T.C.

ALTINBAS UNIVERSITY

Institute of Graduate Studies

Information Technologies

EFFICIENT WSN ROUTING USING BOOTSTAPPED PSO CLUSTERING

Ahmed Thaer OBAID

Master's Thesis

Supervisor

Asst. Prof. Dr. Muhammad ILYAS

Istanbul, 2022

EFFICIENT WSN ROUTING USING BOOTSTAPPED PSO CLUSTERING

Ahmed Thaer OBAID

Information Technologies

Master's Thesis

ALTINBAŞ UNIVERSITY

2022

The thesis titled EFFICIENT WSN ROUTING USING BOOTSTAPPED PSO CLUSTERING prepared by AHMED THAER OBAID and submitted on 09/08/2022 has been **accepted unanimously** for the degree of Master of Science in Information Technologies.

Asst. Prof. Dr. Muhammad ILYAS

Supervisor

Thesis Defense Committee Members:

Asst. Prof. Dr. Muhammad ILYAS	Faculty of Engineering and Architecture, Altinbas University	___________________
Asst. Prof. Dr. Hasan ABDULKADER	Faculty of Engineering and Architecture, Altinbas University	___________________
Asst. Prof. Dr. Ali HAMİTOĞLU	Faculty of Engineering and Natural Science, Istinye University	___________________

I hereby declare that this thesis meets all format and submission requirements of a Master's thesis.

Submission date of the thesis to Institute of Graduate Studies: ___/___/___

I hereby declare that all information 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.

Ahmed Thaer OBAID

Signature

DEDICATION

First I would like to Allah Almighty for the power of mind , health, strength , guidance knowledge and skills to complete this study .This thesis is wholeheartedly dedicated to my beloved father, who have been my source of inspiration, he tells me that" every success in your life will be best gift for me". To my mother, who have been supporting me with the kind and pure love.

PREFACE

I would like to thank my supervisor Asst. Prof. Dr. Muhammad ILYAS for all support during my study. It’s great pleasure to express my deepest gratitude to my friends who have shared with me best moments during my study for the Master degree.

ABSTRACT

EFFICIENT WSN ROUTING USING BOOTSTAPPED PSO CLUSTERING

Obad, Ahmed Thaer

M.Sc., Information Technologies, Altınbaş University,

Supervisor: Asst. Prof. Dr. Muhammad ILYAS

Date: 08/2022

Pages: 43

The increasing convergence of microprocessors, wireless communication, and micro electro-mechanical systems (MEMS) has led to the development of Wireless Sensor Networks (WSNs). Optimization problems for WSN are usually versions of classic problems in the operational research area, such as routing and clustering, which are NP- Difficult. Thus, it is natural to use meta-heuristics to solve these problems. The main objective of this work is to apply the Bootstrapped PSO metaheuristic to form WSN clusters. bootstrapped PSO was chosen because it is a meta-heuristic that proved to be efficient in solving similar problems, such as P-medians, and because it is a method not yet used to solve the problem addressed in this work.

Keywords: PSO, WSN, MEMS, NP-Hard.

TABLE OF CONTENTS

Pages

LIST OF FIGURES

Pages

LIST OF ABBREVIATIONS

AI	:	Artificial Intelligence
IoT	:	Internet of Things
PAN	:	Personal Area Network
FSK	:	Frequency Shift Keying
TDMA	:	Time Division Multiple Access
OFDM	:	Orthogonal Frequency Division Multiplexing

LIST OF SYMBOLS

μ	:	Mobility of electron
λ	:	Wave length
ω	:	Angle frequency

1. INTRODUCTION

1.1 BACKGROUND

The increasing convergence of microprocessors, wireless communication, and micro electro-mechanical systems (MEMS) has led to the development of Wireless Sensor Networks (WSNs). Monitoring and ultimately controlling an environment may be done with the help of a wireless sensor network (WSN). It is common for this network to be made up of hundreds or thousands of tiny autonomous devices (cm 3 or millimeters) known as sensors. Transceiver, power supply, sensing device, memory and CPU are the major components of a sensor node. In a sensor node, the software that runs on the CPU is the logical component [2]. An actuator is a piece of hardware that allows a WSN to take control of the observed environment's variables. The nodes themselves have a limited amount of processing and energy capability, but when they work together, they can achieve a tremendous deal [3] Remote areas (e.g., environmental reserves, oceans, volcanic craters) can be accessed via ad-hoc wireless networks, which can collect data on the phenomena of interest, perform local processing, and distribute the information to an access point via a multi-hop communication scheme without the intervention of technicians or operators. When a network connects with other networks or one or more observers, it uses an access point. A sink node, a sensor, may house the access point, or a base station can house it (BS - Base Station). It is possible to consider wireless sensor networks (WSNs) as an advanced kind of mobile ad hoc network (MANET) [4]. Soon, they will be able to access the Internet. [5].

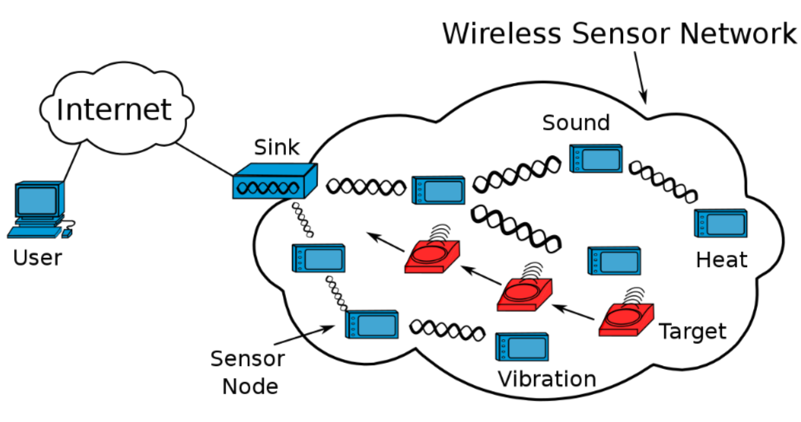

Figure 1.1: WSN Architecture.

1.2 PROBLEM STATEMENT

From a scientific point of view, WSNs present a wide variety of new problems that have not yet been studied or are still incipient research on sensor networks was considered one of the six most challenging areas of research. Another related area was the theory of wireless communication networks, which encompasses WSNs. In the subsection of the chapter, we list some of the problems related to the WSN:

1. There are various ways in which WSNs vary from typical computer networks. Many dispersed pieces make up the typical WSN, which runs without the need for direct human interaction, has significant energy limits and must have self-management systems (self-management). Self-organization, self-maintenance) as a result of dispersed deployment, low node capacity, and topological dynamics. It's possible for wireless sensor network (WSN) nodes to be removed from service due to a variety of causes such as a lack of power or an issue with deposition. [7].
2. Even without the mobility of nodes, the network topology is dynamic. Traditional distributed algorithms such as communication protocols and leader election should be revised for this type of environment before being used directly.
3. Many aspects affect the design of a WSN, including fault tolerance, scalability, manufacturing cost, operational environment, network architecture, hardware limits, transmission medium, and energy consumption. (3) Designing nodes and the protocol stack as a whole must account for each of these considerations. Low-power hardware design and signal propagation mitigation measures are both essential to the physical layer's architecture.
4. Determining the lower limit of power required for self-organizing the network, error control schemes, energy-saving operating modes, and mobility care are the data link layer challenges of network protocols. Medium access control.
5. Handling changes in topology, addressing, scalability and interfacing with other networks are expected requirements for the network layer. Transport layer protocols, on the other hand, must allow end-to-end communication diversity to calculate variations in the characteristics of the communication channel
6. The local processing of data through correlation (merging, counting, aggregation, compression, etc.) are also requirements to be considered in the design of protocols for

dissemination and querying the non-sensors, as well as the security requirements at each of the layers of the protocol stack.

1.3 THESIS OBJECTIVES

1.3.1 General Objectives

Over the last few years, WSN have been the subject of many studies both in hardware and software. The different applications of this type of network usually require specific communication protocols in order to provide the efficient use of sensor resources. Optimization problems for WSN are usually versions of classic problems in the operational research area, such as routing and clustering, which are NP- Difficult. Thus, it is natural to use meta-heuristics to solve these problems. The main objective of this work is to apply the BOOTSTRAPPED PSO metaheuristic to form WSN clusters. Bootstrapped PSO was chosen because it is a meta-heuristic that proved to be efficient in solving similar problems, such as P-medians, and because it is a method not yet used to solve the problem addressed in this work.

1.3.2 Specific Objectives

As for specific objectives, we can highlight:

i. Test the efficiency of bootstrapped PSO to form clusters (Bootstrap is a computer-intensive resampling technique that draws a large number of resamples from the initial data repeatedly with a computer)

ii. Add a post-optimization phase based on Path Relinking to bootstrapped PSO

iii. Develop a version of the algorithm for the multi-level topology

iv. Develop a simulator to perform data collection and transmission over the network

v. Analyze the performance of the proposed algorithms in relation to existing protocols in the literature.

