if the event path is not found. For example we find: Rumor Routing (**RR**) **[27].**

II.2.2.5. Non-coherent and Coherent Data-Processing Based

Through the routing of non-coherent data processing. Locally and before transmission, the raw data is processed by the contract. For further processing, the processing nodes (aggregators) do this. In terms of loading data, it has somewhat lower loading traffic. After the processing step, the data is transferred to the aggregators.

In the processing phase, the duplicates and time stamps are canceled. However, it is not energy efficient. To conserve network energy, coherent data processing is often used, because it is characterized by a long flow of data. By choosing the optimal paths, there will be high energy savings.

There are two important algorithms for each processing step. for incoherent processors, a SWE (Single Winner Algorithm). And for coherent treatments, there is the MWE (Multiple Winner Algorithm) **[28]**.

II.2.3. Route Selection

Wireless sensor networks can choose from three types of routing protocol classification. There are pro-active and re-active. From the combination of the previous two types, we get the third type, which is the hybrid protocol. Of course, each of them has its own effects on the network. We will discuss that later **[27]**.

II.2.3.1. Pro-active Routing Protocols

They are protocols similar to wired networks in their functions; they are known as the table-driven protocols. The basis for constructing the contract routing schedule is the periodic routing of information. In order to find the destination nodes, they must maintain at least one table. The route information is stored in these tables. To maintain network consistency, whatever the network structure changes, nodes respond to these changes by constantly updating. The discovery of the paths in these protocols is already known due to the constant updates in the network. One of the obstacles facing this technology is the high consumption of battery power and the huge amount of bandwidth. There are many table-driven protocols, for example:

- **WRP** (**Wireless Routing Protocol**): It is based on the Bellman algorithm and uses several tables to maintain the accuracy of the information in addition to the update messages. However, it requires a large amount of energy and memory to process in the event of a link failure. It is not effective for mobile networks because it is not scalable**[27].**

II.2.3.2. Re-active Routing Protocols

Re-active routing protocol: It searches for the path from the sender to the receiver only when needed. Also known as the On-demand Protocol. There are good and bad effects of this protocol depending on the type of protocol used. We mention, for example, Temporarily Ordered Routing Algorithm **(TORA)**: Adaptive, Distributive, Energy-saving, Data Forwarding is downward. It does not consume much power when changing the network topology, which reduces communication difficulties. Unfortunately, it does not have a multicast advantage **[27]**.

II.2.3.3. Hybrid routing protocols

Hybrid protocols are a combination of the good effects of both reactive and proactive routing protocols. Taking into account two basic rules: first, in the wireless sensor network, nodes within a certain distance communicate with each other; the second rule is to take into account the change in the structure adjacent to a group of nodes. The nodes on the sides are not affected by the failure of the sink, and vice versa for the nearest nodes.

As a hybrid protocol, we have ZRP (Zone Routing Protocol), which divides the whole network into zones that proactively save the topology. The structure is preserved in data exchange. To access the contract, a query is sent to all the private nodes in that path. Each node that loses the link state sends a notification, making it easier for neighboring nodes to know the path between themselves in that region. What distinguishes the hybrid protocol is the routing traffic, which is relatively less compared to the interactive and proactive protocols. Thanks to its use of little data in guidance. The high delays that cause the network to cost more are what restrict this protocol the most **[27]**.

II.3. Description of hierarchical routing protocols

II.3.1. Low Energy Adaptive Clustering Hierarchy (LEACH)

In the **LEACH** protocol, in order to provide more power periodically, each node is a header for a cluster. This protocol has a special mechanism for electing the cluster head through successive rounds. Each round uses the number of nodes that were not elected in the previous round as a cluster head, as well as the percentage of each cluster head in a cluster. Each round of the protocol goes through two phases: the preparation phase and the steady state phase, which is longer than the previous one **[29]**.

- **Set-up phase:**

In the setup phase, a **TDMA** table is formed by the cluster header in its group for transmissions. **TDMA** scheduling allows each node to close its interface when not in use. The main element in routing and data transmission to the base station is the cluster head. The cluster head collects data from nodes near it and deletes all duplicates.

To filter a node as a cluster head, nodes choose a number between 1 and 0. The node is chosen as the cluster head if the number is less than the result of the following equation.

$$\mathbf{T(n)} = \begin{cases} \dfrac{\mathbf{p}}{\mathbf{1 - p * \left(r * mod\left(\frac{1}{p}\right)\right)}} & \mathbf{If\ \ n\ \in G} \\ \mathbf{0} & Otherwise \end{cases}$$

Where:

P = desired percentage of cluster head.

r = current round

G = the set of nodes which did not become cluster head in last $\frac{1}{p}$ rounds.

After the cluster heads are selected, they are announced using the CSMA MAC protocol. The signal strength received from the announcement is the main factor for joining the remaining nodes to the cluster head closest to it. It takes into account the network topology and the computation costs for the connection. In order to end messages to a CH, TDMA is applied to all nodes of that CH. Moreover, this table applies to CH towards BS. These steps follow the steady-state phase **[30].**

- **Steady-state phase**

Using the TDMA table, the data collected by the nodes is sent to the CH, and the latter sends it to the base station. The transmission process takes place within the specified time period for each node. The node is either in the sending state during its specified period, or it is in a sleeping state. Each CH collects the data and sends it to BS. Before sending, the CH must sense the state of the channel. If it is unavailable, CH waits. Or the data is transmitted by another channel to the BS. **[30]**

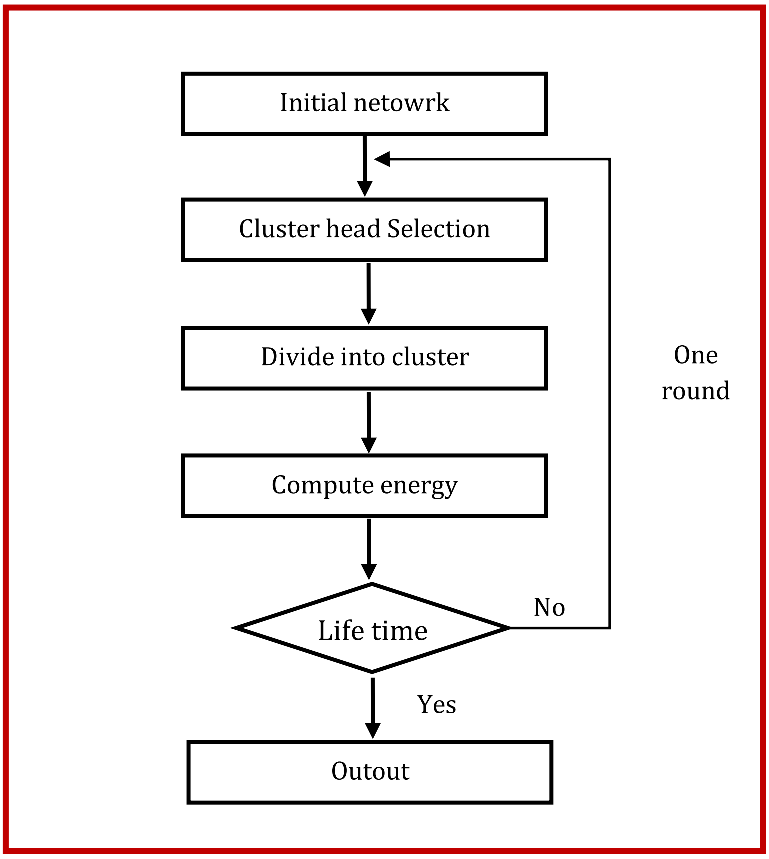

Figure 2.3: Flowchart of LEACH protocol [31].

Advantages: [32]

- The data aggregation from the nodes by the cluster heads helps a lot in reducing congestion in the network

- Because the important thing is to reduce power consumption, the one-hop feature of routing from sensors to the cluster head supports this.
- Extend the network lifetime.
- It does not require information about the nodes location to create the clusters.
- Independence and no needed for control information from the main station. It is not necessary to know all about the network

Disadvantages: [32]

Definitely, the Leech Protocol has drawbacks to its effectiveness. Among its disadvantages are:

- The number of cluster heads is unknown in this protocol and cannot be predetermined.
- Aggregated data is lost if the cluster head dies.
- Random division causes groups to be uneven. This may cause a waste of energy.

II.3.2. Low Energy Adaptive Clustering Hierarchy Centralized (LEACH-C) Protocol

The LEACH-C and LEACH protocols are very similar. The difference being the clusters' formation. LEACH-C selects the cluster head using a centralized cluster algorithm. It is the same as LEACH in the setup phase. They differ in the stable phase. Each node sends its position information (e.g., using GPS) and its power level to the base station, thus being aware of the whole network. After the election of the cluster heads at the base station, this decision is sent to the nodes. All nodes have the same CHs that are sent to them from the base station. In addition, filter the identifiers of the cluster heads. Cluster heads use the TDMA table to aggregate data from member nodes. The energy of the nodes is determined using a deterministic threshold algorithm. It also determines the state of each node in the last cycle, whether it was the head of a block or not. However, it does not specify the position of the CHs nor their number. Due to the good distribution of cluster heads, centralized control helps to improve the production of clusters **[33]**.

