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Lightweight and Efficient Cluster-based Routing Protocol for Wireless Sensor Networks

بروتوكول توجيه خفيف الوزن وفعال قائم على نموزج التجميع في شبكات الاستشعار اللاسلكية

A Thesis Submitted in partial fulfillment for the Requirements of the Degree of Doctor Philosophy in computer science

By

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DEDICATION

To my Lovely parents, Wife, and Daughters.

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All praise to Allah (s.w.t) the most Gracious and most Merciful, by whose grace and blessing this work has been completed. I would like to take this opportunity while relying on the instruction of the Prophet to the effect that "whoever does not thank people does not thank Allah" to express my thanks and gratitude to those who have contributed in one way or another through their advice, criticism, and support in strengthening the quality of this work. I would like to express my gratitude to those who have helped me in my pursuit of knowledge.

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ABSTRACT

Wireless Sensor Networks (WSNs) has gained a great significance from researchers and industry due to its wide applications. The discovery of effective service and removing redundancy are a key to achieve a higher level of ubiquity. Nevertheless, clustering techniques offer many solutions to address the WSN issues, such as energy efficiency, service redundancy, routing delay, scalability, and making WSNs more efficient. Unfortunately, WSNs are still immature and suffering in several aspects. Clustering systems divide sensor networks into many groups. Each group may elect a specific node as a cluster head (CH) to represent the group in the data sending process and the remaining nodes are regular nodes. The CH election approach is playing a key role in improving the network lifetime and reducing the network delay. This research study presents a comprehensive survey, discussing the various issues and challenges facing the design and selection of the appropriate service discovery and cluster-based routing protocols. Additionally, it investigates available clustering techniques. Moreover, to solve the downsides in existing Cluster-based routing protocols in WSNs, a Lightweight and Efficient Dynamic Cluster Head Election Routing (LEDCHE-WSN) Protocol is proposed. The proposed routing algorithm comprises two integrated methods, electing the optimum cluster head, and organizing the re-clustering process dynamically. Finally, the proposed algorithm's mathematical modeling and analysis are introduced. The experimental results reveal the proposed protocol outperforms the LEACH protocol by approximately 32% and the FBCFP protocol by 8%, in terms of power consumption and network lifetime. In terms of Mean Package Delay, LEDCHE-WSN improves the LEACH protocol by 42% and the FBCFP protocol by 15%, and regarding Loss Ratio, it improves the LEACH protocol by approximately 46% and FBCFP protocol by 25%.

المستخلص

في الآونة الأخيرة، اكتسبت شبكات الاستشعار اللاسلكية (WSN) أهمية كبيرة من قبل الباحثين والمؤسسات الصناعية بسبب تطبيقاتها الواسعة. إن اكتشاف الخدمة (service discovery) الفعالة وإزالة التكرار (service redundancy) هي المفتاح الأساسي لتحقيق مستوى أعلى من التواجد في كل مكان. ومع ذلك، تقدم تقنيات التجميع العنقودية (clustering techniques) العديد من الحلول لمعالجة مشكلات شبكات الاستشعار اللاسلكية، مثل كفاءة استخدام الطاقة، وتكرار الخدمة، وتأخير التوجيه، والقابلية للتوسع، وجعل شبكات الاستشعار اللاسلكية أكثر كفاءة. لسوء الحظ، لا تزال شبكات الاستشعار اللاسلكية غير ناضجة وتعاني من عدة جوانب. تقسم أنظمة التجميع العنقودية (Clustering systems) شبكات الاستشعار الى العديد من المجموعات. تنتخب كل مجموعة عقدة محددة - تعرف برأس الكتلة (CH) - لتمثيل المجموعة في عملية إرسال البيانات، والعقد المتبقية تعرف بالعقد العادية. يلعب نهج إنتخاب رأس الكتة دورا محورياً في تحسين عمر الشبكة وتقليل التأخير الحاصل فيها. يقدم هذا البحث دراسة استقصائية شاملة، مع مناقشة مختلف القضايا والتحديات التي تواجه تصميم واختيارالأنسب من بين بروتوكولات إكتشاف الخدمة و البروتوكولات القائمة على التجميع. بالإضافة إلى ذلك، يبحث في تقنيات التجميع المتاحة. و لحل القصور الحاصل في بروتوكولات التوجيه القائمة على المجموعة في شبكات WSNs، تم اقتراح بروتوكول توجيه خفيف الوزن وفعال قائم على نموزج التجميع في شبكات WSNs و الذي سنطلق عليه لغرض هذا البحث اسم (LEDCHE-WSN). تضم خوارزمية التوجيه المقترحة طريقتين متكاملتين، انتخاب رأس المجموعة الأمثل، و عملية إعادة تنظيم و تجميع العنقود ديناميكياً. أخيراً، يتم تقديم النماذج الرياضة للخوارزمية المقترحة وتحليلها. تكشف النتائج التجريبية للبروتوكول المقترح تفوقها على بروتوكول LEACH بنحو 32٪ وعلى بروتوكول FBCFP بنسبة 8٪، من حيث استهلاك الطاقة وعمر الشبكة. و من حيث متوسط تأخير الحزمة، يحسن البروتوكول المقترح LEDCHE-WSN بروتوكول LEACH بنسبة 42٪ وبروتوكول FBCFP بنسبة 15٪، وفيما يتعلق بنسبة الخسارة، فإنه يحسن بروتوكول LEACH بنحو 46٪ وبروتوكول FBCFP بنسبة 25٪.

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LIST OF SYMBOLS/ABBREVIATIONS

6LoWPAN	IPV6 over Low-Power Wireless Personal Area Networks
BAN	Body Area Network
BBC	Beacon Based Clustering
BS	Base Station
CDSWS	Coverage-guaranteed Distributed Sleep/Wake Scheduling
CH	Cluster Head
CPM	Cluster-based Power Management
CS	Compressed Sensing
DBF	Dynamic Bloom Filter
DFLER	
DHT	Distributed Hash Table
DNS	Doman Name Service
ECATCH	Efficient CATCH Algorithm
ELEACH	Enhanced Low Energy Adaptive Clustering Hierarchy
FBCFP	Fuzzy Based Cluster Formation Protocol
FEMCHRP	Fuzzy-Based Energy-Efficient Multiple Cluster Head Selection Routing Protocol for Wireless Sensor Networks
GA	Genetic Algorithm
HWSNs	Heterogeneous WSNs
IoT	Internet of Things
IP	Internet Protocol
LEACH	Low Energy Adaptive Clustering Hierarchy
LEDCHE-WSN	Lightweight and Efficient Dynamic Cluster Head Election Routing
LRTCP	Lightweight Redundancy aware Topology Control Protocol
MAC	Media Access Control
MANETs	Mobile Ad-hoc Networks
MR-LEACH	Measure Ranking LEACH
NCCM-DC	Network Coding based Cluster-level Multipath protocol in Duty-Cycled

NR	Node Rank
NR-LEACH	Node ranked Low Energy Adaptive Clustering Hierarchy
OASIS	Advancement of Structured Information Standards
OWL-DL	Ontology Description logics
P2P	Peer to peer
QoS	Quality of Service
QoS	Quality of Service
SCALAR	Scalable data Lookup and Replication protocol
SD	Service discovery
SDM	Service Discovery Message
SN	Sink Node
SOA	Service Oriented Architecture
TDMA	Time Division Multiple Access
TLV	type-length-value
TLV	Type-Length-Value
TTL	Time to Live
VANETs	Vehicular Ad-hoc Networks
WSN	Wireless Sensor Network
WSNs	Wireless Sensor Networks

CHAPTER I

INTRODUCTION

1.1 Introduction

The current studies are focusing on WSNs, as well as wireless ad-hoc network research, which is generally seen in different protocol layers and has been reviewed in [1-7], and on energy efficiency [8-9]. Mobile and wireless computing have recently evolved, so that the Internet can be connected and surfed wirelessly anywhere and anytime. Furthermore, in most WSN cases, a non-rechargeable battery is used as a sensor's power resource. Thus, distances between nodes are highly increases the energy consumption. Recent researchers have proposed many routing protocol algorithms to address the challenges of MANETs, such as limited nodes power, mobile node failure, limited bandwidth, topology changes, link, etc. Figure 1.1 illustrates the general classification of WSNs and MANETs routing protocols.

Recently, research trends also discuss how to exploit local and foreign services with unknown infrastructure. The emergence of the location-based services makes the Peer-to-Peer service discovery process so important issue for the ubiquity computing.

Service discovery (SD) is the cornerstone of wireless and mobile systems. The discovery of effective service is the key to achieving a higher level of ubiquity, which ensures the availability of services to users and applications significantly, and the high use of services. The research in this field is limited, with a few SD protocols available for specific purposes specified in the 6LoWPAN region. Recently, service-based computing has become a destination for WSNs and MANETs, so the movement of devices and the dynamic nature of the environment pose major challenges to access to knowledge about available services. Various studies have concluded that the computing model located anywhere, anytime can be used for mobile and wireless devices for service providers as well as for service users. As the number of applications in the network continues to grow, the number of services available in the network will continue to grow. In monitoring applications, some sensor nodes collect and detect correlated and redundant data simultaneously. Generally, the cross-layer approach is an important concept to design ad-hoc and/or WSN network routing protocols [10]. Data aggregation is considered a major technique to collect, eliminate and minimize correlated and redundant data by reducing the number of a packet transmitted to the base station, which results in saving power consumption and bandwidth [11], [12]. Further, the Clustering technique is an effective solution to the problem of backbone construction and maintenance in both wireless sensor networks and mobile ad-hoc networks due to their self-regulating nature [13].

Accordingly, the cluster-head approach as the core of typical clustering algorithms is used to achieve a balanced distribution for energy consumption. Wrong selection to the cluster head often causes early depletion of the network energy [10]. Additionally, the attackers can get full control of whole the network without any need to get other nodes, when they get control of all cluster heads. Conversely, the proper cluster head electing may decrease the energy consumption, ensure a constant data flow, increase the data integrity level, and prolong network lifetime [10]. As is well known, the distance between nodes and base stations increased, the time delay is increased. Likewise, the CH must be selected in a way that is closer spatially enough to the base station as well as sensor nodes. As a result, the time delay can be reduced effectively, and the speed of the data transmission can be increased accordingly [1].