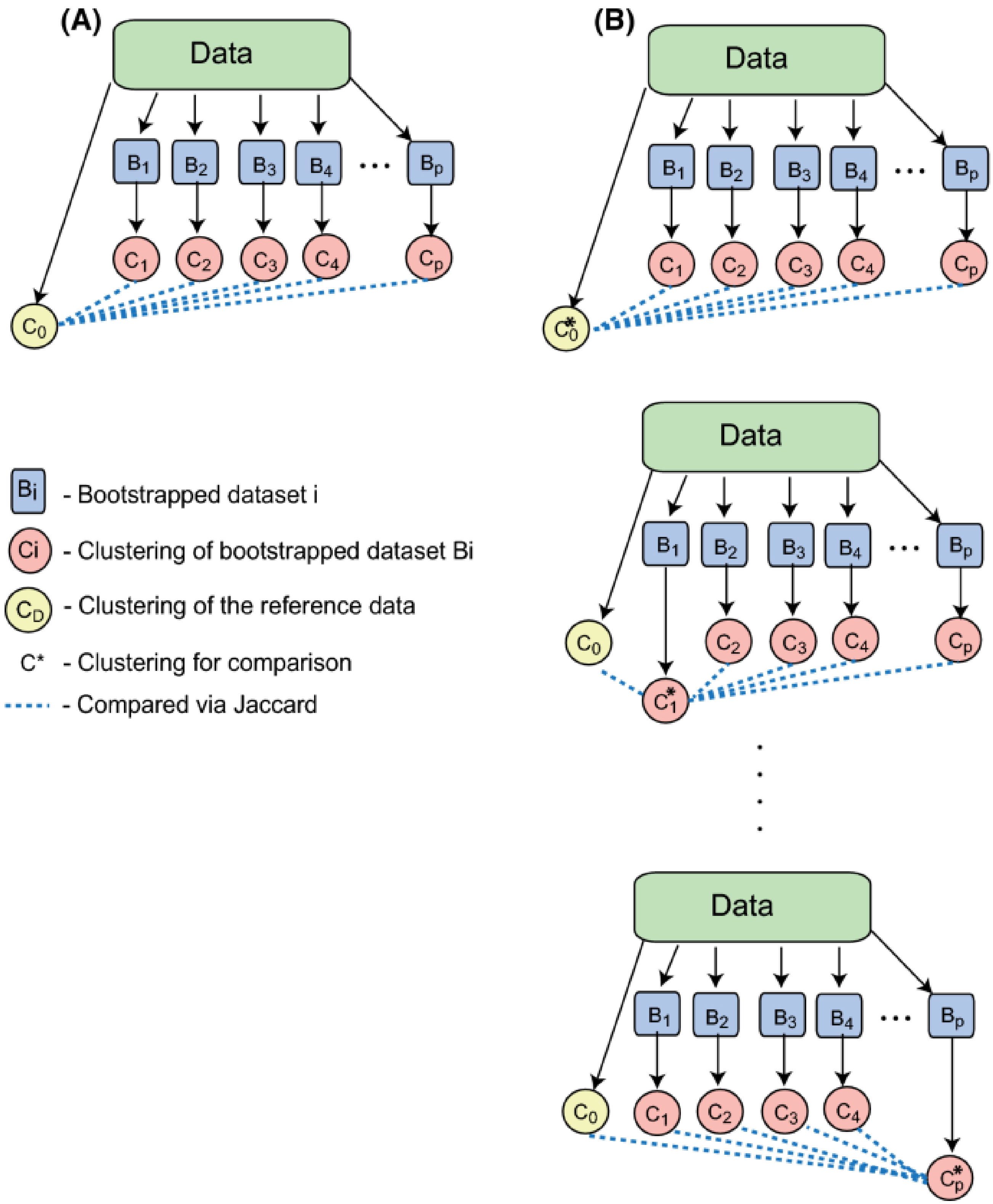

Figure 1.2: Bootstrapping in metaheuristic clustering.

1.4 THESIS ORGANIZATION

The thesis is structured as follows: Section 2 is where we review some of the previous work and implementation on smart grids. Section 3 is where we give a background about all the components. Section 4 is where we explain our model in details and implementation of that model in details, Section 5 is where we simulate our model and record the results obtained. Section 6 is where we conclude our work and put a future scope into perspective.

2. LITRITAURE REVIEW

This chapter aims to explain some of the previous works done in WSN routing and energy efficiency looking for viable answers for the current scenario. The objective is to review some of the past works and the results they achieved during the process.

In [4] the authors provided an investigation on cluster-based routing protocol had been carried out the article presents a taxonomy of routing protocols, as well as design considerations for a high-performance routing protocol. When designing routing protocols, some of the most significant issues to keep in mind are node deployment, energy consumption, node type, network coverage, scalability, and QoS (Quality of Service). Routing protocols were classified based on a number of network-related aspects, including network structure, communication initiator, route formulation, protocol operation, and hope strategy, amongst other considerations. On the basis of their advantages and disadvantages, a comparative study of block, grid, and chain-based routing protocols has been provided. Furthermore, common CBRPs were evaluated and contrasted based on a variety of performance parameters including energy efficiency, cluster stability, complexity, load balancing, and latency. For future design, concerns concerning cluster-based routing algorithms were taken into consideration as part of an attempt to improve performance. In [5, Swati Mishra et al. proposed a classification that was comparable to this. In their presentation, they discussed how they classified WSN RPs based on network topology, protocol functioning, route establishment/nexthop selection, and other factors. A great quantity of information was provided by Olayinka and Attahiru on WSN deployment and application difficulties. WSN load-balanced energy (LBE) resource profiles (RPs) and energy efficiency were the primary topics of discussion in this research. Specifically, they focused on the problems associated with developing and implementing an LBE routing system. Furthermore, they classified routing protocols based on the algorithms and decision-making criteria that were used in the algorithms to create the routing protocols. Protocols for routers were classified according to their energy efficiency as well as their capacity to maintain a steady balance of power consumption. When it comes to decision considerations such as the selection of a cluster in-charge, the building of a cluster, and routing to a base station, the clustering-based routing protocols in a multi-hop clustering network were compared (BS). They also learned about the advantages and disadvantages of the variables that were utilized to tailor these regimens. [6]. Lucia Keleadile

Ketshabetswe ET. al. [7] investigated a range of methods for extending the life of a network and the most efficient routing algorithms, among other things the paper also featured event extraction analysis and RPs that were differentiated by the use of homogeneous and heterogeneous routing protocols, among other things. Further sub-categories were created based on the morphological and behavioral traits of the animals. The researchers concluded by evaluating the performance of a variety of routing strategies and making suggestions for further study. For the development of WSNs and routing protocols, factors such as energy capacity, hardware resources-dependent characteristics, non-static networks, node placement, sensor position, and fault resistance were taken into account, among other things. Shahul Hameed et, al. [8Research gaps and challenges in traditional geographic routing and cross-layer routing systems were examined at length in this paper. Different network topologies, a large number of assets and destinations, multi-objective steering, QoS limits, security measures, energy-efficient technologies, network packages, and development frameworks were all proposed for the future creation of routing protocol designs. According to the authors, node design strategies, sensor node localization techniques, energy-based routing techniques, and QoS aware routing techniques may all be used to overcome these difficulties. Mohammed Salman Arafath ET, al. [9] the use of opportunistic routing (OR) and the features of Quality of Service (QoS), such as the packet receiving ratio, were investigated. In this article, two fundamental roles of routing were explored in relation to data delivery techniques, and the distinctions between OR routing and other routing systems were discussed. According to the methods used in the publication, improved PDR results in a more difficult attack on availability, which is corroborated by the outcomes of the study. Several forwarding node selection approaches have been developed, and a comparison of these techniques is presented to determine which forwarding node is nearest to the sink at the time of transmission. It is stated which QoS metrics have been the subject of the most thorough research by a variety of researchers. They also looked at WSN routing functionalities such as data transmission via clustering and the least routing time method as part of their investigation. They discovered that the strategy with the shortest routing time outperformed the other methods tested. Brijesh L. Kundaliya and Sarman K. Hadia In order to locate the finest WSN RP, we compared and evaluated the current ones. They classified RP as a whole based on factors like as network topology, route finding, and protocol functionality. Besides that, they categorised the well-known RP according to their operational and result criteria, which included aspects such as datacentricity, hierarchicality, and geography, as well as quality of service (QoS). The features and functionality were written out and compared based on their individual strengths and shortcomings, as well as their similarities and differences. Their conclusion was that an RP should deliver data perfectly and precisely in the network and should not compromise its performance under the continually changing topology of the network in the event of certain foreseeable and unknown scenarios that may arise in the network. [Swarm intelligence (SI)-based role-playing games were investigated in detail by Rajesh Tiwari and his colleagues [11]. The author categorizes routing approaches for computer networks that are inspired by biological systems. From 2002 to 2015, he compiled a list of many conventional and SI-based routing methods and systems. Aside from ad hoc and wired networks, the author concentrated on wireless sensor networks (WSNs), pointing out that routing protocols for WSNs are unique from routing techniques for other systems due to the structural challenges that WSNs face. Network properties such as low computation and memory needs, self-organization, low power consumption, scalability, flexibility, and sensor connectivity have all been studied in the literature for networks. Several of the characteristics and taxonomic categorization of Si-based RPs were discussed in detail in the following sections: It was said that ant colonies, bee colonies, and particle swarms exist. Lime mold-based RPs were also addressed in the discussion. Their literature gives a more detailed classification of their work. By evaluating routing systems and offering future concerns for the same, Kalpana Guleria [12] and Amit Kumar Verma [12] were able to identify research gaps in routing protocols. They concentrated on RPs built on classical and SI foundations, respectively. The network structure and characteristics were utilized to further categorize the protocols, and the results were published. They also looked at swarm intelligence, hierarchical protocols, and hybrid protocols, among other things. Finally, they examined the problems and roadblocks that impeded the development of an energy-efficient hierarchical routing design, as well as the execution assessment metrics for the routing techniques under consideration. The study advises that video and imaging-specific routing systems prioritize quality of service (QoS) and energy efficiency. Working on determining how effectively the routing protocol can deal with mobile nodes or sinks, dynamic topology overheads, energy constraints, and quality of service needs should be the primary emphasis of the research.

3. STATE OF THE ART

This chapter shows the main differences between classic computer networks and WSN. What is a WSN and its component parts is defined in detail

3.1 COMPUTER NETWORKS

In the 70's and 80's there was a synergy between the fields of computers and communications that unleashed a drastic change in technologies, products and in the companies themselves that, since then, have been they are jointly dedicated to the computer and communications sectors. From the above, the field of communication networks or computer networks has originated [7]. Any communication system or computer network's fundamental aim is to ease the flow of information. When designing an information transmission system, one of the most critical components to consider is the transmitter. The transmitter converts and encodes the data sent by the source into electromagnetic signals capable of being transferred across a network.

Transmission systems may vary in complexity from as basic as a single transmission line to as sophisticated as a network connecting several sources.

Once the transmission mechanism sends the signal, it is absorbed by the receiver and changed into a form that may be used by the intended recipient.

Despite its apparent simplicity, the model shown is rather sophisticated. One of the most critical responsibilities in a communications system is how the transmission system is used. Other critical operations include establishing an interface, creating a signal, and maintaining synchronization. This section discusses a variety of subjects, including data interchange, error detection and repair, data flow management, addressing and routing, recovery, and message format. Transferring data between computers, terminals, and other processing devices requires a number of methods, some of which are rather sophisticated. To illustrate, consider transferring a file from one computer to another. Both computers must be directly connected to the communications network, but the source system must also establish a direct data connection or supply the communications network with an identity in order for the network to operate effectively. Ensure that the destination system is likewise prepared to accept the data before transferring it. The management software for the destination system must be reviewed to see if it is capable of accepting and storing this file for the specified user. If it is possible, one of you will be needed to undertake a translation operation between the two systems, which will require third-party help. It has been determined that the computers involved must be capable of effective communication. Rather of forcing you to build all of the logic necessary for communication, the challenge is broken down into smaller subtasks that must be completed individually. The many components of a protocol architecture are organized hierarchically in a vertical stack. Each layer in the stack is responsible for a subset of the activities required to interact with the other levels. These essential functions are typically delegated to a lower tier, and their intricacies are usually overlooked at the present layer of the hierarchy. Each layer offers a set of services to the tier above it, while the layer below delivers the same services to the tier below. If the layers are specified properly, no modification to one layer will need corresponding changes to any of the other levels in the system. It is sometimes referred to as the three fundamental network categories that may be used to define networks: wide area networks (WANs), local area networks (LANs), and metropolitan area networks (MANs) (LAN). (man-assisted navigation system). The lines between these classifications are becoming more blurred, both in terms of technological innovation and prospective applications.