II.3.3. Hybrid Energy Efficient Distributed Clustering Protocol (HEED)

The HEED protocol is an extension of LEACH. The goal is to balance energy. So to select clusters, HEED uses node degree, density, or residual energy. It is characterized by multiple hops by adjusting the power of the transmitter between clusters. The HEED protocol aims to attain four goals, which are:

- This balances energy consumption, thus delaying node death.
- The number of iterations is fixed, in which the assembly process must be completed.
- Control expenses can be reduced.
- A well-balanced distribution of CHs produced

Based on two parameters, CHs are selected periodically. The first is the main and is the remaining power for each sensor. The second is the secondary, which allows to calculate the cost of communication. **HEED** is energy efficient. The random selection of **CHs** may cause some nodes to die prematurely **[34]**.

II.3.4. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN)

TEEN is a protocol that groups nodes hierarchically, with each cluster headed by a head. Nodes in each set send their data to CH. Each CH at a lower level sends the collected data to the next above until the BS is reached. The network architecture of this protocol is based on hierarchical clustering. Because the TEEN protocol helps to control the accuracy of the data, the balance of power consumption and the response time, it is effective in using it for applications. Its main defect is that thresholds must be reached in order to get the data **[34].**

II.4. Conclusion

In this chapter, we discussed the types of routing protocols for wireless sensor networks. The main restriction on these networks is their limited battery life. The optimum choice of the type of protocol largely solves the problem of high energy consumption. Each protocol has advantages and disadvantages, but the scope of use and the size of the network help a lot in determining the most appropriate type of protocol. Thus, getting better results.

CHAPTER III:

The Proposed Approach

III.1. Background

Researchers solving optimization problems have focused a lot on algorithms inspired by biology. These algorithms have been widely used in wireless sensor networks for clustering. Among these algorithms, we mention the Firefly algorithm. It is a developmental algorithm inspired by the biological evolution of the firefly insect. In this chapter, we will first discuss the definition of the Firefly algorithm from the biological aspect and its mechanism. Then, we introduce our hybrid protocol, which is a combination of the firefly algorithm and the simulated annealing algorithm.

III.2. Firefly overview

III.2.1. Biological foundations of Firefly:

They are winged insects of the family of Lampyridae and have the ability to fly. These fireflies produce a faint light glow in order to attract each other. Light is produced inside the bodies of these beetles near the surface of their skin. This is thanks to the chemical reaction known as bioluminescence. This ray is used to attract partners in these societies. The firefly periodically releases energy in the form of light **[35]**.

Figure 3.1: Firefly insect.

III.2.2. Firefly Algorithm (FA):

In 2008, Xin-She Yang developed the firefly algorithm. **FA** is one of the most popular algorithms being used to solve global optimization problems **[36].** By improving some of the properties of Firefly, we get a developed algorithm inspired by the Firefly community. Using three basic rules, we simplify and describe the mechanism of the Firefly algorithm:

Firstly, regardless of the sex of the firefly, all fireflies are attracted to each other (Uni-sex).

Secondly, the attraction is proportional to the brightness of the firefly. Each firefly with a lower brightness is attracted to the brighter firefly. In addition, the greater the distance between each pair of fireflies, the lower the brightness and, therefore, the attraction between them decreases. And vice versa. The firefly moves randomly if there is no difference in brightness.

Thirdly, the objective function affects the brightness of the firefly. Sometimes, the brightness and the value of the objective function are proportional to the maximization problem. In a similar way to the fitness function in a genetic algorithm, other shapes of brightness can be defined. **[37]**

$Objective\ function\ f(X), \qquad X = (x_1, \dots, x_d)^T$
$Generate\ initial\ population\ of\ fireflies\ X_i (i = 1,2, \dots, n)$
$Light\ intensity\ I_i\ at\ X_i\ is\ determined\ by\ f(X_i)$
$Define\ light\ absorption\ coefficient\ \boldsymbol{\gamma}$
$\textbf{while}\ (t < MaxGeneration)$
$\quad \textbf{for}\ i = 1{:}n \quad all\ n\ fireflies$
$\quad\quad \textbf{for}\ j = 1{:}i \quad all\ n\ fireflies$
$\quad\quad\quad \textbf{if}\ (I_j > I_i), Move\ firfly\ i\ towards\ j\ in\ d - dimension;\ \textbf{end if}$
$\quad\quad\quad Attractiveness\ varies\ with\ distance\ r\ via\ \exp[-\gamma r]$
$\quad\quad\quad Evaluate\ new\ solusions\ and\ update\ light\ intensity$
$\quad\quad \textbf{end for}\ j$
$\quad \textbf{end for}\ i$
$\quad Rank\ the\ fireflies\ and\ find\ the\ current\ best$
$\textbf{end while}$
$Postprocess\ results\ and\ visualization$

Figure 3.2: Pseudo code of the firefly algorithm (FA) [38].

III.2.3. The principle concepts of the Firefly algorithm

- In the firefly algorithm, fireflies are initialized so that each firefly represents a solution.

- The number of solutions is determined by the size of the population. The search space aims to direct the search towards the best solutions.

- In the following, each firefly is evaluated by its light intensity. The luminosity and attractiveness of each firefly in each iterative stage are also calculated.

- The intensity of the light and the distance between the fireflies determine the attraction function.

- Through the movement function, the firefly's movement is determined. Using tugging, current position, and random walk, after comparing all fireflies in brightness intensity, the position of each firefly is determined according to the other. Through the basics of fireflies and their neighbours.

- Finally, evaluate the new firefly and determine the intensity of its light. The repeating of the firefly comparison stops when the termination conditions are met **[38]**.

III.2.4. Light intensity and attractiveness [39] [40]

In order to apply the firefly algorithm, we need to respect two essential things. The first one is the variation of light intensity, and the second is the formulation of attractiveness. As we said, the attractiveness of fireflies is proportional to their brightness. The brightness is also associated with the objective function.

Conversely, the relativity of attractiveness **β** should be judged by other fireflies or seen in the beholder's eye.

As a result, the attractiveness will vary depending on $\boldsymbol{r_{ij}}$ the distance between firefly **i** and firefly **j**. Furthermore, we should allow the attractiveness to change depending on the degree of absorption.

Extremely, simply, according to the inverse square law, light intensity is changing. We have

$$I(r) = \frac{I_s}{r^2} \qquad (3.1)$$

I_s : represents the intensity at the source. The light intensity $\beta_0$varies with the distance **r** having a fixed light absorption coefficient γ i.e.

$$I = I_0 . e^{-\gamma r} \qquad (3.2)$$

I_0 : Is the initial light intensity. It is possible that the combined effect of both absorptions can be approximated by the inverse square law in order not to face the singularity problem at **r = 0** in($\frac{I_s}{r^2}$)**.** As the following Gaussian form:

$$I(r) = I_0 e^{-\gamma r^2} \qquad (3.3)$$

Firefly's attractiveness **β** is proportional to the light intensity seen by adjacent fireflies. It can be defined as:

$$\beta = \beta_0 e^{-\gamma r^2} \qquad (3.4)$$

β_0 is the attractiveness at **r = 0**. To simplify, the above function can be approximated as:

$$\beta = \frac{\beta_0}{(1+\gamma r^2)} \qquad (3.5)$$

The distance between two fireflies is calculated using Cartesian distance method:

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \qquad (3.6)$$

Firefly i is attracted to brighter firefly **j** and its movement is determined by:

$$\Delta x_i = \beta_0 e^{\gamma r_{ij}^2} + (x_j^t + x_i^t) + \alpha \varepsilon_i \qquad (3.7)$$

III.3. Simulated Annealing

III.3.1. Simulated Annealing Overview

Simulated annealing is a popular algorithm among many metaheuristic algorithms. It is based on trajectories for global optimization. **SA** is searching randomly. It is similar to the **annealing process** in materials processing, which occurs when a metal cools and freezes into a crystalline state with the least amount of energy and larger crystal sizes to reduce defects in metallic structures. The annealing schedule is the careful control of temperature and its cooling rate, which is an essential step in the annealing process. Since its discovery by the scientist Kirkpatrick et al., the **SA** algorithm has been used in a variety of optimization fields.