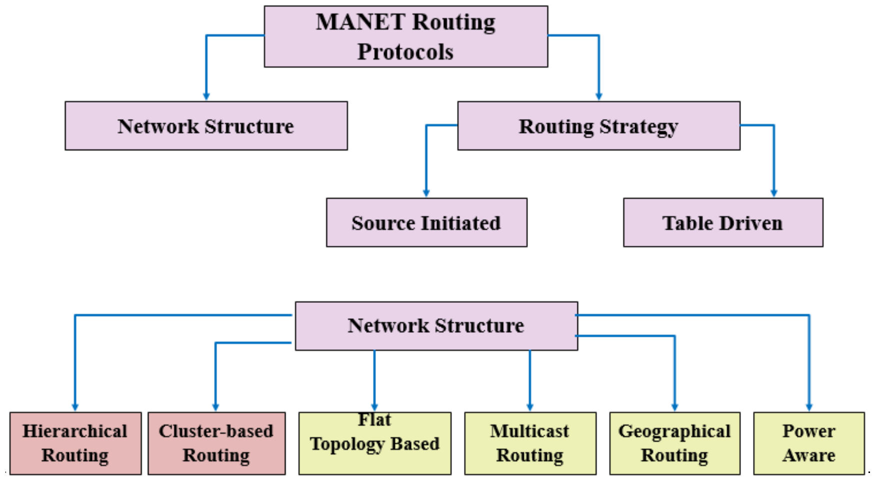

Figure 1.1. General classification of WSNs and MANETs routing protocols.

1.2 Problem Statement and its Significance

Clustering is a common approach used to reduce power consumption and service redundancy issues; however, it lacks a method for electing an optimum cluster head to enhance the data aggregation efficiency. Furthermore, inefficient cluster head election leads to the high-power consumption of the sensor nodes. Besides, the extensive calculation in the cluster head election process, such as node centrality measure, hop count, and density, results in energy depletion quickly, consequently, shortening the lifetime of the network. Finally, the high delays of the WSNs are due to the energy-based path selection. Nevertheless, many proposed algorithms are using different factors and strategies for selecting cluster heads and their role is rotating through sensor nodes to attain load balancing resulting in prolonging the network lifetime.

1.3 Research Question/Hypothesis/Philosophy

1.3.1 Research Question

The main question that will be addressed in this study is how to introduce a Lightweight and efficient Cluster Head Election Routing Protocol for

Wireless Sensor Networks. In addition, there are some additional questions such as follows:

1. Does the proposed protocol is more energy efficient when compared with other relevant protocols?
2. Does the proposed protocol distribute the power load equally between network sensors and better than LEACH protocol?
3. Does the proposed protocol work properly and it will introduce acceptable performance, in terms of energy consumption, latency, and network lifetime?.

1.3.2 Research Hypothesis

The proposed LEDCHE-WSN protocol introduces two integrated methods, electing the optimum cluster head, and making the re-clustering process dynamically. Furthermore, the experimental results of the proposed algorithm can ensure efficient and acceptable performance in terms of energy consumption, latency, loss ratio, and network lifetime

1.3.3 Research Philosophy

The philosophy of the proposed solution is based on many factors; firstly, the proposed LEDCHE-WSN protocol used a hybrid clustering model, a single-hop model is adopted at the cluster core, to make it more simple, fast, lightweight, and easy to deploy. While the multi-hop model is used at the cluster edge to make it more connective and scalable. Moreover, the proposed protocol used a combination of random and periodic methods per round. During the CH election process, the periodic method is used to achieve a good load balance for the network and the random method at the beginning of each round was adopted to provide network security and confidentiality with the addition of some procedures to avoid the limitations of the two methods. Furthermore, the proposed protocol lifted from the regular nodes the cluster formation processes. Instead, the rechargeable SN will do all the previous jobs.

1.4 Research Objectives

The main objective of this study is to propose a new lightweight and efficient dynamic cluster head election routing protocol for wireless sensor networks (in terms of energy consumption, latency, loss ratio, and network lifetime). To reach this main objective, the following partial objectives were defined:

1. Proposal of a new efficient and acceptable performance routing protocol in terms of energy consumption, latency, and loss ratio.
2. Performance assessment of the benchmark protocols that will be used to evaluate and validate the proposed routing protocol
3. Performance evaluation and validation of the proposed algorithms in comparison with other available solutions in the literature.

1.5 Research Scope

This study is mainly focused on investigating and proposing a new lightweight and efficient dynamic cluster head election routing protocol for wireless sensor networks to enhance the cluster-based networks in terms of energy consumption, latency, and network lifetime. This protocol will be implemented in the Sink Node (SN) gateway to select an optimum cluster head dynamically, which enhances the data aggregation efficiency. Finally, the proposed model is compared with other relevant ones to evaluate its efficiency. Figure 2.7 illustrates the scope of this research.

1.6 Research Methodology

The research study followed the quantitative and qualitative research methods. After a comprehensive survey and comparisons about recent techniques in the research field is conducted, a valuable conclusions and observations was reached. Moreover, the new proposed solution was formulated using the mathematical models, flowcharts, and pseudo-code algorithms and simulation to obtain the results. The effectiveness of the new solutions evaluated by comparing the results obtained from the simulation with the most recent counterpart's protocols in terms of energy consumption, latency, loss ratio, and network lifetime.

1.7 Research Contributions

The main contributions of this study can be identified as follows:

1. Proposing a new method to elect the optimum cluster head in Cluster-Based routing protocols of the WSNs

2. Proposing a new method to deal with the failure and/or dead nodes and re-clustering the Cluster-Based Wireless Sensor Networks

3. Performance evaluation and validation of LEDCHE-WSN in comparison with other available solutions in the literature using different scenarios

1.8 Thesis Organization

This thesis is organized into six chapters and the remaining chapters are organized as follows:

Chapter 2, Literature Review: Critically investigates and reviews the state-of-the-art of service discovery protocols considering the redundancy issues. Furthermore, the concepts of the clustering approach are extensively covered.

Chapter 3, Methodology: Describes the methodology used to achieve the objectives of this study. It also specifies the two integrated methods used in the proposed protocol, electing the optimum cluster head, and dynamically organizing the re-clustering process.

Chapter 4, Simulation Tool and its Deployment: Describes the simulation tool used, and why it was chosen. It also describes the network simulation setup, parameters, and corresponding values used to evaluate and validate the performance of the proposed protocol.

Chapter 5, Performance Evaluation and Results Analysis: The effectiveness of the proposed approaches has been proved in this chapter, by comparing the simulated results with its most recent counterpart's protocols in terms of energy consumption, latency, and network lifetime.

Chapter 6, Conclusion and Future Work: Discusses and highlights the contributions and findings of the research work and presents suggestions and recommendations for future study.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter investigates and reviews the state-of-the-art of service discovery protocols and cluster-based routing protocols and their compatibility with WSNs and MANETs. Moreover, different issues and challenges are discussed such as power consumption and redundancy problems with reviewing the data aggregation and clustering techniques as famous cross-layer solutions. The aspects of this chapter can be summarized as follows; the service discovery protocols are critically investigated considering the redundancy problem, methods, mechanisms, and architectures by categorizing them into different categories, comparing them with fundamental parameters in the WSNs, and MANETs environments. Attention has been drawn to the cross-layer solution by discussing different clustering techniques used to solve the power consumption and redundancy problems. The concepts of the clustering approach are extensively covered with a review and discuss famous Cluster Head Election, re-clustering, and self-organization strategies used to enhance the performance of the clustering approach.

2.2 Background

In this section, before the complete survey of service discovery and cluster-based routing protocols in wireless sensor and mobile ad ho networks, the basic concepts of service discovery and clustering approaches, different backgrounds, and requirement ideas will be reviewed first to understand the upcoming aspects.

Wireless Sensor Networks

Wireless Sensor Network (WSN) consists of a large number of sensor nodes, monitors, collects, and processes data of physical and environmental conditions, and then transmits this information to the user terminal wirelessly [14]. The wireless sensor network is one of the most important networks of MANETs, which has gained more attention from researchers due to its wide and vital applications. Figure 2.1 shows popular MANETs Networks.

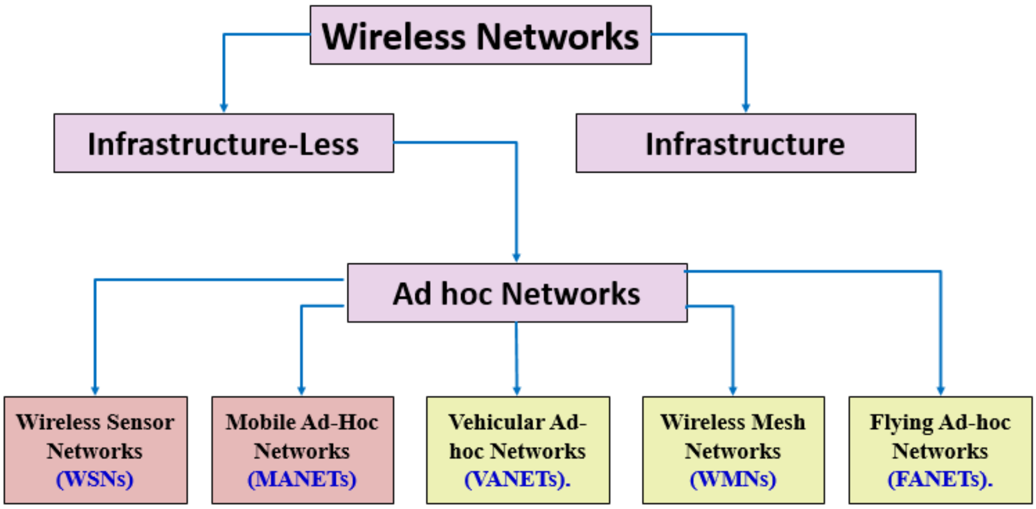

Figure 2.1. Popular WSNs and MANETs Networks.

Recent research trends give more attention to Wireless Sensor Networks when compared with Mobile Ad-Hoc Networks and Vehicular Ad-hoc Networks, which gives this survey great importance. Figure 2.2 reflects the interest of the WSNs research in the past five years.

Mobile Ad hoc Network

A Mobile Ad hoc Network (MANET) represents the ultimate scenario where the network is operated without any fixed infrastructure support at all. Such networks can be deployed very quickly and are inexpensive, as they do not invoke basic infrastructure costs. MANET applications cover various areas, such as military or post-disaster rescue operations, temporary group collaboration at conferences or lectures, sensor networks, and many others [14].

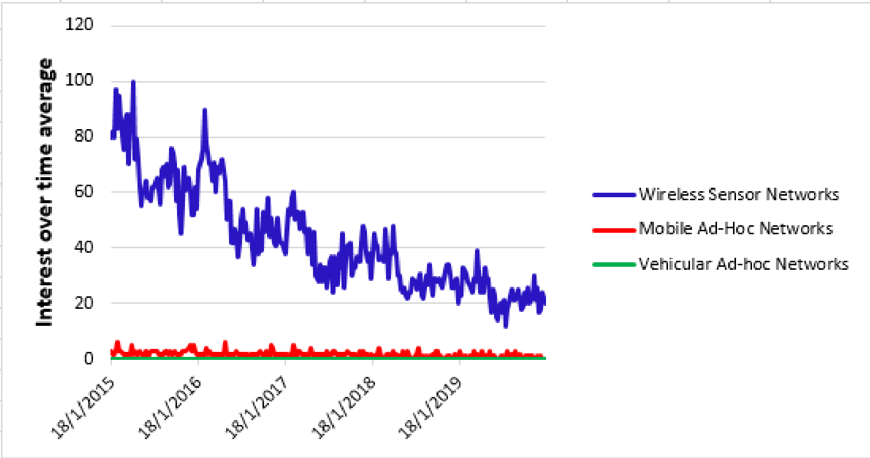

Figure 2.2. The current trend on WSNs, MANETs, and VANETs (source: Google Trends).