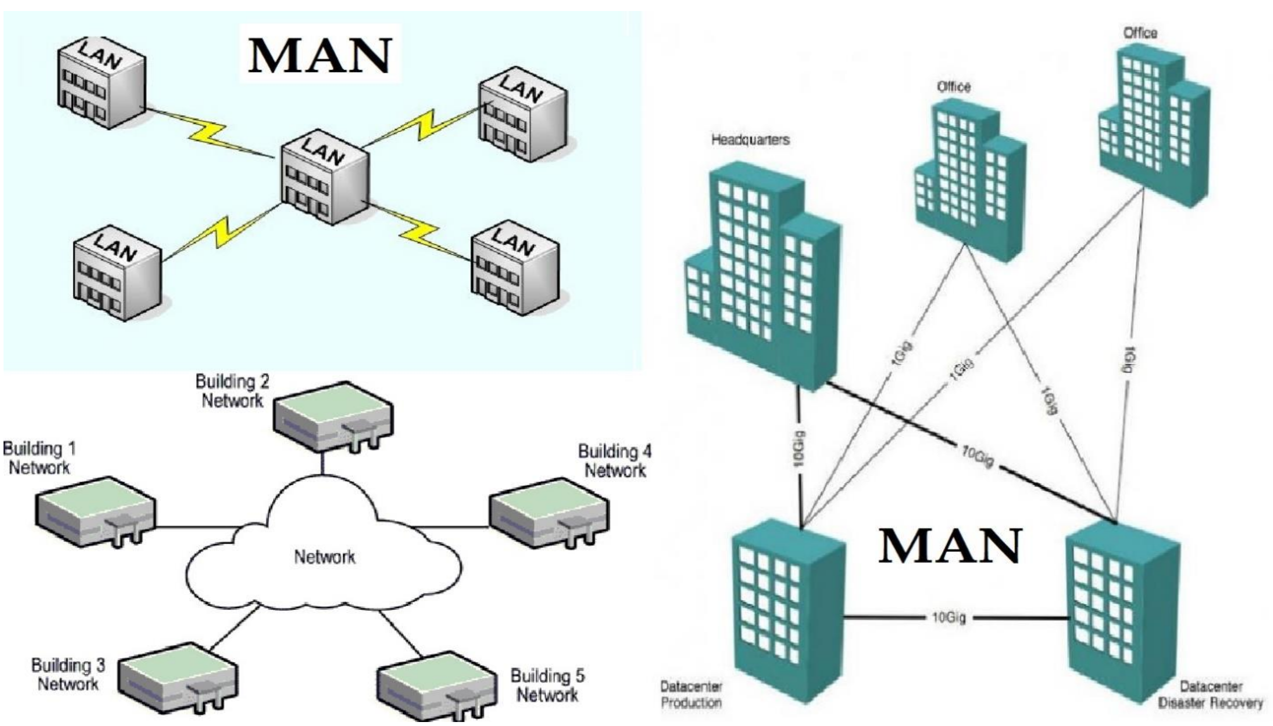

Figure 3.1: LAN WAN and MAN.

3.2 WIRELESS NETWORKS

In the past few years, wireless local area networks (LANs) have taken a significant share of the local area network sector. Businesses are beginning to recognize that wireless local area networks (LANs) are a critical complement to wired networks, allowing them to fulfill their mobile and moving demands while also providing coverage in places where cables cannot be deployed. When data is sent through an inherently insecure medium, such as radio waves, a wireless local area network is formed (LAN). Until recently, wireless local area networks (LANs) were seldom employed owing to their expensive cost, restricted transmission speed, security issues, and licensing requirements. As a consequence of overcoming these obstacles, wireless LANs have gained popularity. It is typical for wireless LANs to be supported by a wired network backbone that links a large number of servers and workstations, as well as bridges and routing devices that enable them to communicate with other networks. Additionally, a control module (CM) serves as a bridge between the wireless local area network and the remainder of the system (LAN). When a wireless LAN is connected to a trunk, the control module acts as a bridge or routing device, enabling data to be sent between the networks. Separate end systems, such as workstations and servers, are maintained. Multiple stations administered by a single hub or other user module (UM) imply that they are also connected to a wireless networking infrastructure.

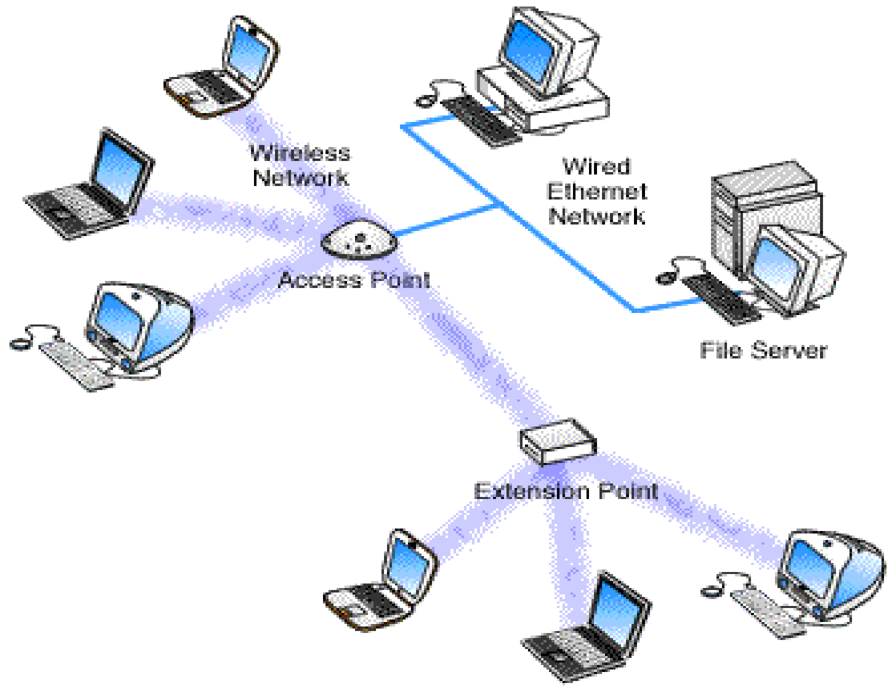

Figure 3.2: Wireless LAN.

3.3 ADHOC MANET NETWORKS

When ad hoc networks were initially established, the military was the first to utilize them. Early in the decade following the Internet's inception (or its first embryo, ARPAnet), the American Defense Department became interested in a new project involving radio-based packet transmission networks (PRNETs), with the goal of enabling battlefield units to communicate freely and cooperatively [8]. An ad-hoc network, sometimes referred to as a mobile ad-hoc network (MANET), is a temporary, point-to-point connection between devices that have similar features and may be formed fast (but without a central server). Consider the following hypothetical situation: A group of workers may convene for a business meeting or conference, each carrying their own computer, which may be temporarily connected to form a temporary network. Due to the fact that each node is prepared to provide info to others, ad hoc wireless networks are decentralized and reliant on ad hoc decisions. amica is a network-based application that supports many users. In conventional networks, this function is performed by routers. In contrast to conventional wireless networks, this one interacts with its neighbors through an access point. As detailed in further detail below, network extensions and nomadic access are provided through wireless networks that are separate from those used for ad-hoc networks (see

Figure 2.3). Each cell of the wireless LAN is equipped with one or more control modules, and depending on the configuration, each cell may include any number of stationary endpoints. Nomad stations may be transferred between cells as needed. Ad-hoc LANs lack infrastructure, and a collection of stations within the same domain may dynamically self-configure to form a network at any point in time.

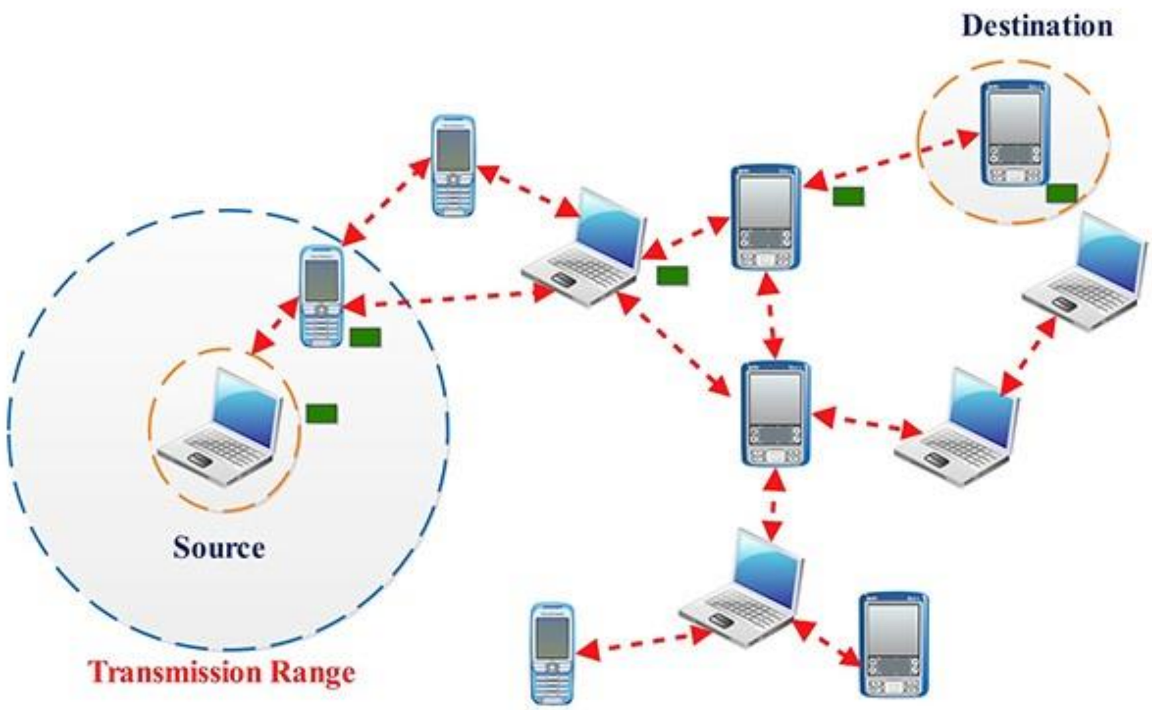

Figure 3.3: Adhoc MANET Networks.