Simulated annealing starts with an essential solution, and then it finds a neighboring answer to this solution. If there is no improvement in the objective function, it will be accepted with a condition that is the probability **P**. The difference between the neighbor's response and the objective function of the current response is **ΔE.**

The temperature **T** is lowered very slowly with every repetition that is implemented. In order to increase the possibility of receiving bad responses, it has to keep the temperature extremely high in the early steps. In other cases, when the temperature is decreased gradually, the likelihood of receiving a bad response decreases. Thus, this algorithm converges to a good solution. This method avoids being confined to a locally optimal position. As a result, the system eventually moves toward a lower energy state. Indeed, a neighbor **x'** in the neighborhood of **x**, **N (x)**, is selected at each level of the solution **x** with a fitness function of **f(x)**. The difference between the objective functions in each step is as follows:

$$\Delta = \boldsymbol{f(x) - (x')} \qquad \textbf{(3.8)}$$

For computing x, we use the equation below, in general, the Boltzmann distribution:

$$\boldsymbol{P_s = \exp\left(-\frac{\Delta}{T}\right)} \ \textbf{OR} \ \boldsymbol{P_{\Delta E,T} = \exp\left(-\frac{\Delta}{KT}\right)} \ \textbf{OR} \ \boldsymbol{P_x = \exp\left(-\frac{\Delta f(x)}{KT}\right)} \qquad \textbf{(3.9)}$$

K: is Boltzmann's constant.

Δ: is the difference between solution Energy and neighbor Energy.

The probability of accepting a random number $r \in (0,1)$ is then compared, and if P>r, x' is accepted. T is the temperature that cooling schema regulates. The simulated annealing algorithm, on the other hand, includes features such as a primary temperature, a procedure for changing the temperature, and a cooling scheme until the process is complete **[40] [41]**.

Physical System	Optimisation Problem
System states	Solutions
Molecular positions	Decision variables
Energy	Objective function
Ground state	Global optimal solution
Metastable state	Local optimum
Rapid quenching	Local search
Temperature	Control parameter T
Careful annealing	Simulated annealing

Table 3.1: Analogy of the Physical System and the Optimization Problem [42].

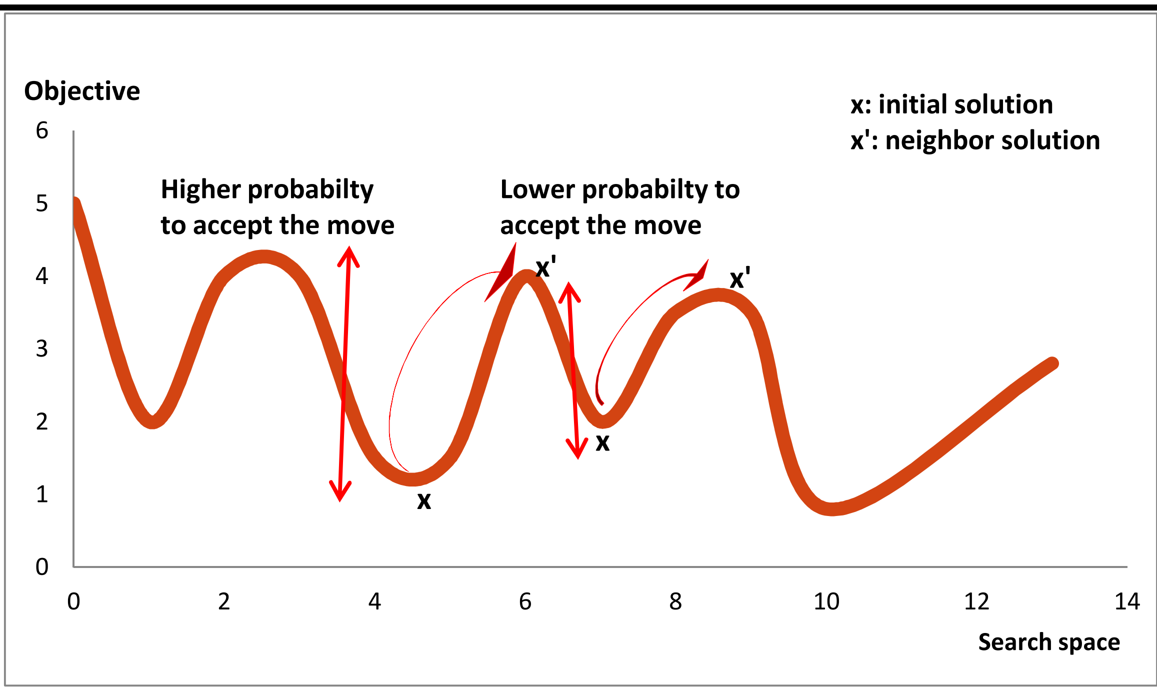

Figure 3.4: Simulated annealing escaping from local optima [42].

From the above figure, we conclude that the higher the temperature, the greater the chance of accepting the worst move. The lower the increase in the objective function at a given temperature, the higher the probability of accepting the move. It is always acceptable to make a better decision **[42].**

III.3.2. General Description of Simulated Annealing [43]

In the following steps, there is the **SA** standard optimization.

a. Generate an initial solution

For the system to be optimized, select a random initial solution. After that, calculate the objective function.

b. Initialize the temperature

The initial temperature T value is a critical parameter for a successful **SA** implementation. If the value is too high, more reduction is required to reach convergence. The search process may be less than perfect if the points are too small, and the global optimum may be exceeded.

c. Select a new solution in the neighborhood of the current solution

A new solution $x_0 + x'$ is accepted as a new recent solution depending on T. The objective functions for $x_0 + x'$ and x_0 are represented by $f(x_0 + x')$ and $f(x_0)$, respectively.

d. Evaluation a new solution

If $\boldsymbol{f}(\boldsymbol{x_0} + \boldsymbol{x}') \leq \boldsymbol{f}(\boldsymbol{x_0})$, then $\boldsymbol{x_0} + \boldsymbol{x}'$ is accepted and it replaces $\boldsymbol{x_0}$, update the existing optimal solution and go to step 6. On the other hand, if $\boldsymbol{f}(\boldsymbol{x_0} + \boldsymbol{x}') > \boldsymbol{f}(\boldsymbol{x_0})$, $\boldsymbol{x_0} + \boldsymbol{x}'$ can also be accepted with a probability base on equation of Boltzmann distribution **(3.9)**

e. Decrease the temperature periodically

Temperature T decreases over the course of the process search; as a result, the probability of accepting deteriorating moves is high at the start of the search and gradually decreases.

g. Repeat step 2 – 6 until a stopping criterion is met

When the termination criterion is met, the computation is completed. Otherwise, steps 2 through 6 are repeated.

III.3.3. Pseudo code of Simulated Annealing

1. *Initialize the system configuration.*
Randomize $x(0)$.
2. *Initialize* T *with a large value.*
3. ***Repeat***:
a. ***Repeat***:
i. *Apply random perturbations to the state* $x = x + \Delta x$.
ii. *Evaluate* $\Delta E(x) = E(x + \Delta x) - E(x)$:
if $\Delta E(x) < 0$, *Keep the new state;*
otherwise, *accept the new state with probabilit* $\boldsymbol{P} = \boldsymbol{e}^{-\frac{\Delta E}{T}}$.
Until *the number of accepted transitions is below a threshold level.*
b. *Set* $T = T - \Delta T$.
until T *is small enough.*

Figure 3.4: Pseudo-code for Simulated annealing algorithm [42].

III.4. Our proposed protocol HRP-FASA (Hybrid routing protocol based on firefly and Simulated Annealing algorithms)

There are various hypotheses which we have posed, for determining our proposed protocol.

First, the energy of each node is limited, and also the nodes are homogenous. **Second,** energy consumption is required by sending and receiving messages. **Third, BS** fully covers the area of sensing. **Forth, the sensor** network is not dynamic (the topology of the network is static; it doesn't change during the execution).

In the **table (3.2)** below, there are the meanings related to the proposed algorithm (**HRP-FASA**) of the principal attributes.

	Firefly & Simulated annealing	HRP-FASA
Firefly	A firefly	A sensor node
	Solution	Each CH in the cluster
	Cost function	f_i (for a sensor node)
	Temperature	TN=The overall residual energy

Table 3.2: The profile of (HRP-FASA).