Service Discovery

The basic function of the node is to provide a mechanism for data and service discovery provided by other nodes to exchange data and various services on the network, this lookup mechanism is termed service discovery (SD) [15]. Briefly, service discovery comprises the identification and location of the services and resources desired by the client [16]. Figure 2.3 is proposed to illustrate the service discovery process in the MANETs and WSNs.

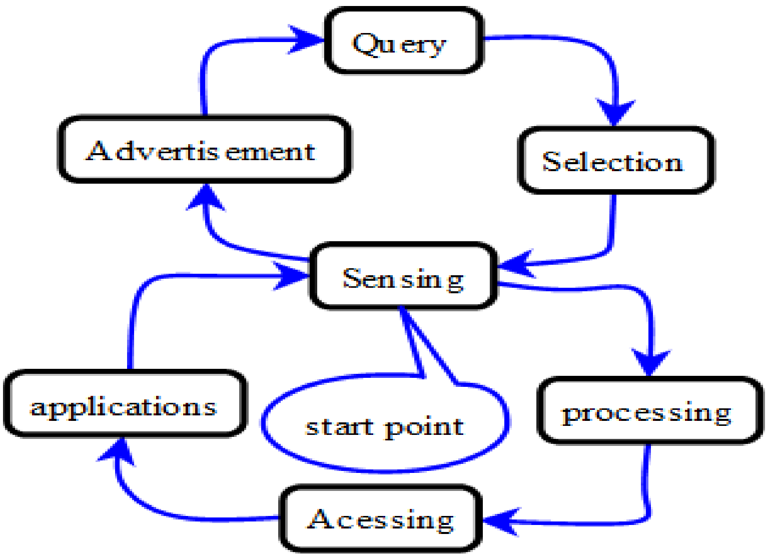

Figure 2.3. The service discovery process in WSNs.

Redundancy Phenomena

All wireless sensor networks are approximately diffused with some degree of redundancy. In surveillance systems, the sensor set may detect one goal of interest at the same time, when multiple copies of the same packet are sent within the network [17]. The data collected are often highly interrelated and redundant. Moreover, it will dissipate energy and lose network power quickly. As a result, redundancy is considered as one of the great problems in the service discovery aspects which drain the energy effectively [11]. So, the optimal use of the spatiotemporal correlation of readings between sensing nodes and the development of the reduction of data redundancy efficiently to save energy are problems that need urgent solutions [18].

6LoWPAN

6LoWPAN [19] is designed as a protocol to allow packets IPv6 to be transmitted on low power networks, specifically IEEE802.15.4. The main objective was to design an adaptive layer that provides several essential functions to improve the shaping of the package IPv6 to IEEE 802.15.4 frames [20], [21].

Cross-layering

Cross-layering is the interaction between the layers in the protocol stack. The research community understands the significant contributions that cross-layers introduced to network performance. Furthermore, cross-layer is designed to eliminate repetitive functions in neighbor layers, and to improve the overall performance of the network, the interconnectivity between stack layers is exploited. Recent studies have shown that integrated cross-layers improve network performance in terms of energy efficiency [22]. Nonetheless, the presented literature is limited to investigating various service redundancy problems and discussing different Cluster-based Routing Protocols methods proposed to solve those problems in Wireless Sensor and Mobile Ad-Hoc Networks.

Clustering Technique

The Clustering process is to divide the sensor network into many groups. Each group elects its cluster head, which is considered as a leader to represent the cluster in the process of sending data. Cluster head election can be set by the network designer or can be done by sensor nodes. Clustering techniques could be used to solve many constraints in wireless sensor networks by authorizing the sensor's architecture differently. It is performed by aggregating the sensors into clusters and giving a specific task to each sensor, then transferring data to upper levels. The main goals of clustering techniques are to gain high energy efficiency, reuse of bandwidth, targets tracking, data collection, and guarantee a long lifespan of the network. Furthermore, clustering is considered one of the famous techniques used to face power consumption and redundancy phenomenon during the process of service discovery [11], [12]. Here, the importance of integration between routing and service discovery is evident. Figure 2.4 and Figure 2.5, illustrate some applications of the clustering concept in military surveillance and precision agriculture monitoring.

Cluster Head and Clustering Operations

Clustering systems divide sensor networks into many groups. Each group elects a specific node as a cluster head to represent the group in the data sending process and the remaining nodes are regular nodes [1].

The rule in operations of clustering considers several rounds. Every round starts with two stages; the preparation stage and the steady-state stage. The first stage involves a mass formation and a cluster head (CH) election process, and the second stage performs the process of data transmission. The CHs' energy consumption is generally large, due to the data collecting process and the transmission for all data collected [13].

Formation of a Cluster

Cluster formation considers two stages, a cluster head election process and nodes identification to the elected cluster heads. A cluster head organizes all the transmissions within the cluster. Thus, the cluster head deals with delivering the prepared packets for the cluster and inter-cluster traffic [1]. However, the proposed solution moves the cluster formation jobs from the elected cluster to the rechargeable SN.

Homogeneous and Heterogeneous Sensor Networks

WSN is called homogeneous if all sensor properties are matched. Sometimes, different types of sensors may coexist in the same network. Heterogeneous WSNs (HWSNs) include sensor nodes with different characteristics. Whereas homogeneous WSNs, all the devices have the same connectivity and computing capabilities. HWSNs allow a variety of operating environments, so they are useful for many applications [8].

Single-hop *versus* Multi-hop Models

Data are transmitted between different nodes and the sink node in one of two methods, the single-hop model and the multi-hop model. In the single-hop model, all sensor nodes transmit their data to the sink node. This model speeds up the data process and makes the implementation easy, resulting in reduced energy consumption. Conversely, single-hop models are infeasible in large-scale environments, as the transmission cost consumes high energy levels, and in the worst case, the sink node cannot be reached. Figure 2.4 illustrates an example of a military surveillance application using the single-hop clustering model.

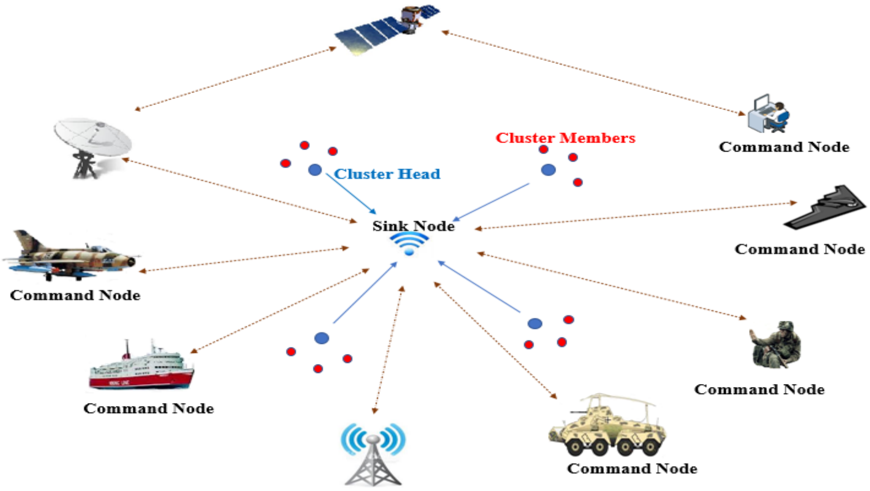

Figure 2.4. Military architecture for monitoring applications using the single-hop clustering model in WSNs.

On the other side, the multi-hop clustering model keeps the sensor nodes at a low level of energy consumption, as multiple cluster heads collect data and transfer them to the sink node. Even so, the synchronization of multi-hop time in the cluster core produces a very high load and data transmission among nodes, causing more packet delay and packet loss and, therefore, quick energy depletion. Consequently, the multi-hop clustering model is suitable for a large-scale area network [14]. Figure 2.5 shows an example of a precision agriculture application using the multi-hop clustering model.

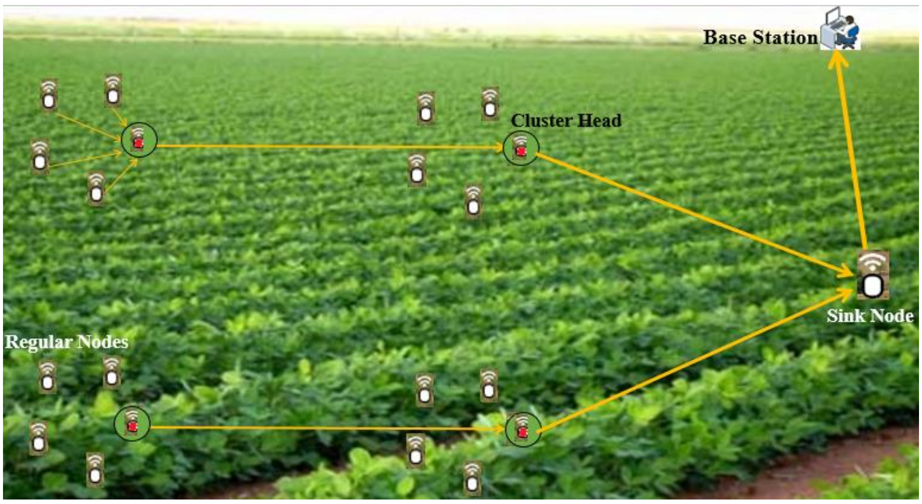

Figure 2.5. Precision agriculture architecture for monitoring applications using the multi-hop clustering model in WSNs.

2.3 Background studies and related Technologies

Section reviews the related work in service discovery protocols and cluster-based routing protocols, by splitting them into two parts. The first part focuses on the most relevant service discovery protocols on the Web, wireless ad-hoc, and MANETs from a historical point of view. The second part investigates more recent service discovery and cluster-based routing protocols for both WSNs and MANETs by reviewing their techniques, strong points of those protocols, and weak points where possible. Figure 2.6 simplifies the organization of this section.

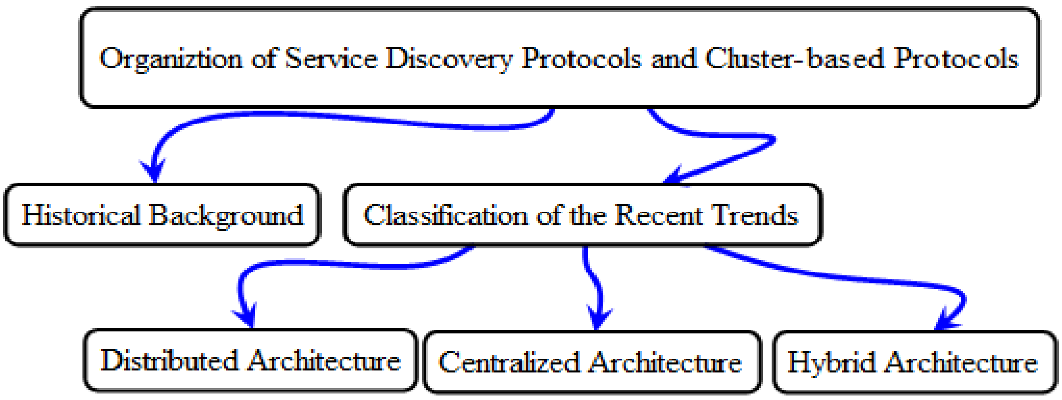

Figure 2.6. Organization of service discovery protocols.