3.4 WIRELESS SENSOR NETWORKS WSN

A wireless sensor network is one of the many types of ad hoc wireless LANs available, and it is one of the most widely used. There are a number of embedded devices in a wireless sensor network (WSN) (sensor nodes). When it comes to nodes in a Wireless Sensor Network, sensor nodes are the most common kind of node (WSN). They are in charge of obtaining the information that will be utilized to reach a decision on the matter. A sensor node is made up of the following components, which are usually found together: a wireless communication subsystem with a limited range for exchanging messages with nearby sensor nodes, a processing subsystem (with a microcontroller and limited memory) for computing or processing the information collected by the sensor, a sensor subsystem composed of one or more sensors that capture information (measures a parameter) from the environment, and an electric power source battery WSN nodes can be placed anywhere, including on solid ground, in the air, underwater, and even on the human body [9]. These devices are responsible for gathering data from the surrounding environment and utilizing it to regulate various variables at various locations throughout the region of interest. Temperature, sound, vibration, pressure, movement, light intensity, humidity, and pressure are just a few of the variables that can be measured by these sensors. Other variables that can be measured include humidity, temperature, and pressure. A central device (also called as a base station, gateway, or sink of the network) receives this information and acts as an interface, delivering it to the end user or system (usually, it is connected to a wired network and/or a high-speed internet service provider). Wireless multi-hop ad hoc networks (MANETs) are a subset of wireless sensor networks (WSNs) [10]. The characteristics of a WSN that cause it to be taken as a different category within wireless networks are: The mobility of the nodes, the changes in routes, the large size and density of the network, the limitations of power, computing capacity, memory and wireless communication and the absence of infrastructure (by default in a WSN there is no centralized entity or any infrastructure. Each node can perform both the function it is a terminal as well as a path pass node, since no distinction is made). A sensor node is a device with a series of capabilities such as computational processing, limited memory, wireless communication interface, and one or more sensors. The components that are part of a sensor are shown in Figure 2.4. The basic hardware of a sensor node consists of a transceiver (transmitter / receiver), a microprocessor, one or more sensors, memory and battery. These components allow the sensor node to work properly, firstly the sensor node captures the information from the environment and modifies it internally with the help of its processor and memory, and then sends packets of the information captured to the station. On base as long as the energy level of the sensor node batteries allow it. If WSNs are to be used in applications such as the capture of vital signals in patients [12], the size of the sensor nodes is important.

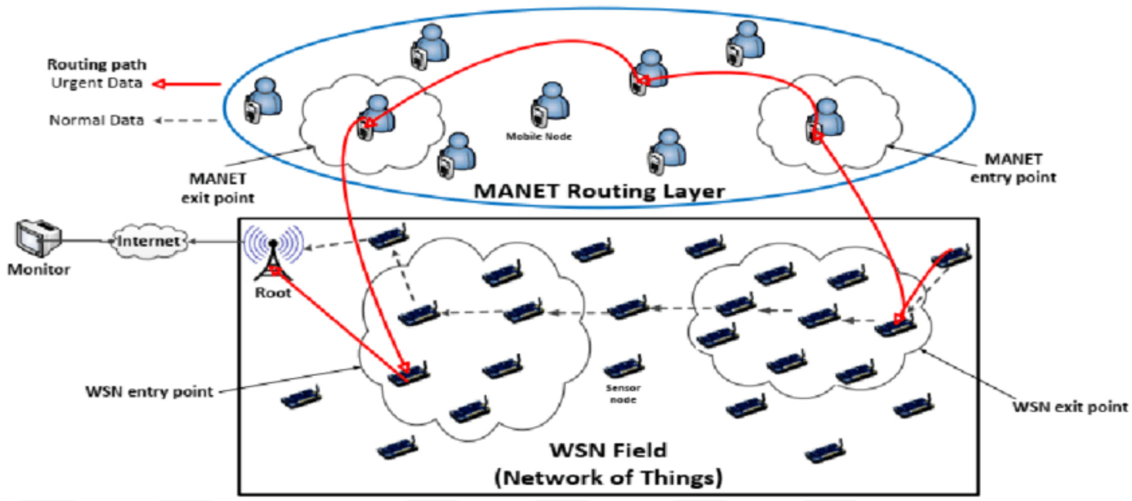

Figure 3.4: MANET Transformation Intro WSN.

In general, the size of the sensor node is limited by that of its power source. The power supply in the sensor nodes is generally provided by a battery, or by a method of obtaining energy [13]. One method to increase the lifetime of the sensor node batteries is to supplement their power supply with energy from the environment. There are several technologies for extracting energy from the environment such as solar energy, thermal energy, kinetic energy, and vibration energy. However, currently there is a lack of economically feasible methods to efficiently exploit these resources with optimal performance. Since one of the main points that is desired when designing a WSN is that it last as long as possible, it is vital to make efficient use of energy in the devices [14]. An important feature of WSN is to minimize the power consumption of the nodes, which at the same time provides the highest possible performance to the users of the system.

3.4.1 Applications of WSN

Due to the adaptability of WSNs, which have a wide range of applications and systems, they have recently made their way into WSN-based systems. As a result of this growth, it is becoming more difficult to undertake conversations regarding common needs for WSN hardware and software issues. A multidisciplinary research problem such as wireless sensor networks (WSNs) presents a unique challenge since it requires tight cooperation among users, application domain specialists, hardware designers, and software developers.

This collection of operations includes the monitoring and control of industrial equipment. Automation and process control in manufacturing. Keeping an eye on the manufacturing process.

Situational awareness is critical in a combat context. Included are the following: Units for detecting facility intrusions, tracking enemy movement, detecting chemical and biological agents, and logistics management in urban warfare It is critical to maintain an eye on the battlefield. Intelligence and surveillance systems, as well as command and control and communications systems, are all under consideration. Military or civil authorities give a certain amount of help.

The physical location of individuals and items.

When it comes to pinpointing your precise position, no other technology compares to low-rate wireless networks. Asset and person monitoring are used in a variety of sectors, including manufacturing, hospitals, residences, and office buildings.

Observing and influencing the material environment is defined as follows: When dispersed sensing systems are used in a variety of biological and environmental control applications, they have the ability to function in a broad variety of environmental circumstances. These include, but are not limited to, the study of marine, terrestrial, and atmospheric habitats, as well as the observation of biological, environmental, and man-made systems. Natural environments are monitored and cataloged (to determine the population and behavior of animals and plants). safeguarding the integrity of certain bodily states (temperature, light, etc.).

Civil protection entails the detection and localization of calamities. Fires, earthquakes, floods, and other natural disasters, as well as many forms of crises, are detected.

Vehicle tire pressure monitoring. Self-observation is the active observation of one's own motions. Vehicle tracking is the technique of monitoring a vehicle's movement. the process of directing traffic flow

At airports, smart labels are available. Wirelessly readable baggage tags are available.

Sensors for soil moisture, insecticides, herbicides, and pH levels, as well as soil moisture sensors, are all used in agricultural applications. It is critical to retain control over harmful chemical levels during an emergency. Detectors for fire and smoke detection. Monitoring catastrophe zones and their evolution.

Responsibilities include monitoring and controlling the machinery. Motion analysis is the study of objects or structures in motion. • Systems for emergency notification in the event of earthquakes and other natural calamities. Two critical roles are inventory control and product quality assurance.

Monitors keep track on patients' whereabouts and health status. Medical gadgets include blood flow sensors, respiration rate sensors, and electrocardiogram (ECG) sensors, among others. The patients are being constantly monitored. This individual assists patients with disabilities in their therapy. A patient's vision improves dramatically as a result of the treatment.

3.4.2 Routing in WSN

It is possible to route data units across a network in order to travel from one location to another. Routes, packets, and messages are all different types of data units that may be routed through a network. The majority of routing algorithms in networked systems are capable of selecting the least-latency routes. Routing devices may be able to offer a visual depiction of the delays faced by various networks in response to this information exchange. Minimum-delay routing contributes to the reduction of network congestion and connection delays across all connections by balancing network traffic. A routing algorithm is required for the proper operation of any network. Routing algorithms for wireless networks must take the network's features and constraints into consideration. Because WSNs, such as ad hoc mobile networks and cellular networks, have unique features, tackling the routing issue in these networks is challenging. The enormous number of sensor nodes in a WSN (hundreds to thousands) complicates the construction of a global routing strategy for their deployment, and keeping the quantity of information relating to the IDs of each node in the network is neither desired nor possible. As a result, WSNs cannot utilize wired network protocols. In order for the WSN nodes to use a cooperative methodology to establish communication, a routing algorithm must be set that meets the established conditions, according to the application's own needs. . Any routing technique proposed to work in WSNs must be efficient in terms of energy consumption, since the sensors are generally powered by batteries and are usually found in places where it is difficult to change or replace them. ´on. The routes defined by the routing algorithm should be established based on a planned objective, such as: Maximize the network's lifetime, ensure that all data captured from the environment reaches the base station, and minimize the overhead of the network. Traffic of the network and the delay of the information from the node that generates it to the base station, etc. A good path is one that provides a minimum cost in accordance with the objective stated in any of the aforementioned questions. The shortest path is not always the one of least cost [18].