The general flowchart of our proposed protocol is in the figure below:

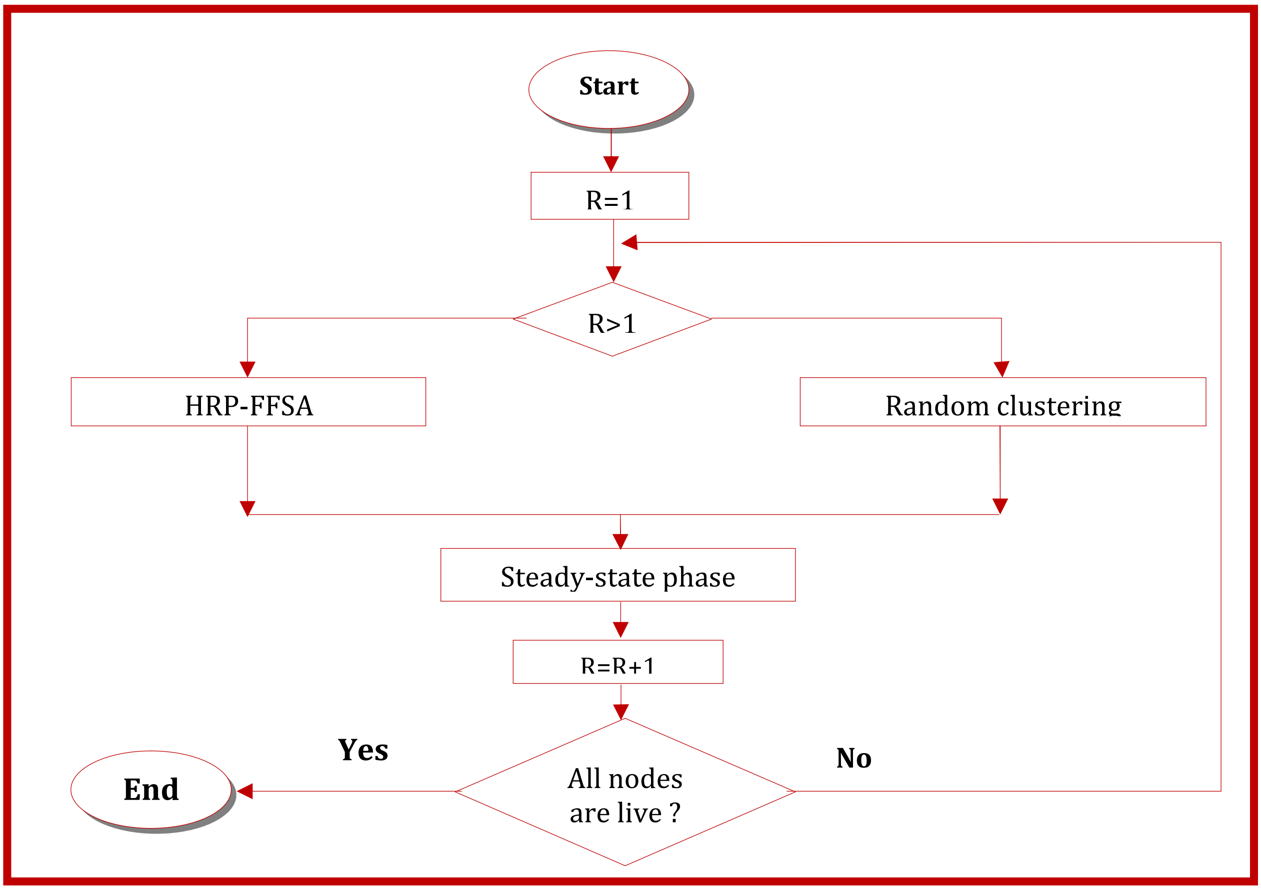

Figure 3.5: General flowchart of HRP-FFSA protocol.

The network topology of our proposed protocol starts with Leach clustering, while for the next rounds we used the hybrid routing protocol (Firefly-Simulated Annealing), which we have been previously explained.

Our proposed protocol is divided into two main phases, which are the set-up phase and the steady-state phase.

III.4.1. Set-up phase

The main issue of our proposed approach is implementing **HRP-FFSA** as novel hybrid energy-efficient routing protocol based on firefly and simulated annealing algorithms. Our proposed protocol aims at selecting the best cluster heads that can minimize the multi-objective cost function involved in this study.

HRP-FFSA is a centralized algorithm that runs in rounds and implemented at the **BS**. Each round is divided into two principal phases, a setup phase in which the best k cluster heads are selected and clusters are formed, followed by a steady state phase in which data are collected and sent to the **BS.**

HRP-FFSA is naturally inspired from the behaviors of fireflies combined with simulated annealing algorithm, where we assume that the **WSN** comprises ***S*** sensors (fireflies). Each sensor represents a solution that can acts as candidate or final CH according to its cost value ***f(s)*** that is proportional to the brightness of the firefly it represents.

For a network with ***S*** nodes and ***k*** clusters, where each cluster has ***m*** members. Clusters are selected as follows:

At the first round (R = 1) cluster heads are selected randomly.

Starting from the second round (**R > 1**), cost-based substituting is involved, where each firefly representing a **CH** node searches among its members for one of eligible cluster heads candidates with the higher intensity value (cost function) for passing the head's role to it, and this by moving to it using Eq. **(3.7).** If it does not exist, the firefly uses the simulated annealing for either choosing the **CH** with lower intensity value or moves randomly in the search space.

In our proposed scheme, **k** cluster heads are chosen on the basis of a multi-objective cost function that takes into consideration three features including the residual energy of nodes, their distance to the base station and the intra-cluster distances. The cost function involved for the optimal clustering in **HRP-FFSA** is defined as the sum of the weighted sub-objective functions involved in this research as follows:

$$\boldsymbol{cost} = \boldsymbol{Maximize}\{\boldsymbol{\beta_1} * \boldsymbol{f_1} + \boldsymbol{\beta_2} * \boldsymbol{f_2}\} \qquad (3.10)$$

Where β_1 and β_2 are constant that are used for weighting the value of each sub-cost terms f_1 *and* f_2 respectively and $\beta_1 + \beta_2 = 1$.

The sub-cost function f_1 is involved to guarantee that the selected **CHs** are those with maximum remaining energy level as the following:

$$\boldsymbol{f_1} = \frac{E_{res}(CH_k)}{\sum_{j=1,2,\dots,M} E_{rem}(m_{k,j})} \qquad k = 1, 2, \dots, K \qquad (3.11)$$

Where $E_{res}(CH_k)$ and $E_{rem}(m_{i,j})$ are the remaining energies of a given CH_k and its members m_j respectively. The higher its remaining energy is, the more the node has the chance to act as a final CH. Since CHs transmit the aggregated data to the BS, it is highly recommended that the selected CHs have high energy levels compared to other nodes.

The second sub-cost function f_2 is utilized to minimize the distance between the selected CHs and the base station. It can be formulated as shown in the following equation:

$$\boldsymbol{f_2} = \frac{\underset{i=1,2,\dots,K}{dist}(CH_k, BS)}{\sum_{j=1,2,\dots,M} dist(m_{k,j}, BS)} \qquad (3.12)$$

Where $dist(CH_k, BS)$ denotes the distance between the CH_k and the **BS**, $dist(m_{i,j}, BS)$ denotes the distance between a given node j assigned to a CH_k and the base station. With minimum f_2 value, **CHs** will consume less energy by forwarding huge amount of data packets for short distances.

Algorithm 3: ***HRP-FFSA Algorithm***

```
γ : Coefficient of absorption;
I_i : Light intensity;
E_rem: Remaining energy node;
P_CH: percentage of cluster heads;
Max_Round: Maximum number of Rounds;
Max_Gen: Maximum number of generations;
T: Temperature ( Node's residual energy);
Begin
   Deploy N nodes randomly;
   Initialize fireflies s_i (i=1,2 ,..., n);
   Attribute one firefly to each node;
   Identify the cost function of each firefly as f(s_i );
   Define the light intensity of firefly i at s_i as I_i according to the cost function f(s_i );
      Set Round =1;
         Choose 'k' CHs randomly according to P_CH;
      Set Round =2;
      Set Gen =1;
      While Round < Max_Round
         While (Gen <Max_Gen)
            For i = 1: K
               For j = 1:M
                  Calculate f(s_i );
                  Calculate f(s_j );
                  If I_j > I_i
                     Move S_i towards S_j using eq. 3.7;
                     Set the nearest node to the new position as final CH.
                     Else
                        Calculate the acceptance value P(SA) P = e^(-Δf/T) ;
                        If P> rand( 0, 1)
                           Move S_i towards S_j using eq. 3.7;
                           Set the nearest node to the new position as final CH;
                           Else
                              Move S_i randomly
                        End if
                  End if
                  Firefly attractiveness is varied with cost function;
               End For j
            End For i
            Gen= Gen+1;
         End While
         Round=Round+1;
      End While
   Clusters formation and data aggregation;
End
```

Figure 3.6: Pseudo code of the proposed ***HRP-FFSA*** algorithm.

III.4.1.1. Cluster formation

In the **first round**, all nodes send messages to the base station. The message contains the **ID**, energy, and position of each node. After that, the **CHs** are chosen randomly by **BS**. To join the nodes to the nearest **CH**, send a request message to the nearest **CH** within its range.

In the **other rounds**, using **HRP-FASA**, the new **CHs** will be chosen in the next few rounds. Each new CH sends a message to the base station consisting of its **ID**, energy, and position. All nodes receive a message from the base station about the elected **CHs**. For transmission to the base station, each **CH** receives a request message from the node of the closest **CH** within its range.