This section introduces a critical investigation for the service discovery protocols considering the redundancy issues. Moreover, attention has been drawn to a cross-layer solution by discussing different clustering techniques used to solve the redundancy issues. Finally, the concepts of the clustering approach are extensively covered with a review and discuss famous Cluster Head Election, re-clustering, and self-organization strategies used to enhance the performance of the clustering approach. Figure 2.7 illustrates the related work approaches followed in this study.

Area ISSUES TECHNIQUES ENHANCEMET METHODS

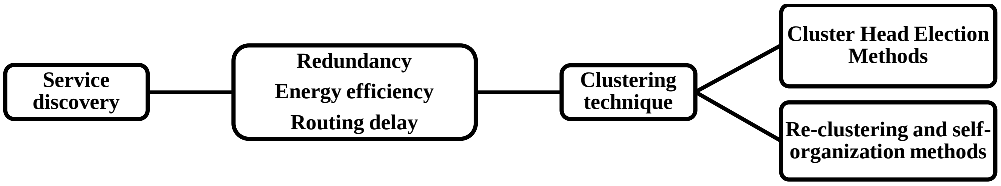

Figure 2.7. Illustration of the related work approaches followed in this study.

Motivation for Better Integration between Service and Route Discovery

In many studies conducted on service discovery protocols for MANETs [28], the discovery of service leads to the client who discovers the address of the node that provides the requested service. In some protocols, a client can obtain more information about the required service. Conversely, the path to the service provider must be independently obtained as part of the path discovery process. This means that a customer must get a mapping from a service type to the provider address and, then, get the path to the service provider and, therefore, it must be conducted in two independent processes. In ad-hoc networks, the service discovery process requires a large number of messages [29]. In summary, the integration approach significantly reduces the consumed bandwidth and an overall latency of the service discovery and the route to the service which greatly improves the performance of such a network. Clustering routing protocols as a cross-layer solution is a good example of integration between service discovery and routing protocols where the clustering techniques are considered as major techniques to eliminate and minimize redundancy in service discovery processes. The traditional understanding is considering the service discovery process as an application layer function. Though, the discovery of service in the network layer reduces communication and processing burdens [28].

2.3.1 Historical Background of Service Discovery Protocols

The most relevant service discovery protocols, which are reference protocols in both the ad-hoc and MANETs networks, will be reviewed, because their characteristics can be slightly modified to be an appropriate solution for SD in WSN networks.

Service discovery protocols, like Service Location Protocol (SLP) [30], introduce a scalable framework to implement service discovery in IP-based networks. SLP designed by IETF's SRVLOC group and SLPv2 is the modernist version which is called in Internet standard as RFC 2608. Like SLP, Simple Service Discovery Protocol (SSDP) [31], has been proposed by IETF's SRVLOC group which was implemented in Microsoft's UPnP architecture. SSDP uses multicast discovery to define the minimum protocol. Furthermore, UC Berkeley has designed the Secure Service Discovery Service (SSDS) [32], which locates services in broadband networks and offers available, fault-tolerant, scalable services. The Universal Description Discovery and Integration (UDDI) has introduced a standard model for discovering and deploying web-based software in a service-oriented infrastructure. UDDIv3.0.2 [33] is the standard of the organization for the Advancement of Structured Information Standards (OASIS). Salutation [34], is designed by the IBM Salutation Consortium that has included a series of standard interfaces, which allow the applications and devices to interact together by describing themselves, advertising their capabilities, requesting a service, and building a session with the service. Moreover, Bonjour [35], is based on IP protocol and assigns the IP addresses to network devices automatically without using a DHCP server. The service discovery protocol is the heart of Bonjour and is internally based on the Multicast DNS Service Discovery - MDNS-SD. Like Salutation, UPnP [36] also works in a small home or office environment and originally introduced to target the device and service discovery. Service Discovery Protocol (SDP) uses Bluetooth devices to search and access services. The Service Discover Protocol (SDP) [37], can search and access services using Bluetooth devices. Jini [38], is designed by Sun Company and based on Java programming language with using distributed object-oriented computing technology. Moreover, Jini has an important component responsible for Service discovery. In the Group-based Service Discovery (GSD) and Allia protocols [39], to make most devices in the network to be fully aware of announced services, peer-to-peer (P2P) information caching technology is used. SD-AODV, SD-DSR, OSLR, and ODMRP are an example of some protocols, which are used to integrate between routing and Service Discovery processes providing a cross-layer solution depending on their lower-layer routing paths [40].

2.3.2 Classification of the Recent Trends

Many concepts and technologies have proven their capabilities in IP networks, but the service discovery and cluster-based routing protocols in Wireless Sensor Network and Mobile Ad-Hoc networks are still immature. In this section, the service discovery and cluster-based mechanisms for WSNs and MANET network protocols will be described. Also, the results and strong points of those protocols will be stated. Furthermore, weak points will be identified. Service discovery protocols and cluster-based routing protocols are categorized into different architecture classifications, as follows.

2.3.2.1 Fully Distributed Architecture

The fully distributed architecture has only one level of hierarchy and its resources are equally shared between nodes. Also, it is participating in service discovery tasks. Moreover, the central entity of the fully distributed architecture, which controls service discovery, does not contain a single point of failure.

To reduce the amount of transmitting data, in [41], the authors proposed a protocol architecture where it performs a local computation. On the other hand, this method involves heavy data transmission as the transmission is made from each node to the base station which means this method is not energy efficient. To minimize the number of messages in the network while maintaining the minimum time waiting for services, a simple service discovery protocol [42] was introduced. Remote procedure calls are used to restore service once discovered, allowing richer interaction with the sensor. Still, more modification is needed to find proper trajectories to the network with concave boundaries, obstacles, holes.

P2P networks are usually divided into two types, structured and unstructured. Authors in [43] introduced corrections to enhance the performance of these two types. The results has revealed that the unstructured protocols are not extendable and extremely flexible, and are high power consumption and delaying. In unstructured networks, selective forwarding has been used to reduce consumed bandwidth.

Due to improving service discovery in MANETs, the authors of [44] introduced a new approach to using association rules mining. The technology of mining has been applied to broadcasting the concepts to service discovery, by exploiting the correlations between the consumers' requests in the same session, which happens in most cases.

Using Sleep/Wake scheduling and topology control techniques, authors in [45] proposed an adaptive partitioning scheme to degrade the power consumption in Wireless Sensor Networks. Moreover, a distributed heuristic algorithm CPA is introduced to approximate a good solution.

Earlier, a model was introduced to accurately analyze the performance of bulk data dissemination protocols in WSN networks [46]. By using the shortest propagation path in the model, feasible network topologies can be introduced. However, the dissemination and exchange of the bulk data spend the energy and shorten the WSNs lifetime.

A middleware structure for special operations applications was proposed in [47], which acts as a system to discover and customize services. The main objectives of the proposed system are to locate, assign and reserve a certain service to the group that needs this service by reducing the human intervention as more as possible. Nevertheless, this study handles emergency response operations, but, did not deal with security issues in their system.

To identify areas and appropriate sources, a MANET-based technology that is controlled by the discovery of scattered WSNs is introduced in [48]. Nonetheless, implementing this research needs expensive architecture in the real world [49].

Meanwhile, P2P Jini [50] introduces a new SOA method to handle services in wireless sensor networks. This method is suitable for most sensors with simple resources, and it can transform the sensors nodes with limited-source into real services. However, using broadcasting in the remote lookup leads to excessive signaling, which in turn leads to the consumption of battery power.

To accurately analyse the performance of data dissemination protocols in WSNs, a mathematical model in [51] was introduced. Moreover, by using the shortest propagation path in the model, feasible network topologies can be introduced. On the other hand, when the node does not find the new code, it copies the data in each node, thus its software will be isolated and will not be updated.

One important aspect of the coverage-guaranteed distributed sleep/wake scheduling (CDSWS) scheme [52], is to extend the network lifetime while guaranteeing better network coverage [53]. Even so, this concept assumes that some nodes are rich in sources and must be synchronized, which means maintenance costs. In addition, the concept of distributed directories is less consistent with the IP-enabled Low-power and Lossy Networks (LLNs), due to the burden of re-registration and re-clustering [53].

Due to maintaining the trade-off between messages' number reduction and the discovery success rate, a Location-Aware Service Discovery Protocol in the intermediate nodes for MANETs was proposed in [54]. In order to reduce message responses, the data collection system is used. Moreover, it introduces a service invocation mechanism to ensure attendance success. Still, there is no trade-off between the length of time to store the message in a node and the scalability.

The importance of scalable data lookup and replication protocol (SCALAR) [55] is that it replicates interactive and scalable data lookup for MANETs. According to the author, SCALAR is the first protocol to implement a virtual backbone architecture to run the process of redundancy and data lookup in MANETs [56]. Though, SCALAR attains better performance, but at the expense of increased overhead. Moreover, it does not consider the node's instability in the network. Furthermore, Ontology Description logics (OWL-DL) and dynamic bloom filter (DBF) techniques are utilized in the Semantic Service Discovery Model [57], to provide described services and facilitate discovery [58]. However, caching is inefficient, due to data control requests often referring to a small set of data as well as infrequent. In turn, the authors in [59] exploited the intelligence of a swarm to present the QoS-aware architecture of cluster-based service discovery. In order to process the service request and send the response back to the client, the QoS aware server was selected.

To extend the life of the network while ensuring network coverage, SEEC [60] is introduced, which is a coverage-guaranteed distributed sleep/wake scheduling design [61]. Nevertheless, it may be the reverse situation, because nodes are not rechargeable, unexpected node failures are likely to become the norm rather than the exceptions. Moreover, to exploit the redundancy of the sensors in the same place, an algorithm that divides the network into groups is introduced in [62]. Thus, by closing redundant nodes and maintaining the important group of work nodes, the backbone connectivity is maintained. Nonetheless, finding the exact Threshold of Connectivity level (Tcl) value gives minimum group numbers, but it is so difficult if the nodes are not as redundancy degree.

Another adaptive method to optimize unstructured random walk content discovery protocol is proposed in [63]. Firstly, it formalizes this protocol exploiting the queuing system called G-network with adopting two types of customers, negative and positive. Secondly, this protocol is improved by a gradient descent based on the cost process criteria. Even so, this protocol does not simulate and evaluate in a realistic situation.

DINAS [64], allows proper naming resolution for WSNs. Moreover, it is based on three corners, namely: Bloom filters, distributed caches, and overlay routing strategies. Likewise, for the nodes to resolve the name to derive the address, DINAS binds the name with its IPv6 address.