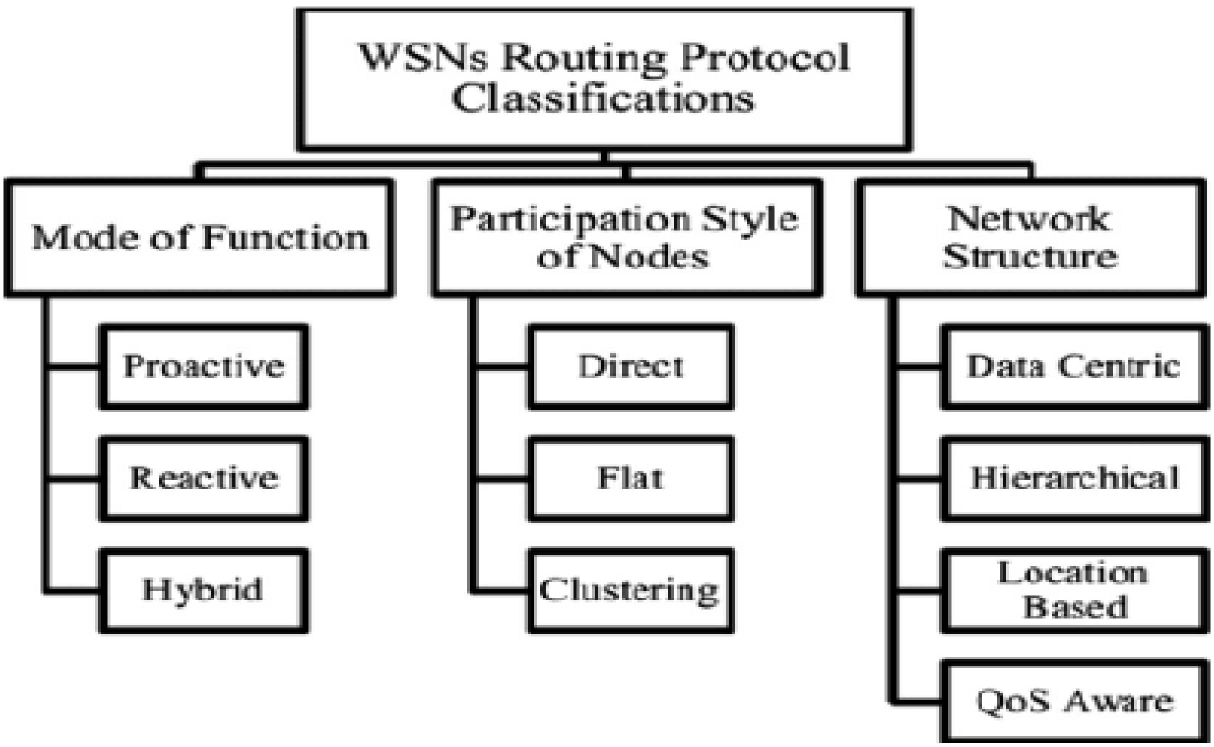

Figure 3. 5: WSN routing protocols classification.

3.4.3 Routing Algorithms in WSN

WSN routing algorithms may be classified into two groups based on their network design and routing criteria. The routing algorithms in this network can be classified into three categories based on their structure: flat routing, which utilizes position information to send data to the network's desired regions, hierarchical routing, which groups nodes together so that the cluster organizing nodes can aggregate and reduce data to conserve energy, and location-based routing. The most often used form of network routing method is flat routing. The second way to categorize them is depending on their path through the system: According to coherence principles [19], several channels, inquiries, negotiation, and service quality (QoS). A wireless sensor network's (WSN) topology may have a major effect on the routing strategy utilized.

Typically, nodes in flat networks do the same duty and cooperate together to accomplish the network's objective. Due to the enormous number of nodes, it is not feasible to assign each one a unique global ID. As a result, the base station sends queries to certain places and then waits for data from sensors situated in those areas, regardless of which sensor nodes generated the data. Environment.

Hierarchical routing was originally developed in wireless networks in the early 1990s as a solution to communication challenges related to scalability and efficiency. Hierarchical routing is thus utilized in WSNs to achieve the most energy-efficient routing feasible. A hierarchical design may be used to process and transmit information, while a hierarchical architecture can be used to detect and collect information. When groups are formed and well defined roles are assigned to leaders, the system's scalability, longevity, and energy efficiency all improve. The quantity of messages supplied to the base station may be limited by the use of hierarchical routing, which reduces power consumption while simultaneously consolidating network data. It consists mostly of two layers: one for group leader selection and another for traffic routing throughout the network. However, it is critical to emphasize that the bulk of techniques in this sector have nothing to do with roads and everything to do with information distribution.

Routing is determined by the user's location: The sensor nodes may be identified by their placements in this kind of routing. The distance between two nodes that are physically near to one another may be approximated using the input signal's levels. Neighbors may exchange information to determine the location of nodes in their near area [20, 21, and 22]. To ascertain the position of the nodes, GPS devices may be used to establish a direct connection with a satellite. If no activity is detected on the nodes, a location-based system may be put to sleep [23, 24]. This is done in order to maintain electricity.

This section describes a selection of the several routing algorithms available. Several of these methods may fall under one or more of the earlier-mentioned routing types.

Rather than relying on a single route, multipath routing systems use a large number of pathways to optimize overall network performance. The fault tolerance of an algorithm is defined by the probability of an alternate path between a source and a destination being accessible in the case that the primary route is unavailable.

i. Algorithms for request-based routing (a.k.a. request-based routing): The destination nodes send a data query (detection task) via the network to a node, which then transfers the data. It returned to the node that started the inquiry in the first place. This kind of routing is shown in the previously stated directed broadcast.

ii. Negotiated routing methods: These systems make use of descriptors for data negotiation in order to minimize the amount of duplicate data provided. Their communication choices are also influenced by the resources accessible to them.

The network employs quality-of-service-based routing algorithms to strike a compromise between energy consumption and data quality (QoS). Prior to data being delivered to the base station, the network must satisfy certain requirements. The following table summarizes these parameters.

To operate successfully, Wi-Fi sensor networks (WSNs) rely on a diverse set of data processing techniques. Routing algorithms use a variety of data processing methods. Sensor nodes work together to process data in a more general way. Non-consistent data processing is another kind of data processing technology. In a non-consistent data processing routing architecture, nodes process data locally before transmitting it to other nodes for extra processing. Aggregators are the nodes that do the actual processing. After minimum processing, data is sent consistently to the "aggregators." Adding timestamps and eliminating duplicates are two common examples of basic processing.

4. PROPOSED METHOD

4.1 CHAPTER OVERVIEW

It is common for this network to be made up of hundreds or thousands of tiny autonomous devices (cm 3 or millimeters) known as sensors. Transceiver, power supply, sensing device, memory and CPU are the major components of a sensor node. In a sensor node, the software that runs on the CPU is the logical component [2]. An actuator is a piece of hardware that allows a WSN to take control of the observed environment's variables. The nodes themselves have a limited amount of processing and energy capability, but when they work together, they can achieve a tremendous deal [3] Remote areas (e.g., environmental reserves, oceans, volcanic craters) can be accessed via ad-hoc wireless networks, which can collect data on the phenomena of interest, perform local processing, and distribute the information to an access point via a multi-hop communication scheme without the intervention of technicians or operators. When a network connects with other networks or one or more observers, it uses an access point. A sink node, a sensor, may house the access point, or a base station can house it (BS - Base Station). It is possible to consider wireless sensor networks (WSNs) as an advanced kind of mobile ad hoc network (MANET) [4]. Soon, they will be able to access the Internet. Swarm intelligence (SI)-based role-playing games were investigated in detail by Rajesh Tiwari and his colleagues [11]. The author categorizes routing approaches for computer networks that are inspired by biological systems. From 2002 to 2015, he compiled a list of many conventional and SI-based routing methods and systems. Aside from ad hoc and wired networks, the author concentrated on wireless sensor networks (WSNs), pointing out that routing protocols for WSNs are unique from routing techniques for other systems due to the structural challenges that WSNs face. Network properties such as low computation and memory needs, self-organization, low power consumption, scalability, flexibility, and sensor connectivity have all been studied in the literature for networks. Several of the characteristics and taxonomic categorization of Si-based RPs were discussed in detail in the following sections: It was said that ant colonies, bee colonies, and particle swarms exist. Lime mold-based RPs were also addressed in the discussion. Their literature gives a more detailed classification of their work. By evaluating routing systems and offering future concerns for the same, Kalpana Guleria [12] and Amit Kumar Verma [12] were able to identify research gaps in routing protocols. They concentrated on RPs built on classical and SI foundations, respectively. The network structure and characteristics were utilized to further categorize the protocols, and the results were published. They also looked at swarm intelligence, hierarchical protocols, and hybrid protocols, among other things. Finally, they examined the problems and roadblocks that impeded the development of an energy-efficient hierarchical routing design, as well as the execution assessment metrics for the routing techniques under consideration.

Our paper advises that specific routing systems prioritize quality of service (QoS) and energy efficiency are optimized using a version of fast PSO algorithm for clustering the node in a WSN. Working on determining how effectively the routing protocol can deal with mobile nodes or sinks, dynamic topology overheads, energy constraints, and quality of service needs should be the primary emphasis of the research.

4.2 WSN

From a scientific point of view, WSNs present a wide variety of new problems that have not yet been studied or are still incipient research on sensor networks was considered one of the six most challenging areas of research. Another related area was the theory of wireless communication networks, which encompasses WSNs. In the subsection of the chapter, we list some of the problems related to the WSN:

i. There are various ways in which WSNs vary from typical computer networks. Many dispersed pieces make up the typical WSN, which runs without the need for direct human interaction, has significant energy limits and must have self-management systems (self-management). Self-organization, self-maintenance) as a result of dispersed deployment, low node capacity, and topological dynamics. It's possible for wireless sensor network (WSN) nodes to be removed from service due to a variety of causes such as a lack of power or an issue with deposition. [7].
ii. Even without the mobility of nodes, the network topology is dynamic. Traditional distributed algorithms such as communication protocols and leader election should be revised for this type of environment before being used directly.
iii. Many aspects affect the design of a WSN, including fault tolerance, scalability, manufacturing cost, operational environment, network architecture, hardware limits, transmission medium, and energy consumption. (3) Designing nodes and the protocol

stack as a whole must account for each of these considerations. Low-power hardware design and signal propagation mitigation measures are both essential to the physical layer's architecture.

iv. Determining the lower limit of power required for self-organizing the network, error control schemes, energy-saving operating modes, and mobility care are the data link layer challenges of network protocols. Medium access control.

v. Handling changes in topology, addressing, scalability and interfacing with other networks are expected requirements for the network layer. Transport layer protocols, on the other hand, must allow end-to-end communication diversity to calculate variations in the characteristics of the communication channel

vi. The local processing of data through correlation (merging, counting, aggregation, compression, etc.) are also requirements to be considered in the design of protocols for dissemination and querying the non-sensors, as well as the security requirements at each of the layers of the protocol stack.