The general flowchart of cluster formation is shown in the figure below:

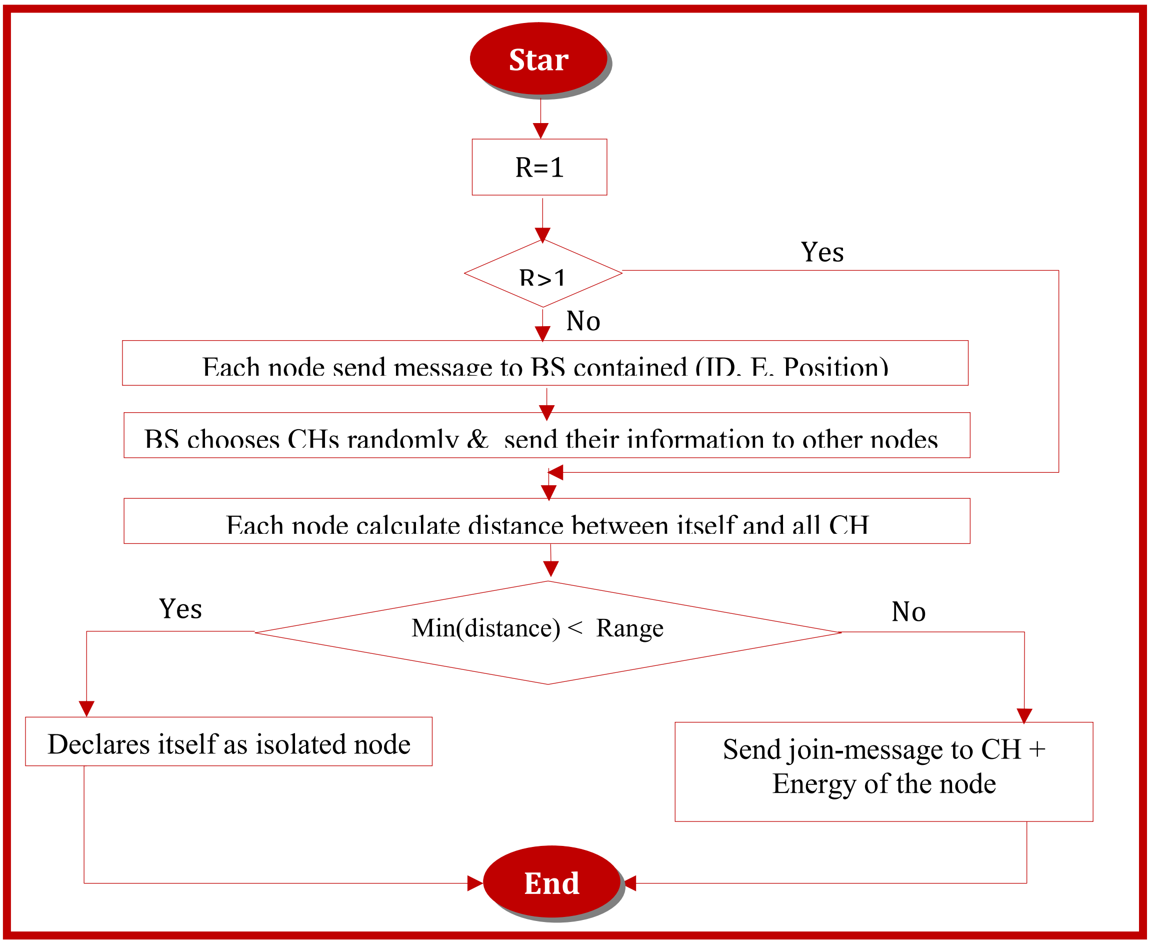

Figure 3.7: flowchart of cluster formation.

III.4.1. Steady-state phase

This is the phase of data transfer. In this phase, the cluster head sends the data that it has collected to the base station. According to a time slot in the **TDMA** schedule, each cluster's member nodes transmit their sensed data to their own CHs. The **CHs** forward the aggregated data to **BS** via relay nodes (**CHs**). They are then turned off until the next available slot in the **TDMA** schedule. If it is found to be an isolated node, it will send its data to the base station where the coverage of the network is total.

III.5. The detailed flowchart of our proposed protocol

Fig.3.8 shows the detailed flowchart of the proposed **HRP-FFSA** algorithm applied for selecting the optimal cluster heads positioning.

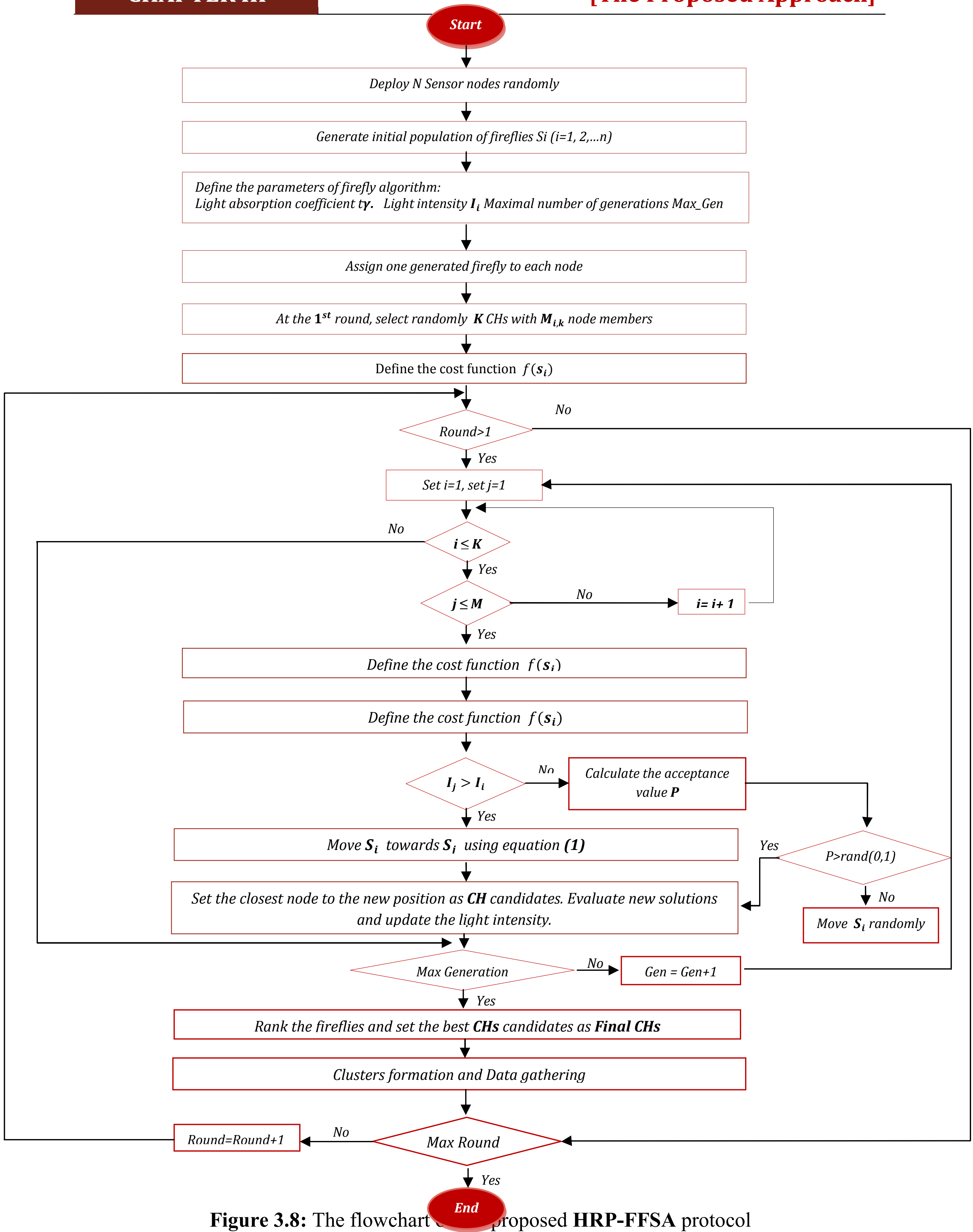

Figure 3.8: The flowchart of the proposed **HRP-FFSA** protocol

III.6. Conclusion

Our proposed protocol is based on the **HRP-FFSA** protocol with enhancement using the Firefly algorithm. In order to preserve network connectivity and reduce energy consumption, we made various enhancements employing the firefly algorithm and simulated annealing.

The network performance will be examined using a simulator. The **LEACH**, **LEACH-C**, and **HRP-FASA** protocols are executed and tested in the next chapter using the **MATLAB** environment.

CHAPTER IV:

Simulation,

Results,

and Analysis

IV.1. Background

In this chapter, we will firstly discuss the **MATLAB** environment. Then, we provide the section of our work implementation, in which we suggest a series of experiments to simulate, test, validate, and analyse the results of our protocol and associated work in terms of energy efficiency and the amount of data packets sent to the BS. We chose the MATLAB environment for simulating and evaluating our research since it makes creating GUIs (Graphical User Interfaces) simple.

IV.2. MATLAB Platform [44][45]

The MathWorks is the company that distributes **MATLAB**. Since it was created for matrix computation, MATrix LABoratory is the original of the word **'MATLAB'**.