EADP [65] proposed a service discovery mechanism, which is suitable for 6LoWPAN networks. To achieve high quality, EADP adopts fully-distributed concepts on the adaptive push-pull model [64]. Conversely, the authors assert that EADP does not explain the characterization of the period that can be fit in small packages, nor is it just to describe one service. Moreover, using limited flooding for service discovery is not masked, because of insufficient information about network topology and routing protocol that is used.

Furthermore, PPBFTS [66] uses a reliable and fault-tolerant routing algorithm to establish primary paths using a load balancing approach and establishing backup paths with calculating the possibilities for blocking existing paths. On the other hand, the Probe Packets add more state information to the network, thus causing more overhead to the network and reducing the lifetime.

To locate and discover resources in a mobile ad-hoc network, the authors in [67] uses DHT and fault-tolerant technology, this architecture can manage resources, Quality of Service, load balancing, and prioritization requests [68]. Still, resource sharing in disconnected topology is not addressed deeply. Due to a temporary path, the end-to-end networks connectivity could not create always in a disconnected ubiquitous stub network..

From the pool of proposed models, a modern service discovery method is presented [22] for detecting services joined into OLSRv2. Service discovery message (SDM) is a modern type-length-value structure (TLV) integrated with OLSRv2 protocol aiming to advertise services [69] and [70]. However, OLSRv2 does not provide the best route in terms of response time and bandwidth. In addition, multi-route packet transmission is not guaranteed and no provision is required to ensure that packets are moved on a priority basis. For instance, ICP [71] is a power-saving and location-aware protocol that schedules the sleep/awake beacon intervals, to decrease the packet dropping and energy saving due to the problem of hidden terminals. Nevertheless, the neighbor's sensitiveness is weak and leads to a high delay in messaging between nodes.

HEBM [72] is a novel hierarchical approach, which aims to optimize energy consumption by turning off the node's radio periodically according to sleeping control rules. Generally, clustering approaches introduce high maintenance overhead, inherited from the high costs of re-assembly and re-registration.

One advantage of LRTCP [73], is the exaptation of the nature of the sensor's redundancy located in the same place by organizing them in the form of groups, thus the connectivity of the backbone is maintained by selecting a minimum of active nodes and redundant nodes are turned off [74]. Nonetheless, the LRTCP does not consider the quality of the link between the nodes, cause in reducing the performance of the network. Moreover, this work considers only homogeneous and static wireless sensor networks and failure in heterogeneous and dynamic wireless sensor networks.

As mentioned, the central entity of the entire distributed architecture that controls service discovery does not have a single point of failure. Furthermore, the fully distributed architecture has only one level of hierarchy and its resources are shared equally among nodes. Moreover, the nodes participate in service discovery tasks. Conversely, in the distributed architecture there is more signaling, multi-hop routing, and data transmission between nodes, resulting in energy depletion.

2.3.2.2 Centralized Architecture

All types of service information management, buffering service, and service selection methods are performed in this type of architecture by a central directory on behalf of the network nodes. This directory can be a device or any resource-rich gateway in the network.

A promising and modern address allocation based on a type is presented in [75], to intensify the mobile object to discover the preferred service in the new place [76]. However, the IPv6 addresses that contain service types cannot be compressed. Moreover, the previous service types do not compatible with the design basics of the IPv6 layer.

To solve the distance-sensitive service discovery problem, a new localized algorithm to calculate and load the fixed storage load per node is proposed in [77]. Nevertheless, this study does not deal with more general dispatch challenges, where an event may happen in an arbitrary location, and the event location incoming rounds are unpredictable [78].

A cross-layer solution SCA is proposed in [79]. It merges a truncated ARQ in the link layer and collaborative diversity at the physical layer [80]. Nonetheless, attacks like misdirection, black holes, wormholes, and replay could break the current route or prevent a new route [73].

Adaptive Sevilla [81] is an intermediate program that provides an adaptive service that provides the capability to align with the resources used by WSN applications [82]. Even so, this program considers heterogeneity but fails to consider the error-tolerant, which is so important for implementing SHM.

The numerical simulations presented in [83] has showed significant improvements in energy efficiency when applying compressed sensing (CS) to collect data in WANs.

To achieve stability and increase the Time to Live (TTL) of mobile hosts, the technique called Cluster-based Power Management (CPM) was introduced in [84]. Though, the full centralization of the network traffic to a single node and the additional account costs makes the process of managing and organizing data is very difficult, thus leading to a power drain and slowing the network.

Based on the IPv6-based *k*-Anycast communication model, the 6LoWPAN service model was presented in [85]. Moreover, the proposed model overcomes the failure of dormant sensor nodes.

Agnostic Diagnosis (AD) [86] allows detecting failure online. In addition, a silent failure that is discovered by AD has effectively expanded the scope and capacity of the WSN diagnosis [87], [88], [89]. Still, such protocols are not able to determine the original reason behind the packet losses, whether it is a cause of channel quality or caused by sensor nodes themselves. Moreover, although it is efficient in diagnosing the static fault, it is not recommended to use it in dynamic fault diagnosis. Furthermore, the introduced approach is limited to some node's context parameters, also it does not deal with link failure as an example.

Taking into account the recycled WSN role, a model in [90] is designed to optimize overall network life by improving the energy efficiency of the bottleneck [91]. However, regarding reducing energy usage, simple nodes do not benefit from NC. Also, the data reliability sending is decreased by XOR NC.

More importantly, HDACS [92] is a new method by modifying the hierarchical network using Compressive Sensing (CS). AHDACS specifies scattered values dynamically, based on the level of signal differences in original zones [93]. Nevertheless, this approach is based on the assumption that is no packet loss in wireless sensor networks. Practically, packet loss is widespread in wireless networks due to different factors, such as channel noise, power constraint, and environmental complexity.

CSAR [94], originally introduced a Content Scent-based Architecture of mobile ad-hoc networks [95], [96]. On the other hand, although it offers more reliable in-network services and better load balancing, it may not warranty due to the traditional end-to-end QoS cannot be applied for multiple paths, especially, when considering node mobility and simultaneous transmissions by multiple nodes. Moreover, the work in [97] proposed discovery protocols that work in two different methods. The first uses the postal address and the DNS system through the Internet, and the second is a sponsor for the maximum number of hops using the AODV routing protocol [98]. Although DNS query solves independent of the network device name, this needs high efforts to synchronize the DNS server or use the Multicast-DNS method to bypass centralized design. Another new prediction technique is introduced in [99] to use to predict the proactive in addition to reactive overhead with adjusting the overhead based on the overhead.

Notice that all the steps in [100] declare the methods to deal with the fast streaming data coming from the sensor networks. In order to handle and store the data into a predefined format (XML and also in MySQL RDBMS), middleware software is used. However, the process and dealing with XML and MySQL RDBMS format waste the energy which causes, in short, the network lifetime.

The fundamental idea of a Novel Energy Entropy Based on Clusterhead Selection Algorithm for WSNs (EE-CSAW) [101] method, is to reduce the number of times the cluster head is constructed; this protocol introduces a new criterion for node stability and selects a stable cluster head with the support of the entropy metric.

In this type of architecture, service information management, caching service, and service selection methods were implemented by a central directory on behalf of network nodes. This directory can be a device or any resource-rich gateway in the network. Nevertheless, the full centralized architecture of the network traffic to a single node and the additional account costs makes the process of managing and organizing data is very difficult, thus leading to a power drain and slowing the network.

2.3.2.3 Hybrid Architecture

Hierarchical architecture is treated in a decentralized manner. It contains a set of hardware layers, and we find rich-resource devices as we rise the hierarchy.

To the best of the authors' knowledge, LEACH [102] is the first protocol based on the clustering approach, that uses random selection of cluster heads to distribute the power load equally between network sensors [103]. Nonetheless, in the optimum results, the distribution of heads of LEACH's cluster heads is uneven. In addition, some nodes cause a waste of energy in transmitting data to a too far area from cluster heads.

On the other hand, WCA in [104], introduced a clustering algorithm distributed based on weight and that it can dynamically adapt itself with the continuous changes of the ad-hoc network's topology. Furthermore, CH selection is a very complex process as various factors must be considered to select the best node in the cluster [105]. Conversely, it is a one-hop cluster, so it has a complexity of O(n) and needs synchronized clocks [106].

HEED [107], select the heads of the cluster periodically based on the hybrid of the residual energy of the node and the secondary parameters, such as near the node of its neighbors or node degree. The head consumes low overhead on the message and achieves a balanced distribution of cluster heads across the network. However, HEED is not considered the situation of a high probability of a low-energy node to being the cluster head rather than the high-energy nodes[108]. Moreover, this work needs to enhance decision-making accuracy [109].

Another Clustering concept is the DEEAC model [110], which aggregates the sensors into groups. DEEAC protocol is adaptive for each node within the network in terms of reporting data and remaining energy [111]. Although the clusters are distributed properly along with the network in DEEAC, power consumption is increased across all networks.

Simply, SLEACH [112] involves a distributed cluster forming technique that enables the self-organize of a large number of nodes, as well as algorithms for clusters adaptation. Cluster heads are selected randomly for each round. However, the randomization technique of electing the cluster head leads to more delay, the reason is the repetition of the wrong elections for the holes and the more time needed to get out of those holes.

To enhance the ability of load balance, CMDS [113] exploits the multipath and cluster approaches, which extend the lifetime of the network. Conversely, a "single point of failure" is one of the most prominent problems of centralized architecture, which causes more maintenance overhead.

It is important to highlight that the RTCP [114] exploits the existence of redundant sensors in one area by organizing them into clusters, some active nodes are maintained and the redundant nodes are stopped to keep the backbone connected. Even so, the value of the Threshold of Connectivity level (Tcl), selected by application affects the number of ready-made groups. Few groups are made up when the Tcl value is small. So, finding the true value of Tcl shows the minimum number of groups, and it is very difficult when the nodes do not have the same redundancy ratio.

On the other hand, GECP [115] uses Sleep/Wake scheduling technology to prolong the network lifetime by ensuring the network connectivity of wireless sensor networks [116]. Even so, GECP reduced power consumption but failed to predict the dynamic target. at the same time, multiple nodes were worked to prohibit target loss, as a result, essential energy was consumed.

Meanwhile, there are some projects like NDAPSO [117], that presented energy-aware and clustered node architecture by using a modern cluster head competition mechanism. Moreover, to adjust the area partition line, the PSO algorithm is used for better network performance [118]. However, the clustered approaches suffer from scattering and aggregating processes, which add more complexity and overhead to the WSN network.

To configure clusters and transition the head location to disseminate the energy payload equally among all the nodes, the energy-efficient cluster-head selection algorithm was introduced in [27]. This algorithm depends on the transmission energy level for each node [119], [120]. Although, electing the CHs without considering the node's locations may affect negatively the whole network performance. Moreover, the energy level checking for each node periodically is introduced more overhead and complexity to the network.