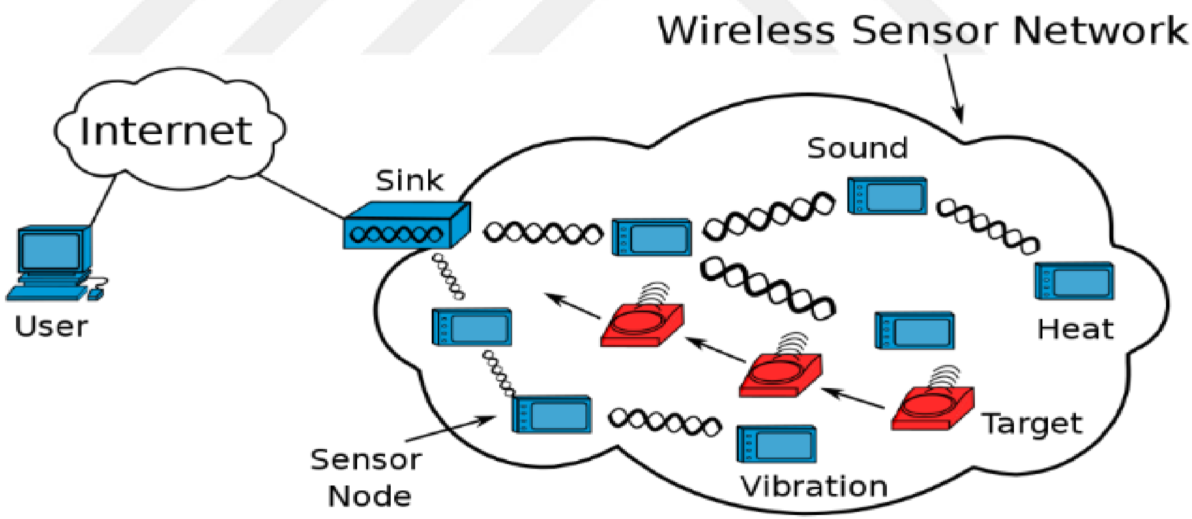

Figure 4.1: WSN Architecture.

4.3 PSO ALGORITHM

Eberhart and Kennedy (1995) invented PSO, a stochastic optimization technique based on swarm intelligence (1996). (1995). PSO is suitable for representing social creatures such as insects, livestock, birds, and fish, as well as a range of other organisms. To find food, these swarms communicate, with each swarm member adapting his or her search approach in response to the swarm's aggregate experiences. Swarm mode, akin to evolutionary algorithms, allowing PSO to simultaneously explore a large portion of the optimized objective function's solution space in the same manner as evolutionary techniques do. This is a defining feature of the PSO technique. Another field of research is artificial life, which is concerned with the development of systems that behave like live beings.

It is feasible to deduce solutions from a population of particles created by PSO with random velocities. Pbest is a unique identifier issued to each particle that serves as a reference point throughout the search procedure. In addition to the position gained by any particle in the current population, the global best value, gbesf, and the position acquired by any particle in the current population are two additional best values recorded by the global version of the particle swarm optimizer. The bootstrap approach is a statistical strategy for estimating population values that involves averaging estimates from several small data sets.

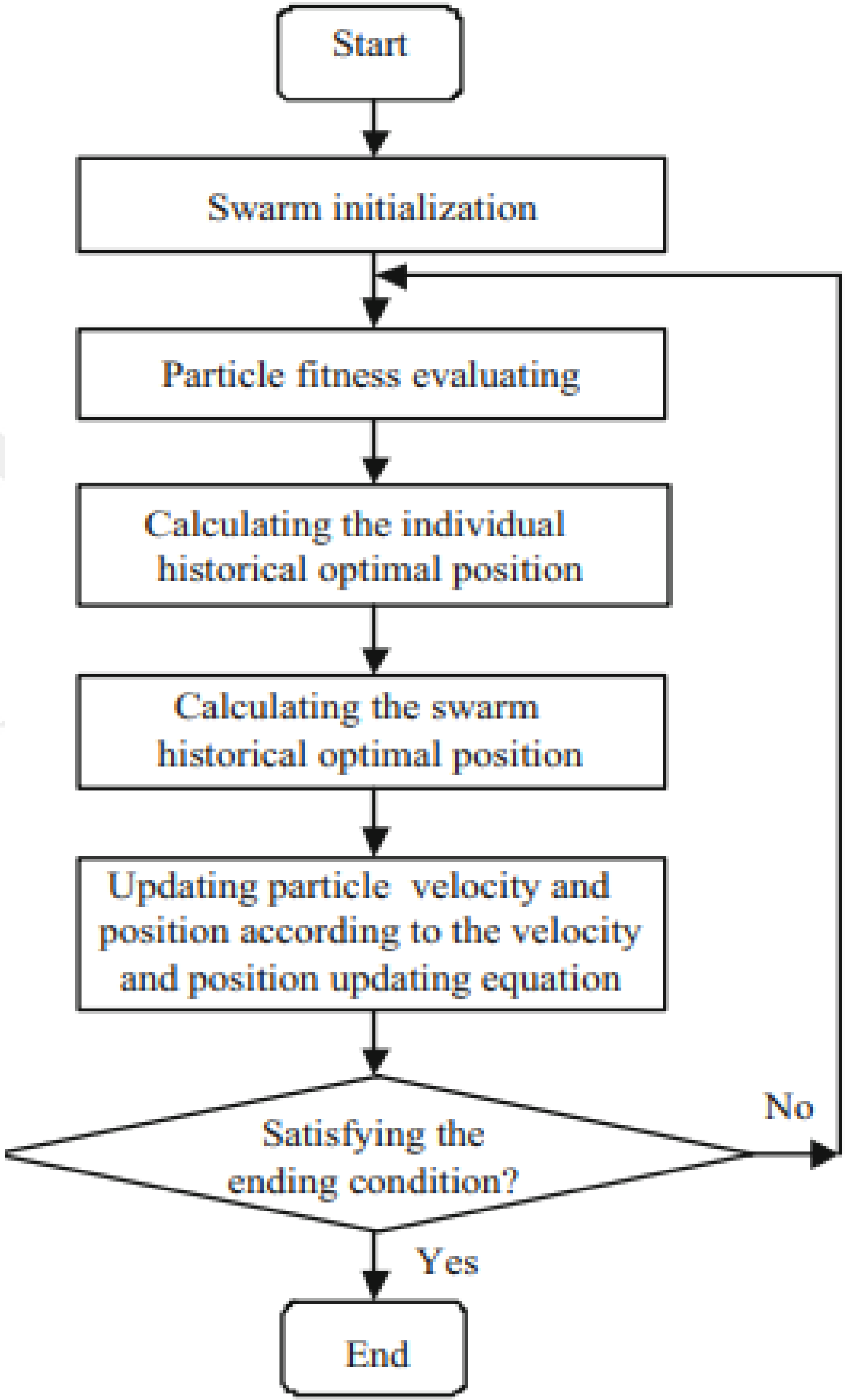

Figure 4.2: PSO algorithm steps.

In other words, samples are created by randomly picking observations from a huge dataset and then re-inputting them into the dataset. Due to the nature of this sampling procedure, one observation may be included many times in a small sample. This sample technique is referred to as "sampling with replacement.

The process for building one sample can be summarized as follows:
➢ Choose the size of the sample. ➢ While the size of the sample is less than the chosen size ➢ Randomly select an observation from the dataset ➢ Add it to the sample

i. The bootstrap method may be used to calculate the population size of a population. Small samples are gathered over time, and statistics are generated and averaged. This approach is summarized as follows:

ii. Select a few bootstrap tests to run.

iii. Utilize a small sample size.

iv. If you want to execute a bootstrap test many times, a replacement sample of the desired size may be drawn each time.

v. Conduct a statistical analysis of the sampled data.

vi. Divide the total number of samples by the average of the sample statistics you've collected so far.

vii. To get the PSO up and running, the following actions are required:

viii. To estimate population statistics, a dataset is sampled via replacement, and the sample is then used to estimate population statistics.

ix. This technique allows for the estimation of the mean and standard deviation. The capacity of a machine learning model to predict data that was not included in the training set may be evaluated.

x. When assessing the competency of a machine learning model, confidence intervals may be offered, which is a feature that is not typically accessible when using cross-validation or other approaches. Below, we will describe the bootstrapped PSO algorithm in further depth:

FOR each particle x_i in population P

$v_i = \underline{v} + (\overline{v} - \underline{v}) \times U_i(0,1)$;

//Use uniform probability distribution to initialize the velocity of particle x_i, where $\overline{v}$ and $\underline{v}$ denote the upper and lower boundary of velocity

$x_i = \underline{x} + (\overline{x} - \underline{x}) \times U_i(0,1)$;

//Use uniform probability distribution to initialize the position of particle x_i, where $\overline{x}$ and $\underline{x}$ denote the upper and lower boundary of search space

$pbest_i = x_i$;//The personal best position of each particle

END FOR

$gbest = \min_{x_i \in P} \left[f(x_i) \right]$;//The global best position of all particles

DO

FOR each particle x_i in population P

$v_i \leftarrow w \cdot v_i + c_1 \cdot r_1 \cdot (pbest_i - x_i) + c_2 \cdot r_2 \cdot (gbest - x_i)$;

//In this paper, we let $c_1 = c_2 = 2$. And, w decreases linearly from 0.9 to 0.4 with the increase of iteration.

$x_i \leftarrow x_i + v_i$;

IF $f(x_i) \prec f(pbest_i)$ THEN $pbest_i = x_i$; END IF

//Update the personal best position of each particle

IF $f(x_i) \prec f(gbest)$ THEN $gbest = pbest_i$; END IF

//Update the global best position of all particles

END FOR

UNTIL the termination condition is met

OUTPUT $gbest$;

4.4 PROPOSED ALGORITHM

In this work, three algorithms based on the Bootstrapped PSO metaheuristic are proposed to solve the problem of forming a fixed number of clusters in WSN. This problem can be considered as being a version of the p-median problem where the points (sensors) can be chosen as being median (cluter heads) and will be responsible for meeting the demands of the clients (member sensors). Clustering problems are combinatorial optimization problems known as NP-Hard [11] Thus, the development of an algorithm that solves the problem exactly in viable computational time is unlikely. In addition to the proposed approaches to the problem, a simulator was developed to perform the data transmission phase. In the simulation, initially the clustering algorithms are executed to form a network topology.