- **MATLAB®** is used by millions of scientists in various fields across the world. It was designed to evaluate and design the systems and technologies that were developing in our world.
- The **MATLAB** language, which is built on matrices, is the most intuitive way to represent computer mathematics in the world.
- **MATLAB** allows to take your thoughts beyond the computer screen.
- Experimentation, investigation, and discovery are all encouraged in the desktop environment.
- The **MATLAB** features and tools are designed to function together.
- Built-in visuals make data visualisation and analysis simple.
- Can use **MATLAB** code to deploy algorithms and applications online. By integrating it with other languages, **MATLAB** is also used in corporate and production systems.
- May expand to clusters and clouds and execute your analysis on larger data sets.

IV.3. System model

IV.3.1. Network model [46]

- Initially, all nodes are fixed and have a uniform energy.
- Nodes are randomly distributed, in a space of 2-dimension.
- Nodes are with the same ability to communicate and process.
- Nodes are with the same probability to be selected as cluster head.
- Each node can be selected to act as a cluster head.
- Each node can transmit at variable power levels, depending on its distance from the receiver.

IV.3.2. Energy dissipation model [46]

Assuming the symmetric of wireless cannels; when sending or receiving messages between $\boldsymbol{X_i}$ and $\boldsymbol{X_j}$, the energy consumption is equal. When the distance between two communicating nodes exceeds the threshold value $\boldsymbol{d(X_i, X_j) \geq d_0}$, the multopath fading channel model $\boldsymbol{d^4(X_i, X_j)}$ is used. Otherwise, if the distance is less than the threshold value, it will choose the free space channel model $\boldsymbol{d^2(X_i, X_j)}$. So there is large energy consumption, or consumption loss. The energy consumption for a **p-bit** message transmitted over distance $\boldsymbol{d(X_i, X_j)}$ is given by:

$$\boldsymbol{E_T\big(p, d(x_i, x_j)\big) = \begin{cases} p * E_{elec} + p * \varepsilon_{fs} * d^2(x_i, x_j), & if \quad d(x_i, x_j) < d_0 \\ p * E_{elec} + p * \varepsilon_{mp} * d^4(x_i, x_j), & if \quad d(x_i, x_j) \geq d_0 \end{cases}} \quad (4.1)$$

Where:

- $\boldsymbol{d_0}$: Threshold distance.
- The energy consumed for receiving a message of p-bits size is calculated as follows:

$$\boldsymbol{E_R(p) = p * E_{elec}} \qquad (4.2)$$

- $\boldsymbol{E_{elec}}$**:** Enough energy to send or receive a single bit.
- $\boldsymbol{\varepsilon_{fs}}$**:** The "free space channel" is represented by the amplification factor.
- $\boldsymbol{\varepsilon_{mp}}$**:** The "multipath fading channel" is represented by the amplification factor.
- $\boldsymbol{p}$ **:** The message's size
- $\boldsymbol{d}$**:** The length of the distance between the sender and the receiver.

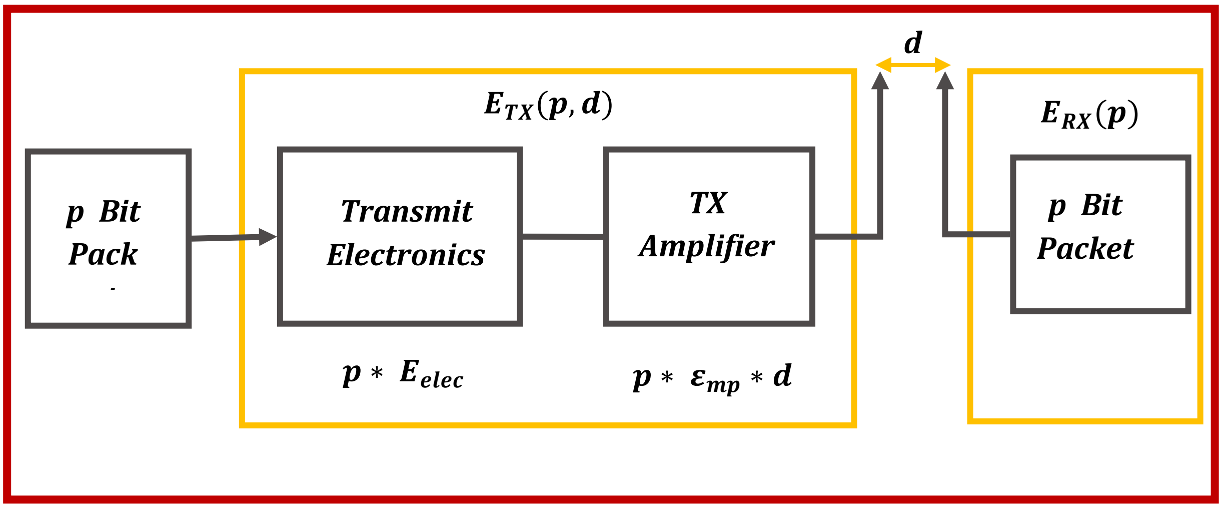

Figure 4.1: Energy dissipation model. [47]

IV.3.3. Hardware characteristics for MATLAB environment

On the same machine, we use our simulation to test our protocol effectiveness and compare it with other routing protocols (**LEAC**, **LEACH-C**). The main characteristics of our personal computer are:

- **Processor:** Intel(R) Pentium(R) CPU B960 @ 2.20GHz 2.20
- **Memory (RAM):** 4.00 GO
- **Operation system:** Microsoft Windows 7 Professional 64bits.

IV.4. Description of Simulation interface

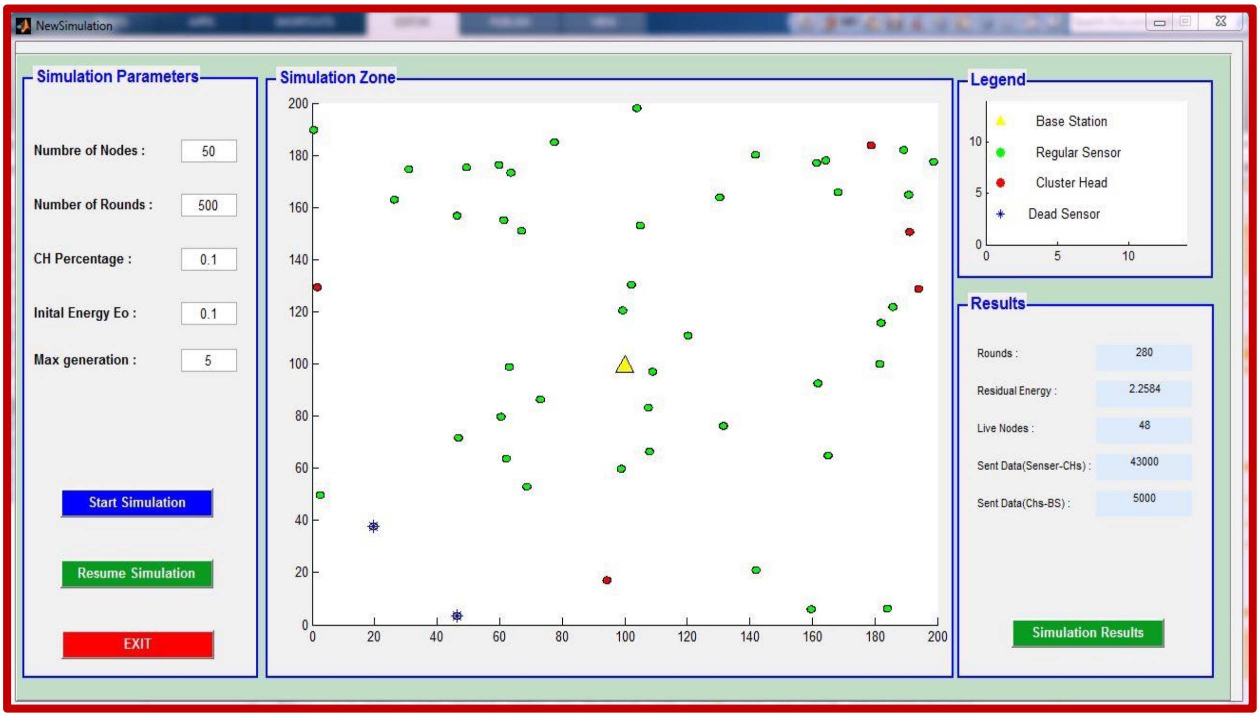

Figure 4.2: The main interface of Simulation.

Simulation interface consists of:

1. **Simulation parameters**: To simulate the protocols all simulation parameters must be entered
2. **Simulation zone**: This part is subdivided in two sections: The first section represents the simulation area. The second section exist a set of radio button "Show parameters" that enables to show or hide location parameters.
3. **Legend**: the legend that represents components of the simulation zone
4. **Simulation results**: represents the current results of the simulation which are in order: number of rounds, residual energy, number of live nodes, data sent to BS.
5. **Simulation control buttons**:
   - **Simulation button**: To start the simulation.
   - **Pause button:** to stop the simulation at any time.
   - **Exit button**: to exit the application
   - **Results button**: to display the result at the second interface as described below.