One of the optimal algorithms is LEACH-C [121], which is more power-efficiency in selecting several cluster heads, due to calculating the power level for each node and the square sum of the distances between each node [122]. Moreover, provides an equal power consumption load between the nodes [123]. Nevertheless, this protocol does not guarantee the continuation of the network operator when the Cluster Head died unexpectedly.

Furthermore, SelectCast [124] makes a trade-off between the gathering efficiency and clustering throughput, to investigate the qualitative and primal properties of WSNs regarding aggregation capacity. Nonetheless, most of the data aggregation protocols do not deal properly with the sudden failure of the Cluster Head.

On the other hand, the MR-LEACH protocol [125] merges the geographical closeness of the nodes with the measurement redundancy, so redundant nodes are aggregated regarding their redundancy and only one node transmits data in each group [126]. Conversely, MR-LEACH does not take into account event triggering, also it is initial deployment does not comprise explicit redundancy.

One strength of FEMCHRP [127], is that the cluster heads are elected using the fuzzy logic and the Dijkstra algorithm is applied to perform the data transfer process by selecting the shortest energy path [128]. Although, the application of two methods of elections and the repetition of each round lead to drain energy significantly.

It is important to highlight that the essential role of DEMC protocol [129], is to elect the cluster head according to the energy level, connectivity, and stability and transfer the information from the source to the destination. Also, it reduces energy consumption and formed efficient routing. However, maintaining the routing table periodically makes the side of security weak, as well as delays due to the failure of some nodes.

Meanwhile, NR-LEACH [130], is a new algorithm for cluster head selection to enhance the LEACH protocol and improve the total network lifetime based on the node rank (NR) algorithm. On the other side, NR-LEACH depletion node energy quickly, due to the repeating of calculating the path cost and the number of links between the nodes in each round, to elect cluster head.

To promote an effective cluster head selection considering the distance, energy, and delay in WSNs, a new method from Firefly with Cyclic Randomization

(FCR) algorithms is introduced in [131]. However, the randomization method in cluster head election itself caused in delay, due to the false election of the failure nodes (holes) and more time needed to get out of those holes.

By exploiting the benefits of fuzzy clustering and the Genetic Algorithm (GA), DFLCHES [132] introduce an effective cluster head selection that enhancement the lifetime of the network. Even so, the extensive calculation such as node density, hop count, and centrality measure resulting in depletion of energy quickly and thus shortening the network lifetime.

Likewise, the work in [133] considers the average number of clusters and the transmission range for the control messages effectively prolong the network lifetime. Moreover, it is adopted the derivative-free Nelder–Mead Simplex method, to achieve joint optimization values of (kopt, Ropt). Although, the heavy calculations of the average number of clusters and transmission range of the control messages in each round result in the depletion of the network's power and the delay of operations in it greatly.

The major advantage of the modern ASDF [134], is providing independence between the platform and the service location. In addition, the ASDF protocol is compatible with all types of dynamic network systems.

Another promising approach was proposed in [135], which exploits the battery recharge and redundancy of nodes regarding sensing and uses the battery charge recovery mechanisms, to enhance the network lifetime [136]. However, this protocol does not address how to apply the network remainder when the wireless sensor network is disconnected.

Based on DHT (Distributed Hash Table) a scalable service discovery protocol is presented in [137]. This protocol does not depend on flooding does not multicast and does not require a central lookup server, so it is more scalable [138], [139]. Nevertheless, using a separate overlay in this protocol leads to more effort for underlay routing. Moreover, there are many weaknesses in using traditional DHT approaches.

Due to the major challenge of cluster-based concepts, which is specified each node to its right cluster, the authors proposed an algorithm known as BBC (Beacon Based Clustering) [140]. The fast and cost-effective centroid estimation technique makes the algorithms more practicable for mobile ad-hoc networks [141]. Nonetheless, the essential limitation of the cell-based cluster solutions is the prior condition of a former accurate localization of the nodes, else the nodes will not be able to specify themselves to their correct cells. Moreover, the periodical Beacon approaches lead to bleeding the energy.

Based on the data aggregation approach, READA is introduced [11]. The spatial correlation of data in the network is exploited [142], [143]. Conversely, data duplication exists somewhere even after compression. Moreover, in this method, the classifier is trained with the group of data that is fully irrelevant to their location.

A new scalable data-centric storage method for sensor networks called ASST is presented in [144]. Using the ASST distributed hash, easy access to the data stored in the sensor is possible. Sometimes uniform query dissemination cannot be achieved over the network, thus increasing or decreasing the same distance to the four edges, causing the non-unified dissemination of query to the load imbalance.

Regarding the homogeneous clustering algorithms in wireless sensor networks, a modern and energy-efficient method was introduced [145]. Moreover, the cluster members are distributed uniformly as the life of the network is extended [146]. Still, communication among the nodes is the major energy depletion process.

Through gathering reports from nodes, Iso-Map [147] provides sufficient power by mapping the contour only in wireless networks [148]. Despite that, in Iso-Map each mobile node requires to be modeled and programmed independently, so it is not cost-efficient. Moreover, it is more complex due to the existing of several mobile nodes.

Only for the dynamic, mobile, and heterogeneous WSNs, NanoSD [148] is designed. By mapping the tree structure of nanoSD protocol, a compressing of readable user service IDs into optimal binary strings was obtained which causes in reducing the packet sizes and minimize the communication overhead [64]. However, nanoSD makes an effort to decrease packet size, but to traffic reduction, it does not offer any advanced forwarding techniques.

In order to enhance the stable area of the clustering structure process, a new protocol WEP was presented [149] using the characteristics parameters of heterogeneity. Even so, most of the proposed methods focus on energy measurement at the expense of new burdens added in terms of mathematical and transmission complexity, which leads to more power consumption. On the other hand, a modern method of collecting data for mobile users on a network-wide scale is presented in [150]. The data collection tree is always updated in the system as the mobile user moves [151]. However, depending on the data collection process during communications between the sensors and the sink nodes is consuming the energy extremely, due to high path loss exponents.

Based on the weight-dependent aggregation approach, a flexible algorithm is provided [152]. This algorithm is a type of 2- hop clustering algorithm, so it is more stable and flexible against topological changes when compared with the classical 1-hop clustering methods [153]. Moreover, Direct communication is only feasible for small network sizes, and for large-scale networks, multi-hop communication is suitable and more scalable [154]. Conversely, in MANET the large and flat networks are managed using clustering topology, which needs extra construction and maintenance costs.

A famous localized distance-sensitive agent-based service discovery algorithm was proposed [155], to improve the basic iMesh structure [156]. Although, this work requires more hardware which means more cost.

Using a combination of mobile and static agents, LEDMPR was introduced in [157]. This method presented a location-aware event that triggered the WSN multi-path routing system [158]. However, due to the different channel characteristics, the agent-based routing approach can not directly be implemented underwater, and it was essentially developed for terrestrial sensor networks.

An analytical model for the performance of the hashing hierarchical location-based server protocols was introduced in [159]. After a complete analysis that increases the total cost of energy to serve the location, two new location service protocols are introduced to reduce the distance traveled by updating the query packets and the location.

Node's degree-based mechanism is proposed by [160], where it receives the power level, the constant factor, remaining time battery. The idea of cluster weight has made cluster creation very fast, which in turn has made network services more accessible [161]. On the other hand, because the CH method in this system depends on the weighted parameters, each parameter weight will change depending on the application change.

The most notable advantage is that several effective algorithms are introduced in [162] to scale the life of the network until a certain percentage of the nodes die [163]. Despite that, it does not take into account some basic parameters, such as distance and degree of the node.

According to protocols for the discovery of Web services and approaches in [164], a formula was introduced to measure the energy cost in an ad-hoc environment. In order to make comparative studies between existing discovery concepts, the presented formula based on Ci parameters is used which will permit us to assess any web services discovery method based on the overall consumed power.

Furthermore, three methods are presented in [165] to gain their objectives namely: a source-aware redundant packet forwarding system, Increasing the extensive parameters, and the Monte Carlo method [166]. On the other side, due to Tough physical characteristics, the existing deployment designs in the coalmine are not proper for CWSNs in ultra-deep shafts.

The main objectives of the architecture of the secure multicast service discovery presented in [167], are to locate a certain resource and save it to the groups it needs.

Similarly, the main objectives of a service discovery technique introduced in [168] which is based on a secure role for emergency intervention in mobile ad-hoc networks, are to ensure the availability and confidentiality of mutual information among the components through access control based on the role.

Using the Sleep Scheduling technique, a guaranteed service coverage protocol for Wireless Sensor Networks was introduced in [169]. In addition, the Sleep Scheduling mechanism is controlled by the sleep factor [170], [171], [172], [173]. However, the sleep schedule technique cannot fix the coverage hole in the network precisely, when there is no active and inactive node in the coverage slot area. Also, NCCM-DC [174] is a high-performance protocol produced to achieve transmission reliability and enhance energy efficiency. Moreover, a cooperative state transition mechanism and the dormancy algorithm are used to meet energy efficiency [175], [176]. The proposed algorithm is compatible with WSNs with limited power [177]. Nevertheless, the synchronization of multi-hop time produces a very high load.

A modern model based on the web services discovery approach is introduced in [178], to measure the total cost of energy consumed in MANET. Moreover, based on cross-layer routing techniques, a modern web services discovery protocol for MANET is proposed and enhanced [179]. Nonetheless, regarding the high-diversity traffic classification, existing classification mechanisms are lacking in the features section in terms of feature quality and quantity.

Another novel algorithm is MCRR, which provides an optimization of the dynamic channel allocation introduced in [180]. Even so, this study introduces a software-defined networking SDN-assisted quality of experience, unless it did not address buffer occupancy, which reduces the quality of experience and starves the system [181], [182]. Furthermore, it does not give reporting under homogeneous and heterogeneous circumstances.

To reduce the workload of the cluster head and produce a more accurate, reliable result, a distributed, general-purpose reasoning engine for WSN, which uses fuzzy logic and ECATCH algorithm is introduced by DFLER [183]. Conversely, transferring data from all nodes to their cluster head (CH) leads to a bottleneck problem that drains energy too much.

The hierarchical architecture was dealt with in a decentralized manner. It has a set of hardware layers, and we find hardware rich in resources as we go up the hierarchy. As stated in the discussion of the tables' results below, the best energy-saving architecture is the hybrid architecture, which gains the advantages of distributed and centralized approaches and overcomes the limitations of their approaches.

2.4 Discussion and Open Issues

Through this extensive survey of service discovery protocols and cluster-based routing protocols in both MANETs and WSNs, some issues, problems, and most commonly used techniques in solving problems have been identified considering the strengths and weaknesses. In addition, many complexities, difficulties faced by researchers, and the recommendations made by researchers to facilitate research in this broad area are mentioned. Consequently, issues that are still open and need further research, improvement, and development have been concluded. Services in the Ubiquitous are a promising field of research in the present era so that the user can benefit from all services around the world.

2.4.1 Comparison of Service Discovery Protocols and Cluster-Based Routing Protocols

The most promising proposals were compared and the performance was analyzed and discussed to reach some valuable observations with important results and recommendations, which are shown in the tables below.