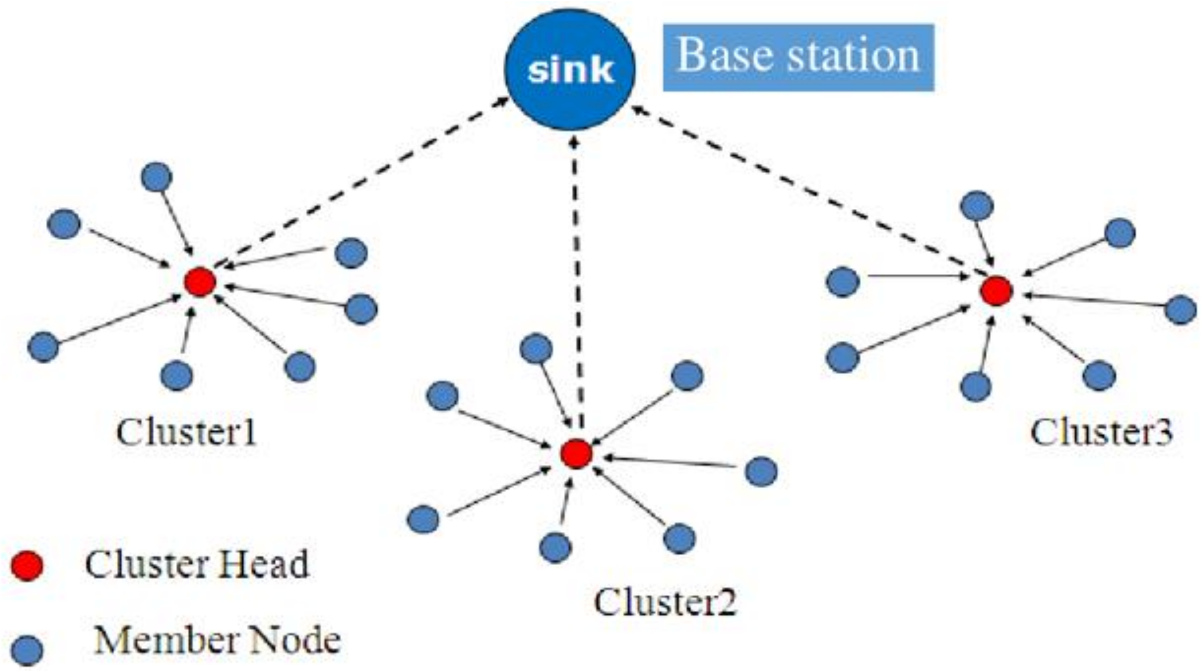

Figure 4.3: WSN clustering of cluster head CH.

4.5 BOOTSTRAPPED PSO SIMULATION

With the topology established, transmissions are made and the energy spent is subtracted from the energy of the sensors. The simulation is executed until the stop criterion is reached (the network is considered dead). This phase is important to evaluate the performance of the algorithms throughout the lifetime of the network. This phase is divided into rounds, as proposed by LEACH and a new network configuration is formed at each round (the clustering algorithm is executed again). Bootstrapped pso (greedy randomized adaptive search procedure) is a metaheuristic proposed in [12] widely used to solve combinatorial optimization problems to obtain good quality solutions in time. Acceptable computational bootstrapped pso is an iterative method where at each iteration a new solution is obtained, and consists of a construction phase followed by a local search phase The algorithm performs these two phases in several iterations until a stopping criterion is reached, which can be a maximum number of iterations, processing time, among others. The construction phase is responsible for generating a valid initial solution to the problem using a partially random greedy algorithm. In this phase, it is important to emphasize the presence of randomness in the generation of initial solutions, guaranteeing that at each bootstrapped pso iteration, the algorithm will have an initial solution potentially different. The local search phase is responsible for trying to improve the initial solution obtained in the previous phase in order to obtain an optimal location. At the end of the algorithm, the best solution found is returned as the new valid network topology.

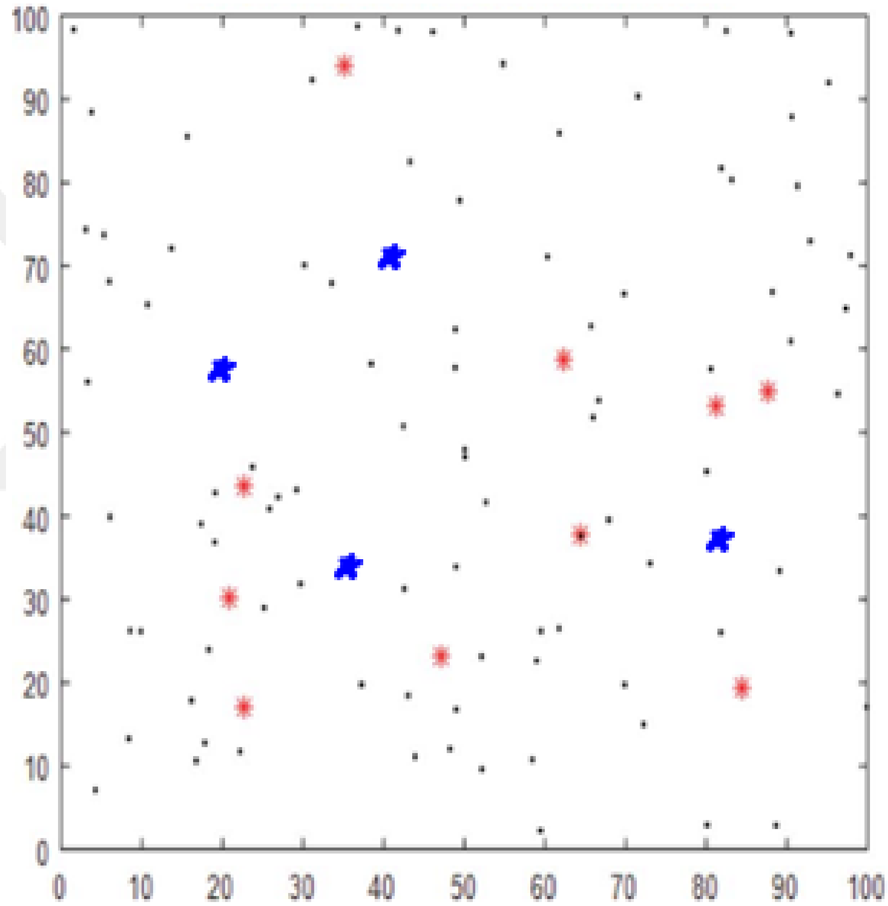

Figure 4.4: Red Nodes Ch_o , Blue Nodes Are The Chg Nodes And Black Nodes Are The WSN Nodes.

4.6 PATH RELINKING

The Path-Relinking technique is a mechanism with the purpose of combining intensification and diversification exploring the trajectory that connects two good quality solutions (solution elite actions) produced earlier during the local search phase. Path-Relinking requires a pair of distinct solutions, say CHo (source solution) and CHg (guide solution). There are several ways to implement Path Relinking [13] such as:

i. Forward relinking: the path is built from a CHo solution, which has the worst quality, towards c not to CHg.

ii. Backward relinking: the path is built from a CHo solution, which has the best quality, towards CHg.

iii. Bidirectional relinking: two paths are built, the first from CHo towards CHg and the other from CHg towards Cho.

iv. Mixed relinking: two paths are explored simultaneously originating from CHo and CHg, and meet in an intermediate solution.

In this work, two versions of Path Relinking were implemented: forward Path-Relinking and Backward Path-Relinking. The Forward Path-Relinking version obtained better results and therefore was adopted in this work. The Path-Relinking procedure starts from the source solution (CHo) and gradually transforms it into the guide solution (CHg). The transformation is done by inserting CHg −CHo elements and removing CHo −CHg elements. In other words, the path between two solutions is built by exchange moves. The number of steps needed to transform CHo into CHg is |CHg−CHo| (which is the same as |CHo−CHg|, which is the symmetric difference of CHo and CHg). At each transformation step, the best solution obtained is chosen. Solutions less and less similar to the source solution and more and more similar to the guide solution are generated. Path-Relinking returns the best solution found on the path between the two solutions.

4.7 CHAPTER CONCULSION

This work addressed the clustering problem in wireless sensor networks, which is a known NP-Hard problem. Thus, we opted for the use of heuristic techniques in order to obtain satisfactory results in viable computational time. An algorithm based on PSO were developed, which is a widely used metaheuristic to solve combinatorial optimization problems. The version of the algorithm, called Bootstrapped PSO was implemented using solution construction and local search techniques commonly used for the P-Medians problem. In order to improve the obtained results, we proposed adding a post-optimization phase based on Path Relinking. While MOPSO and PSO form clusters in only one level, bootstrapped PSO was developed to obtain multi-level topologies. In order to determine the best configuration for each algorithm, a parameter calibration analysis was carried out for each algorithm.

5. CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

This work addressed the clustering problem in wireless sensor networks, which is a known NP-Hard problem. Thus, we opted for the use of heuristic techniques in order to obtain satisfactory results in viable computational time. Three algorithms based on bootstrapped PSO were developed, which is a widely used metaheuristic to solve combinatorial optimization problems. The first version of the algorithm, called PSO was implemented using solution construction and local search techniques commonly used for the P-Medians problem. In order to improve the obtained results, the second version, called MOPSO was developed adding a post-optimization phase based on Path Relinking. While MOPSO and PSO form clusters in only one level, bootstrapped PSO was developed to obtain multi-level topologies. In order to determine the best configuration for each algorithm, a parameter calibration study was carried out for each algorithm. Thus, it is possible to observe the impact that each parameter has on the algorithm and it was possible to determine the value with the best cost/benefit for each parameter. Due to the lack of instances in the literature, a set of 100 distinct instances was generated, with a number of sensors ranging from 5 to 13. Several tests were carried out with clustering algorithms present in the literature. Bootstrapped PSO were compared with LEACH and LEACH-C in order to verify the difference between the single-level topology and the multi-level topology. Bootstrapped PSO was also compared with EEMC for multilevel topologies. Five executions of each algorithm were made for each instance and the average of these five executions was used as a final comparative result.

5.2 FUTURE WORK

For future work, it is possible to employ the use of other heuristic methods not yet used in this problem. Due to the diversity of WSN applications, there are many types of networks with particular characteristics (such as mobile sensors / cluster heads, sensors with different processing capacities and different types of data collection) that can be addressed using clustering with meta-heuristics.

REFERENCES

[1] S. Misra et al. (eds.), “Guide to Wireless Sensor Networks”, Computer Communications and Networks, Springer-Verlag London Limited 2009, ISBN 978-1-84882-217-7.

[2] Giordano S., Stojmenovic I., “Position Based Routing Algorithms for Ad Hoc Networks: A Taxonomy”, In: Cheng X., Huang X., Du DZ. (eds) Ad Hoc Wireless Networking. Network Theory and Applications, Boston, MA, Springer, vol. 14, pp. 103-136, 2014.

[3] L. D. Nardis and M. G. D. Benedetto, “Overview of the IEEE 802.15.4/4a standards for low data rate Wireless Personal Data Networks,” In 4th Workshop on Positioning, Navigation and Communication, pp. 285–289, March 2017.