IV.5. Simulation of the routing protocols

In this part, we will present the results obtained. We will compare our results with other protocols' simulation results (**LEACH** & **LEACH-C**). By applying the same initial values and assuming that the nodes are not mobile (each one has a fixed position) during all the period of simulation. The base station is located in the centre of the monitored area.

Parameters	Scenario
Protocols	**HRP-FFSA & LEACH &LEACH-C**
Number of nodes	50
Location of BS	(100,100)
Simulation area	200**m** × 200**m**
Node deployment	**Random**
Packet size	6400 **bit**
Initial energy	0.1 **j**
E_{elec}	50 **nJ/bit**
ε_{fs}	10 **pJ/bit/**m^2
E_{da}	5 **pJ/bit/sig**
E_{mp}	0.0013 **pJ/bit/**m^2
d_0	15 **m**

Table 4.1: **Simulation parameters.**

HRP-FASA 's simulation parameters	Proposed value
Generation	5
α, β, γ	1

Table 4.2: **HRP-FASA 's simulation parameters**

IV.5.1. Number of rounds

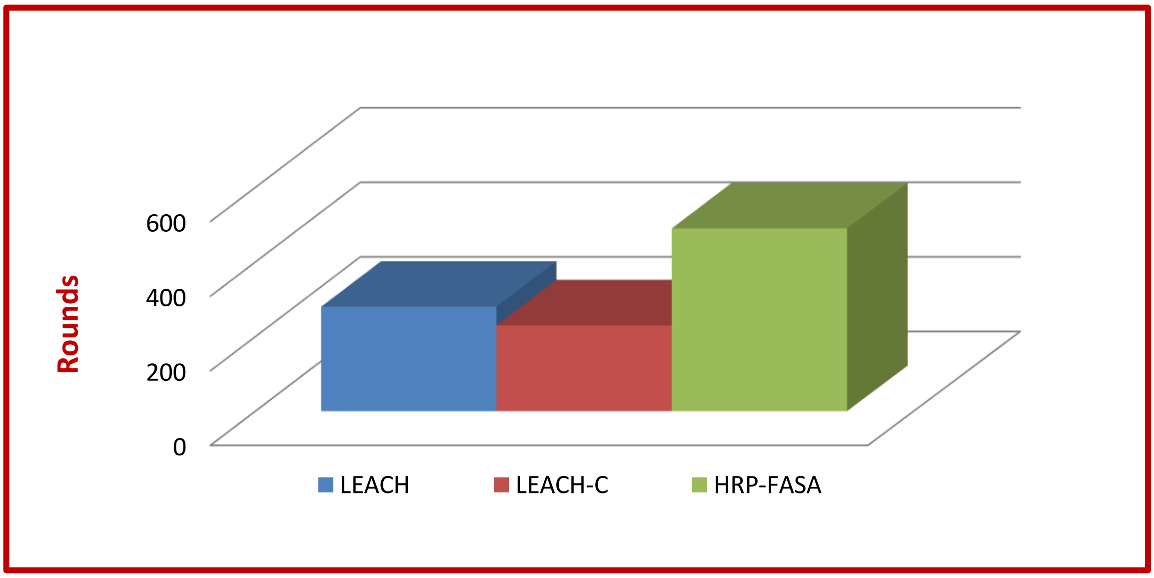

Figure 4.3: Number of rounds v/s the three protocol types

From **Figure 4.3**, it can be shown that the HRP-FASA protocol has a higher number of rounds: about 240 rounds as compared to the LEACH and LEACH-C protocols.

IV.5.2. Residual energy

Table 4.4 shows the residual energy per round for the three protocols **HRP-FASA, LEACH,** and **LEACH-C**.

Rounds	LEACH	LEACH-C	HRP-FASA
0	5	5	5
1	4,97616996	4,97631409	4,976515
100	2,55743497	2,45698002	4,057264
150	1,34167493	1,156362	3,611709
200	0,28876916	0,03938816	3,148636
250	0,00716912	0	2,644899
300	0	0	2,209045
350	0	0	1,780478
400	0	0	1,368059
450	0	0	0,9732723
500	0	0	0,5746622

Table 4.3: The residual energy of simulated protocols per rounds.

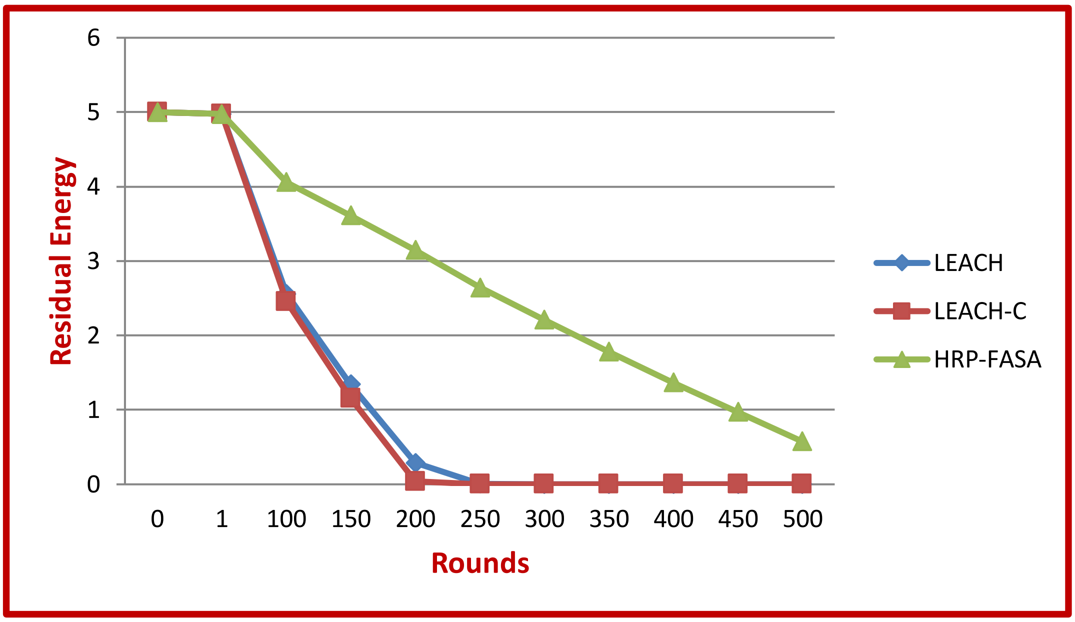

Figure 4.4: The residual energy per rounds.

Figure 4.4 represents the total remaining energy within the system during rounds of each protocol involved in the study. The two other protocols showed a gradual decrease in energy, while our proposed HRP-FFSA protocol has an ordinary decrease with rounds until round 100, because it keeps the same cluster number for each round, in the **LEACH** and **LEACH-C** protocols, network energy is totally consumed at the 490th round.

IV.5.3. Live Nodes

Table 4.5 Comparison of the live nodes versus No. of rounds for the three protocols **HRP-FASA**, **LEACH** and **LEACH-C**.

Rounds	LEACH	LEACH-C	HRP-FASA
1	50	50	50
150	49	50	50
180	46	50	50
200	27	13	50
225	13	2	49
250	1	0	48
300	0	0	28
400	0	0	20
500	0	0	3

Table 4.4: Alive nodes of each protocol per rounds.

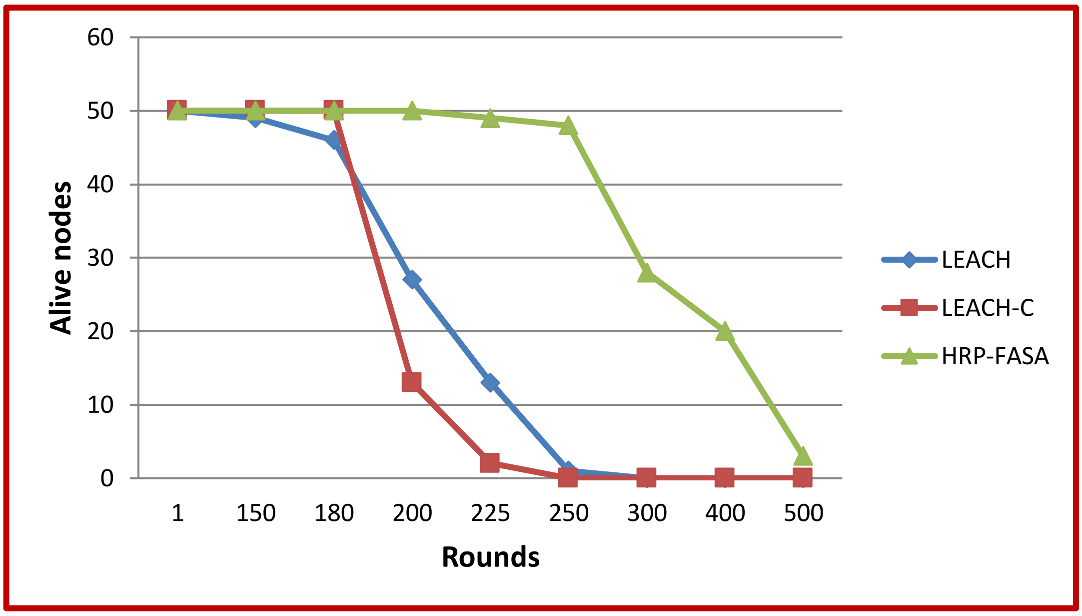

Figure 4.5: Alive nodes of each protocol per rounds.