Table 2.1: A Comparison of the most relevant solutions for service discovery protocols and cluster-based routing protocols in terms of techniques used, strengths, and weaknesses.

Protocol	Year	Technique	Classification	Strengths	Weaknesses
This protocol	2021	- Combined CH election Method - Self-configuring cluster formation	Hybrid clustering scheme	1) Introduces a new and efficient method to elect the CH 2) Simple, easy, and light 3) Deletes the dead nodes from the topology list 4) Self-configuring the re-clustering process dynamically 5) Complexes tracking the CHs by attackers	Ignore to face the challenge of electing CH node dead/failure while performing its work (Future work)
Energy Optimization in Cluster-Based Routing Protocols for Large-Area Wireless Sensor Networks [133]	2019	Derivative-free Nelder–Mead Simplex method	Hybrid clustering scheme	The proposed Protocol decreases energy consumption effectively	The heavy calculations of the transmission range of the control messages and the average number of clusters in each round result in the delay of operations in it greatly and the depletion of the network's energy

DFLCHES Scheme [204]	2018	Genetic algorithms /Elbow method/Fuzzy predictive method	Adaptive schemes	1) Effective cluster head selection that enhancement the lifetime of the network 2)Out-performed the KBPSO and LEACH schemes in terms of packet drop ratio, total energy consumption, and number of average delays	The extensive calculation such as node centrality measure, hop count, and density, resulting in energy depletion quickly, consequently, shortening the lifetime of the network
A new algorithm for cluster head selection in LEACH protocol for wireless sensor networks [130]	2018	NR algorithm	Combined metric schemes	1) The true weight enhancement for a specific node to success can act as a cluster head 2) Overcomes the previous algorithms in terms of the performance	The node energy depletion quickly, due to the counting process for the cost of the path between the nodes and the number of links among nodes to elect CH
A TOPSIS Based Cluster Head Selection for Wireless Sensor Networks [203]	2016	TOPSIS algorithm and measures the (distance to BS, transmission rate, Residual energy)	Combined metric schemes	Improve the lifetime of the network compared to LEACH and AHP	Focusing on the accuracy degree at the expense of the new burdens that can be added in terms of mathematical complexity and increasing of signals
Clustering Approach in Wireless Sensor Networks Based on K-means: limitations and Recommendations [204]	2015	Residual energy measuring method and the nodes' threshold value	Adaptive schemes	Better nodes' working in the network in comparison to the LEACH	Consumed power in the residual energy measuring and calculated it with the threshold value for all nodes, itself considered as an additional burden on the network
Energy Efficient distributed cluster head scheduling scheme for two-tiered WSNs [205]	2015	Remaining energy/Cluster optimal centrality degree	Adaptive schemes	Overcome frequent election of cluster head and Fair energy load balancing among cluster-based networks	The residual energy level measurement and signal strength to each node adds more burdens to the network, resulting in more energy consuming
Cluster head selection optimization based on genetic algorithm [206]	2015	Calculating the residual energy, inter-and intra-cluster distance	Adaptive scheme	Good lifetime and network load balancing	Repetitive residual energy and distances calculation adds more burdens lead to delaying the whole network and quickly power depletion

DCHEP [207]	2015	Remaining energy measuring and other sensors connectivity	Hybrid clustering scheme	1) Scalable and flexible solution targeting intense WSNs with random mobility 2) Achieve high growth in energy performance and availability compared to LEACH	1) Residual energy calculated for the nodes is unsuccessful in the case of the nodes rapidly movement 2) Resulting in connectivity loss continuously
The Energy Efficient Multi-Hop Clustering Process for Data Transmission in Mobile Sensor Networks [129]	2014	Energy level Measuring, Stability, Connectivity	Hybrid clustering scheme	1) Introduce high bandwidth and low delay in the network 2) Periodical cluster head election is enhanced to form effective routing and reduce energy consumption 3) Well connectivity and stability	1) Periodically maintaining the routing table makes the security side so weak 2) Residual energy calculating of the nodes is often unsuccessful in rapid nodes movement especially in the critical cases 3) Delays due to the failure of some nodes.
LEACH [100]	2002	- A random CH election - Adaptive, self-configuring cluster formation	Deterministic schemes	1) Distribute power waste evenly across the sensors 2) High scalability 3) Robustness the security issues 4) simple, low overhead, and fast	1) The random method adds more limitations 3) Some nodes cause a waste of energy in transmitting data to a too far area from cluster heads. 3) High redundancy of data

Table 2.2: A Comparison of the promising central architecture for service discovery protocols and cluster-based routing protocols under different factors.

Year	**Protocol**	**Architecture**	**Technique**	**Power saving**	**Redundancy -Aware**	**6LoWPAN support**	**Location Awareness**	**Target Network**
2011	Compressed Data Aggregation	C	Compressive Sensing	High	Yes	No	Yes	WSN
2013	Enhancement of Lifetime using Duty Cycle	C	Duty cycled technique	High	No	No	No	WSN

2013	Agnostic Diagnosis	C	Temporal &spatial Detection	Middle	No	No	Yes	WSN
2013	A Service Model for 6LoWPAN	C	Clustering-based search techniques	High	Yes	No	Yes	WSN
2014	HDACS	C	Compressive Sensing	High	Yes	No	Yes	WSN
2015	HARMS-based	C	DNS Search	Middle	No	Yes	Yes	MANET
2015	Performance Improvement Through	C	Prediction technique	Middle	No	Yes	Yes	MANET
2016	EE-CSAW	C	Clustering-based	High	Yes	No	Yes	WSN

Table 2.3: A Comparison of the promising fully distributed architecture for service discovery protocols and cluster-based routing protocols under different factors.

Year	Protocol	Architecture	Technique	Power saving	Redundancy -Aware	6LoWPAN support	Location Awareness	Target network
2010	Middleware support for service discovery	D	Middleware technique	Low	No	Yes	Yes	MANET
2011	A WSN-driven service discovery	D	A WSN-Driven SD Technique	Low	No	Yes	Yes	Hybrid Network
2011	Peer-to-Peer Jini for Truly Service-Oriented WSNs	D	DNS Search /Entity Search	Middle	No	No	No	WSN
2012	Bulk data dissemination in Modeling and analysis	D	Real-time Data Retrieval	Middle	No	No	No	WSN
2013	SCALAR	D	Virtual backbone &RR mechanism	Middle	Yes	Yes	Yes	MANET
2013	The DBF-based semantic	D	DBF OWL-DL	Middle	No	No	Yes	MANET

2014	DINAS	D	Bloom filters	Middle	No	No	Yes	WSN
2015	NDAPSO	D	PSO algorithm	High	Yes	No	Yes	WSN
2015	Cross-Layer for OLSRv2	D	MPR technique	Middle	No	Yes	Yes	MANET
2015	Publish or subscribe middleware	D	Message broadcasting	Middle	Yes	Yes	Yes	MANET
2016	Optimization of Dynamic Channel Allocation	D	k-means clustering	Middle	Yes	No	Yes	WSN
2018	RTCP	D	Sleep/Awake scheduling	High	Yes	No	Yes	WSN

Table 2.4: A Comparison of the promising hybrid architecture for service discovery protocols and cluster-based routing protocols under different factors.

Year	Protocol	Architecture	Technique	Power saving	Redundancy -Aware	6LoWPAN support	Location Awareness	Target network
2010	WCA	H	Weighted Clustering	High	Yes	No	Yes	WSN
2010	An Energy-Efficient Cluster-Head Selection	H	Sleep/Awake scheduling	High	Yes	No	Yes	WSN
2011	Ubiquitous Data Collection	H	Mapping Tree Structure	Middle	No	No	No	WSN
2012	Improving iMesh Based	H	Distance sensitive	High	No	No	Yes	WSAN
2012	An Energy Efficiency Optimized LEACH_C	H	Clustering-based search techniques	High	Yes	No	Yes	WSN
2012	SelectCast	H	Block coding	High	Yes	No	Yes	WSN
2013	Clustering algorithms with energy-harvesting	H	energy-harvesting techniques	High	Yes	No	Yes	WSN
2013	LEDMPR	H	Location-based	High	No	No	Yes	WSN

2013	Energy-efficient location	H	location query	High	No	No	Yes	MANET
2013	MR-LEACH	H	geographic proximity	High	Yes	No	Yes	WSN
2014	Evaluating the Energy Consumption of Web	H	Measuring the Energy Cost	High	No	No	Yes	MANET
2016	Cross-Layer Routing Based on Semantic Web	H	Cross layer /Discovery Diameter	High	No	No	No	MANET
2016	NCCM-DC	H	NC and Dormancy	High	Yes	No	Yes	WSN
2017	DFLER	H	clustering method	High	Yes	No	Yes	WSN
2017	NR - LEACH		Node Rank algorithm	High	Yes	No	Yes	WSN
2017	Cluster head selection for energy-efficient and delay-less routing in wireless sensor network	H	Firefly with FCR algorithm	High	Yes	No	Yes	WSN
2018	DFLCHES	H	Fuzzy predictive method	High	Yes	No	Yes	WSN
2019	Energy Optimization in Cluster-Based Routing Protocols	H	Derivative-free Nelder–Mead Simplex method	High	Yes	No	Yes	Large-Area WSN

2.4.2 Discussion and Results Analysis

After checking and reflecting on the above comparison tables, the outcome is the following observations and conclusions. Referring to TABLE 2.2, TABLE 2.3, TABLE 2.4, all systems that considered the redundancy problem, their results indicate the high scores in energy-saving factor compared to others. In addition, most of the algorithms that take into account the problem of power consumption and redundancy adopted the clustering approaches and the results of their power-saving were high as presented in TABLE 2.2, TABLE 2.3, TABLE 2.4. Thus, the clustering method is one of the most effective technologies in terms of power saving and reduction of redundancy as shown in TABLE 2.1. Furthermore, in TABLE 2.3, it is noticed that "low" classification used to determine the degree of energy-saving emerged intensively in the systems that rely on a distributed architecture, and this is because in distributed architecture there is more signaling, multi-hop routing, and data transmission between nodes, resulting in energy depletion. Similarly, note that most of the systems that considered the problem of redundancy and its impact on energy consumption were in WSNs as shown in TABLE 2.2, TABLE 2.3, TABLE 2.4, and the reason is the problem of energy consumption has found a greater interest in wireless sensor networks than in other networks. Besides, most models that were considered redundancy and power consumption problem adopted dynamic cluster head election technology and the power-saving results were high as shown in TABLE 2.1 In fact, the dynamic cluster head election technology is one of the most effective ways to reduce redundancy and achieve energy saving from TABLE 2.1. Moreover, from TABLE 2.1, some of the protocols adopted the randomization method in cluster head election, and this method has limitations, such as repetitive delays, because of the false election for failure or dead nodes (holes), which needed more time to get out of those holes. Moreover, the high random routing method enhances the privacy of location, reduces hackers' chances to get successive packets, and makes it more complex to guess the next packet [184] as described in TABLE 2.1. Additionally, some protocols make the cluster head election periodically, which gain the load balancing and prolong the network lifetime, On the other hand, makes the side of security weak, when an attacker gets full control of the network without having to get any other nodes, when gets a hold of all CHs [185] drawn from TABLE 2.1. Alternatively, the majority of the protocols that tried to enhance the dynamic cluster head election adopted the measuring methods, such as measuring the residual energy, hop count, node density, the distance between nodes and base stations. The problem is that all these protocols focused on the degree of accuracy at the expense of the new burdens that can be added in terms of mathematical complexity and increasing the signaling process, which results in depletion of energy quickly and thus shortening the network lifetime, according to TABLE 2.1. Few proposals, reported, used combined metric approaches, which we considered as a good method to overcome the drawbacks of random, periodical, and measuring approaches, and at the same time gain their advantages. So, still, these researches are immature. In TABLE 2.2, TABLE 2.3, TABLE 2.4 it is noticed that the classification factor "Location awareness" is present in most of the systems studied in the survey. The reason is that node location is so important in routing and determining the path to and from the node and for other purposes. In the same way, note that most of the systems that adopted the 6LoWPAN protocol had the results of "Low" or "Middle" energy efficiency from TABLE 2.2, TABLE 2.3, TABLE 2.4. This is since the 6LoWPAN protocol is used to extend the network and integrate it into other networks, which in turn increases the distance traveled by packets and doubles routing processes, all of which lead to more power consumption. This deep comparison concludes that the best energy-saving architecture is the hybrid architecture, which gains the advantages of distributed and centralized approaches and overcomes the limitations of their approaches.