[4] Santar Pal Singh and S. C. Sharma, “A survey on cluster-based routing protocols in wireless sensor networks”, International conference on advance computing technologies and applications, procedia, Computer Science, Elsevier, vol, 45, pp. 687-695, 2015.

[5] S. Mishra, R. Bano, S. Kumar and V. Dixit, "A literature survey on routing protocol in wireless sensor network", 2017 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS), Coimbatore, pp. 1-4, 2017.

[6] Olayinka O. Ogundile and Attahiru S. Alfa, “A Survey on an EnergyEfficient and Energy-Balanced Routing Protocol for Wireless Sensor Networks”, Sensors (Basel), 17(5), 1084, 2017.

[7] Ketshabetswe, Lucia Keleadile, et al. "Communication protocols for wireless sensor networks: A survey and comparison." Heliyon 5.5 (2019): e01591

[8] Shahul Hameed A. and Berlin Hency V., “A literature review on routing methods for wireless sensor networks”, International Journal of Pure and Applied Mathematics, vol. 120, no. 7, pp. 343-351, 2018.

[9] Mohammed Salman Arafath, Khaleel Ur Rahman Khan and K. V. N. Sunitha, “Pithy Review on Routing Protocols in Wireless Sensor Networks and Least Routing Time Opportunistic Technique in WSN”, 10th international Conference on Computer & Electrical Engineering, IOP Conf. Series, Journal of Physics, 11-13 October, Edmonton, Canada, 2017

[10] Kundaliya, B.L., Hadia, S.K. Routing Algorithms for Wireless Sensor Networks: Analysed and Compared. Wireless Pers Commun 110, 85– 107 (2020). https://doi.org/10.1007/s11277-019-06713-3.

[11] Kumar J., Tripathi S. and Tiwari R. K., "A survey on routing protocols for wireless sensor networks using swarm intelligence', International Journal of Internet Technology and Secured Transactions, vol. 6, No. 2, pp.79–102, 2016.

[12] Kalpana Guleria and Anil Kumar Verma, "Comprehensive review for energy efficient hierarchical routing protocols on wireless sensor networks", Wireless Networks, vol. 25, Issue 3, pp. 1159-1183, 2019.

[13] Kaur T. and Kumar D., "Computational intelligence-based energy efficient routing protocols with QoS assurance for wireless sensor networks: a survey', Int. J. Wireless and Mobile Computing, vol. 16, no. 2, pp.172–193, 2019

[14] Al-Mousawi, A.J. Evolutionary intelligence in wireless sensor network: routing, clustering, localization and coverage. Wireless Netw 26, 5595–5621 (2020). https://doi.org/10.1007/s11276-019- 02008-4

[15] Mohamed, Reem E., Ahmed I. Saleh, Maher Abdelrazzak, and Ahmed S. Samra. "Survey on wireless sensor network applications and energy efficient routing protocols." Wireless Personal Communications 101, no. 2 (2018): 1019-1055.

[16] Islam, Tariq, and Yong Kyu Lee. "A Comprehensive Survey of Recent Routing Protocols for Underwater Acoustic Sensor Networks." Sensors 19.19 (2019): 4256.

[17] M Khalil, A Khalid, FU Khan and A Shabbir, "A Review of Routing Protocol Selection for Wireless Sensor Networks in Smart Cities", 24th Asia-Pacific Conference on Communications (APCC), IEEE, pp. 610-615, 2018

[18] Lin Li, Donghui Li, "An Energy-Balanced Routing Protocol for a Wireless Sensor Network", Journal of Sensors, vol. 2018, 12 pages, 2018. https://doi.org/10.1155/2018/8505616.

[19] Istwal, Yasha, and Shashi Kant Verma. "Dual cluster head routing protocol with super node in WSN." Wireless Personal Communications 104.2 (2019): 561-575.

[20] Amine Rais, Khalid Bouragba, Mohammed Ouzzif, "Routing and Clustering of Sensor Nodes in the Honeycomb Architecture", Journal of Computer Networks and Communications, vol. 2019, 4861294, 12 pages, 2019. https://doi.org/ 10.1155/2019/4861294.

[21] Liang, H., Yang, S., Li, L. et al. Research on routing optimization of WSNs based on improved LEACH protocol. J Wireless Com Network 2019, 194 (2019). https://doi.org/10.1186/s13638-019-1509- y.

[22] Hamzah, Abdulmughni, et al. "Energy-efficient fuzzy-logic-based clustering technique for hierarchical routing protocols in wireless sensor networks." Sensors 19.3 (2019): 561.

[23] Wu, H., Zhu, H., Zhang, L., & Song, Y. (2019). Energy Efficient Chain Based Routing Protocol for Orchard Wireless Sensor Network. Journal of Electrical Engineering & Technology, 14(5), 2137-2146.

[24] Thangaramya, K., Kulothungan, K., Logambigai, R., Selvi, M., Ganapathy, S., & Kannan, A. (2019). Energy aware cluster and neurofuzzy based routing algorithm for wireless sensor networks in IoT. Computer Networks, 151, 211-223.

[25] Chithaluru, Premkumar, Rajeev Tiwari, and Kamal Kumar. "AREOR– Adaptive ranking based energy efficient opportunistic routing scheme in Wireless Sensor Network." Computer Networks 162 (2019): 106863.

[26] Mengjia Zeng, Xu Huang, Bo Zheng, Xiangxiang Fan, "A Heterogeneous Energy Wireless Sensor Network Clustering Protocol", Wireless Communications and Mobile Computing, vol. 2019, 11 pages, 2019. https://doi.org/10.1155/2019/7 367281.

[27] Aranzazu-Suescun, C., & Cardei, M. (2019). Anchor-based routing protocol with dynamic clustering for Internet of Things WSNs. EURASIP Journal on Wireless Communications and Networking, 2019(1), 130.

[28] Rodríguez, Alma, Carolina Del-Valle-Soto, and Ramiro Velázquez. "Energy-Efficient Clustering Routing Protocol for Wireless Sensor Networks Based on Yellow Saddle Goatfish Algorithm." Mathematics 8.9 (2020): 1515.

[29] Kashif Naseer Qureshi, Muhammad Umair Bashir, Jaime Lloret, Antonio Leon, "Optimized Cluster-Based Dynamic Energy-Aware Routing Protocol for Wireless Sensor Networks in Agriculture Precision", Journal of Sensors, vol. 2020, 19 pages, 2020.

[30] Anamika Walter, Manoj Singh and Shankar Sharan Tripathi, “Energy efficient routing protocol in wireless sensor network”, International Journal of Computer Engineering and Technology (IJCET), vol. 11, Issue 2, pp. 31-48, March-April 2020.

[31] Nalluri Prophess Raj Kumar and Josemin Bala Gnanadhas, “Cluster Centroid-Based Energy Efficient Routing Protocol for WSN-Assisted IoT”, Advances in Science, Technology and Engineering Systems Journal, vol. 5, No. 4, pp. 296-313, 2020.

[32] Turki Ali Alghamdi, “Energy efficient protocol in wireless sensor network: optimized cluster head selection model”, Telecommunication Systems, Springer, vol. 74, pp. 331-345, 2020.

[33] Mehta, Deepak, and Sharad Saxena. "MCH-EOR: Multi-objective cluster head based energy-aware optimized routing algorithm in wireless sensor networks." Sustainable Computing: Informatics and Systems 28 (2020): 100406.

[34] El Khediri, S., Khan, R. U., Nasri, N., & Kachouri, A. (2020). Energy efficient adaptive clustering hierarchy approach for wireless sensor networks. International Journal of Electronics, 1-20.

[35] Shivkumar S. Jawaligi and G. S. Biradar, “QoS oriented and delay tolerant WSN routing protocol for data gathering in IoT ecosystem”, International Journal of Internet Technology and Secured Transactions, vol. 8, No. 3, pp. 480-487, 2018

[36] Habib Mostafaei, “Energy-Efficient Algorithm for Reliable Routing of Wireless Sensor Networks”, IEEE Transactions on Industrial Electronics, vol. 66, Issue 7, pp. 4467-4475, July 2019.

[37] N. Z. Cedeño, O. P. Asqui and E. E. Chaw, "The performance of QoS in wireless sensor networks", 2019 14th Iberian Conference on Information Systems and Technologies (CISTI), Coimbra, Portugal, pp. 1-5, 2019.

[38] Haseeb K., Abbas N., Saleem M. Q., Sheta O. E., Awan K., Islam N., et al., “RCER:Reliable Cluster-based Energy-aware Routing protocol for heterogeneous Wireless Sensor Networks”, PLoS ONE 14(9), 2019.

[39] Layla Aziz, Hanane Aznaoui, "Efficient Routing Approach Using a Collaborative Strategy", Journal of Sensors, vol. 2020, Article ID 2547061, 17 pages, 2020.

[40] R. Sunitha, J. Chandrika, “Evolutionary Computing Assisted Wireless Sensor Network Mining for QoS-Centric and Energy-efficient Routing Protocol”, International Journal of Engineering (IJE), IJE Transactions B: Applications, vol. 33, No. 5, pp. 791-797, May 2020.

[41] Srivastava, Vikas, Sachin Tripathi, and Karan Singh. "Energy efficient optimized rate based congestion control routing in wireless sensor network." Journal of Ambient Intelligence and Humanized Computing 11.3 (2020): 1325-1338.

[42] A. Hawbani et al., "Zone Probabilistic Routing for Wireless Sensor Networks", in IEEE Transactions on Mobile Computing, vol. 18, no. 3, pp. 728-741, 1 March 2019.

[43] Miyandoab, Fardin Derogarian, João Canas Ferreira, and Vítor M. Grade Tavares. "Analysis and evaluation of an energy-efficient routing protocol for WSNs combining source routing and minimum cost forwarding." Journal of Mobile Multimedia 14.4 (2018): 469-504.

[44] X. Wang, Y. Peng and L. Huang, "An Improved Unequal ClusterBased Routing Protocol for Energy Efficient Wireless Sensor Networks," 2019 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS), Changsha, China, pp. 165-169, 2019.

[45] Selvi M., Thangaramya K., Ganapathy S. et al., “An Energy Aware Trust Based Secure Routing Algorithm for Effective Communication in Wireless Sensor Networks”, Wireless Pers. Commun., vol. 105, pp. 1475–1490, 2019.

[46] Deebak, Bakkiam David, and Fadi Al-Turjman. "A hybrid secure routing and monitoring mechanism in IoT-based wireless sensor networks." Ad Hoc Networks 97 (2020): 102022.