From **figure 4.4**, we can see that the number of living nodes decreases with the increasing of rounds. In our hybrid protocol, there are some nodes that are still alive until the 500th round, while the nodes of the **LEACH** and **LEACH-C** protocols are dead rapidly after the 250th round. As illustrated above.

IV.5.4. Data delivery to BS

Rounds	LEACH	LEACH-C	HRP-FASA
1	45	91	4000
50	57358	54067	252000
100	227209	214418	742000
200	900488	856119	1711000
300	1603375	1087806	3165000
400	1603375	1319493	5104000
500	1603375	1551180	7384000

Table 4.5: Data received by BS for each protocol.

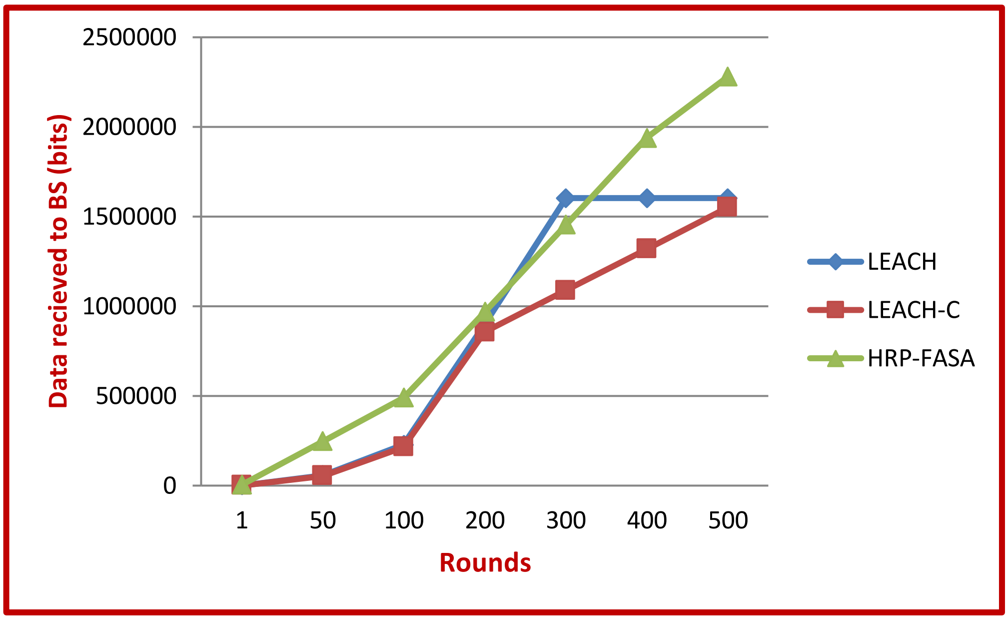

Figure 4.6: The data received by BS versus No. of rounds.

We observed in **Figure 4.6** the number of packets which were sent per round for the three protocols. As we show, the **LEACH** and **LEACH-C** protocols usually have a lower number of packets than our proposed protocol **HRP-FASA**.

IV.5.5. First dead node (FDN)

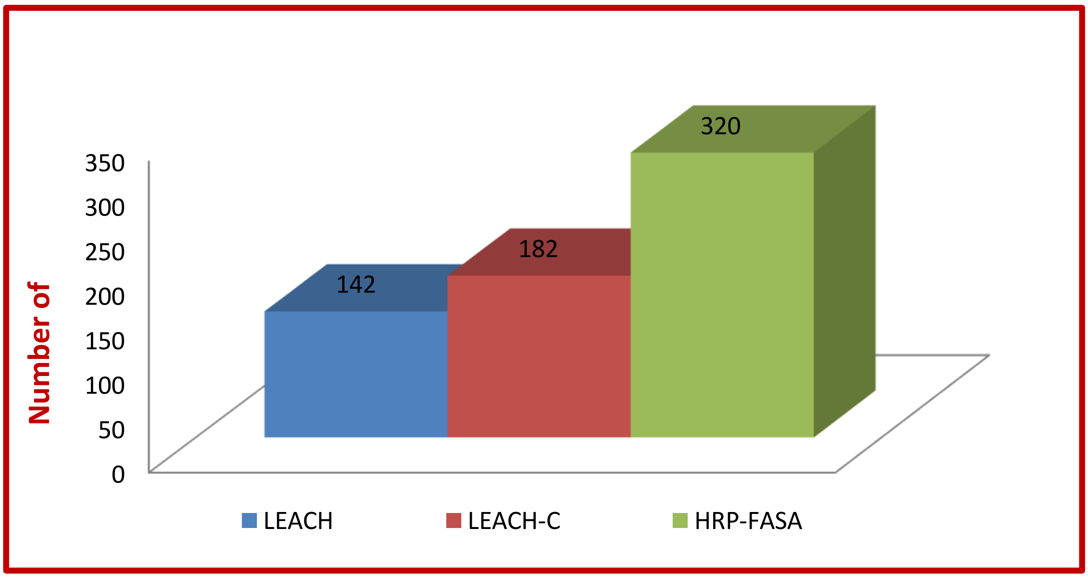

Figure 4.7: The first dead node of each protocol.

Figure 4.7 presents the first dead node dies through the simulation rounds for the three protocols. Results show that LEACH is the first protocol losing the first node. However, LEACH-C is better than LEACH protocol. the first node die in LEACH-C is in the 282th round. We see that Our protocol HRP-FASA is the best one. It lost the first node in the 390th rounds , due to CHs optimal Selection.

IV.6. Discussion

After analysing the three protocols' performance, we discovered that our suggested protocol has various advantages, particularly in terms of energy usage, data received by the base station, network lifetime extension. This is because of:

- The CH's optimal position in each round is determined by the best cluster head energy, the minimal distance to the base station, and other factors.
- Accepting some bad solutions is a feature of our proposed protocol that allows it to avoid being stuck in local minima.
- Because of the CHs and member nodes' having less energy in each round, the number of rounds has an impact on the network's lifetime.
- The amount of energy consumed is determined by the number of packets sent and received as well as the distance between the transmitter and the recipient.
- Due to the amount of data provided to the BS, LEACH and LEACH-C utilize more energy than HRP-FFSA.
- The network's stability will be substantially decreased with the death of the first node. The time at which the first node dies (FND) is a good indicator of such a network's lifetime in such situations.

IV.7. Conclusion

In this chapter, by simulating our proposed protocol **HRP-FFSA**, we have reached new results. In comparison, the results that we obtained using our proposed model are more effective than those of **LEACH** & **LEACH-C**, especially in terms of energy consumption and the amount of data transmitted to the base station. We concluded that our protocol is more efficient compared to others.

General Conclusion

Wireless sensor networks are known for their great role in monitoring and tracking natural phenomena. These networks consist of a set of lifetime-limited sensor nodes. The decreasing battery level of the nodes is the biggest difficulty for these networks. Increasing the efficiency of wireless sensor networks depends on reducing energy consumption at the lowest possible cost in order to increase the network lifetime.

Based on an improved and more efficient hybrid protocol between firefly and simulated annealing algorithms that we proposed, we present an improved and more efficient strategy. We compared our hybrid protocol with both the Leach and Leach-C hierarchical routing protocols to prove that we entered the same raw data but we got different results between our proposed protocol and the other two protocols, **LEACH** and **LEACH-C.** This comparison was made on a computer with the Windows 7 operating system and using Matlab platform 2013 version. We compared:

- Energy consumption during the simulation period (for each of the rounds).
- he number of alive nodes in each round
- And the first dead nodes of each protocol.
- The amount of data sent to each cluster head and to the base station

The simulation results have proven that **HRP-FASA** performs better than other involved protocols and this in increasing the network lifetime, effectively delaying the dead of the first node. Furthermore, the amount of data packets transferred to the BS is considerably increased.

In the future, and as a suggestion to increase the efficiency of our proposed protocol, it would be better if this protocol were applied to high-resolution simulators for wireless sensor networks. Among them are: **NS2**, **NS3**, **OMNET++**, **OPNET**. Make adjustments to the clustering in the first round instead of being random. Using another hierarchical routing protocol, for example **LEACH-E** or **LEACH-M.** implementing a multi-hop version of **HRP-FASA** aiming to reduce the overall energy consumed by cluster heads, especially those that are located far away from the Base station.

There is no doubt that wireless sensor networks need extensive work to develop and improve their efficiency. Therefore, new protocols or the hybridization between nature-inspired optimization algorithms must be proposed because that makes a big difference in increasing the network lifetime.

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