2.4.3 Open Issues

Based on the above presented discussion, a set of open research challenges and issues that should be addressed in the future in service discovery and cluster-based techniques are summarized as follows:

- Cross-layer techniques: The importance of cross-layer techniques lies in the fact that they get the benefits of information coming from other layers. Thus, the problem in a layer and its solution come from another layer. For example, routing in the network layer helps in the service discovery process and resolving the redundancy problem in the application layer. So far, cross-layered design suffers from different problems of its own, and research continues to provide possible solutions to those issues.

- Clustering technique: Most modern energy-efficient clustering sensor networks protocols are depending on location, average power, density, residual energy, etc., which have proven highly efficient in energy saving. The field is still open and needs further research.
- Cluster head election techniques: To make the clustering approaches more efficient, many researchers adopted the dynamic cluster head election routing protocol, to prolong the network lifetime and make good network load balancing. There are many researchers' proposed different techniques to determine the optimum method of electing the cluster head, but still, these researches are immature.
- Service lookup mechanism: Most service discovery protocols address the service search technique issues and provide different scenarios for solutions, but still this topic is immature.
- Service propagation: There is no appropriate self-configuration technique for the mobile nodes, which has led to the emergence of the service propagation problem for this type of node. Therefore, attention must be given to the service discovery issues related to mobility.
- Scalability: The efficiency of query and load balancing greatly affect scalability. Moreover, the delay is a core performance measure for network scalability, so we need protocols that implement algorithms while avoiding the case where servers are loaded with large amounts of service information, including information messages and multiple registrations, this issue still needs further research.

- Redundancy: Almost all wireless networks are present with some redundancy. If this redundancy is not used intelligently, repetition leads to energy wasting. Much of the research has been written in this field and there is still a fertile field.
- Security issue: Security and privacy are playing a pivotal role, especially when a group of entities interacts with each other during the service discovery process. Future studies are still in the direction of using a new trust mechanism to improve the routing protocol to provide secure and effective routing.

Figure 2.8 contains branches of open issues in each field, which in turn includes leaves that declare the corresponding objectives, available solution techniques, and the relationships between. Thus, this figure is so important for the researchers. Moreover, it helps them to broaden their understanding of the issues in the field and helps them to identify the problem clearly and identify the objectives accurately. Furthermore, it gives them clear guidance to solve their problem innovatively. In addition to this, it explains the relationship between all the scientific papers under the survey from a conceptual point of view, which is difficult to understand at first sight. For example, it is difficult to understand the relation of clustering routing protocols with the service discovery protocols, but through this figure, it is easy to understand this relationship. For all these reasons, the researchers are invited to adopt this figure in their survey papers and update this figure according to the development in this area each one based on his interest.

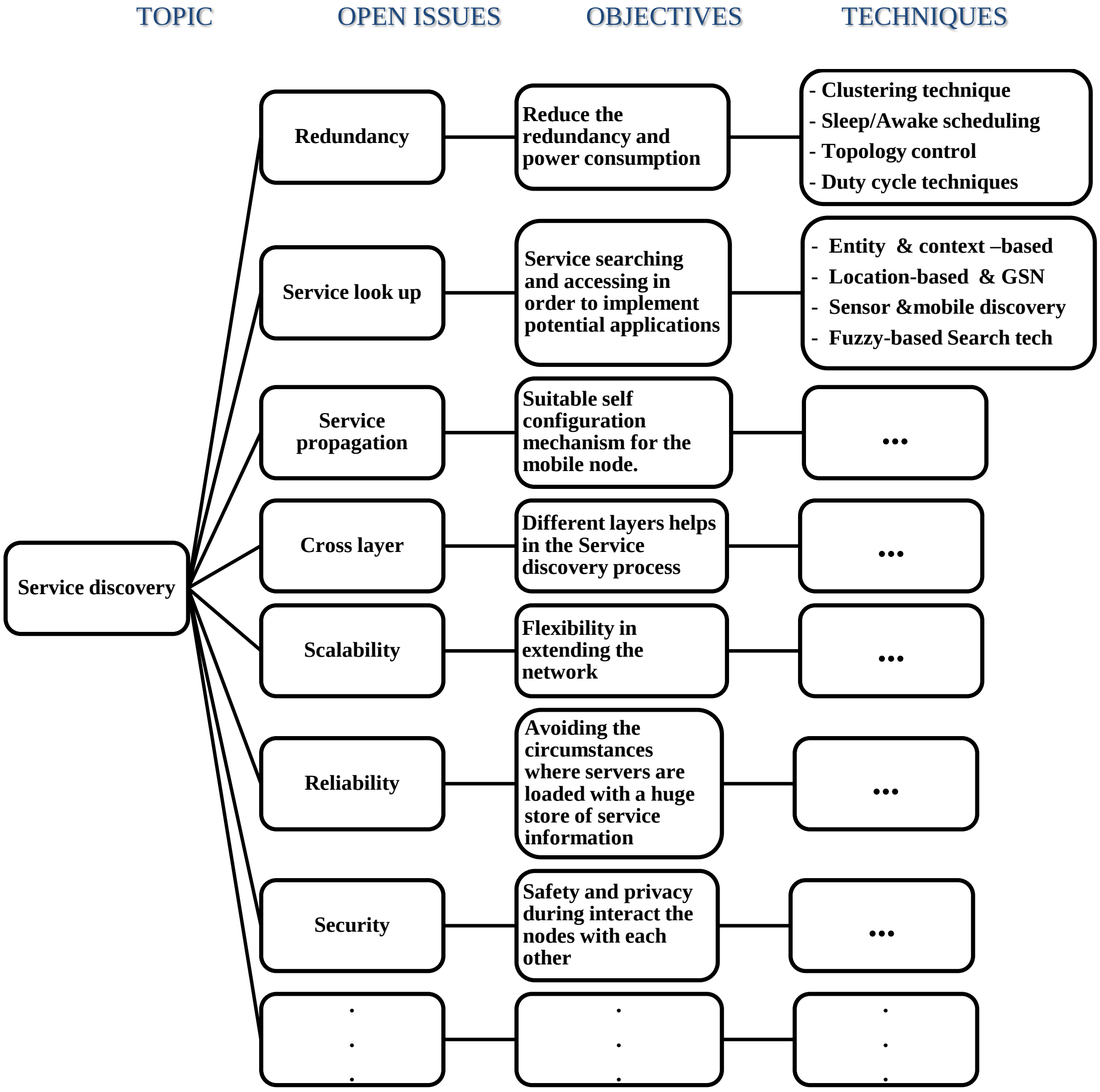

Figure 2.8. Open issues and their objectives and available solution techniques.

2.5 Summary

Service discovery protocols and cluster-based routing protocols are extensively surveyed in both MANETs and WSNs due to their similarity and convergence in problems and complexities. Thus, solutions in MANETs can be used in WSNs with some modifications and improvements. This chapter covered most of the related issues of service discovery protocols such as power consumption, redundancy phenomena, techniques focusing on the clustering method, which is used to solve the redundancy problem, architectures, and expositing the pros and cons. Furthermore, attention has been drawn to the cross-layer solution by discussing different clustering techniques used to solve the power consumption and redundancy problems. In addition, a form has been proposed to clarify the life cycle of the service discovery process. Moreover, a comprehensive comparison table is introduced, which compares the protocols from different perspectives such as energy efficiency, redundancy-aware, location awareness, technique, 6LoWPAN support, and other comparison criteria, discussed these protocols, and come up with important results and valuable recommendations. Furthermore, a new figure has been designed to clarify to the researchers various of the open issues related to the service discovery and the corresponding objectives and problem-solving techniques. So, the researchers are invited to adopt this figure in their survey papers and update this figure according to the development in this area each one based on his interest.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Introduction

The research study followed the quantitative and qualitative methods. Cluster Head Election techniques are extensively covered by reviewing and discussing the most recent related contributions, to determine the open issues and gaps that are not filled yet. Moreover, a new proposed solution was formulated using mathematical models, flowcharts, and pseudo-code algorithms. The effectiveness of the new proposed solution was proven by comparing the simulated results with its most recent counterpart's protocols in terms of energy consumption, latency, loss ratio, and network lifetime.

In Wireless Sensor Network (WSN) environments, small, energy-efficient, low-cost sensor nodes exchange the sensed data with the base station (BS) effectively [131], [186]. The evolution in memory, processors, and microelectronic devices enable to perform different programmed tasks, in turn, allow sensing and computing elements to be integrated into small devices [187]. Moreover, WSNs is formed by scattering separated sensors [188]-[189] for environmental monitoring or physical conditions, such as temperature, pressure, precision agriculture, sound, machine surveillance, intelligent buildings, facility management, habitat monitoring, preventive maintenance, logistics, and transport, etc. Subsequently, their data passed via the network to the main location cooperatively [190]. Battlefield supervision is an example of military applications encouraged to develop wireless sensor networks. Today, these networks are used in many manufacturing and consumer applications, such as control and process monitoring, healthcare, and medicines [191], [192], [193], etc. Clustering is one of the most effective concepts used to solve the problem of power consumption and redundancy in the discovered services. Moreover, the clustering method can guarantee network connectivity, enhance the network robustness, and balance the power consumption when the nodes number and distance between the nodes increase [23]. Furthermore, the clustering system provides two- or three-times longer network life compared to other systems [24]. Figure 3.1 illustrates the basic and famous schemes used to reduce energy consumption, including the cluster-based architecture under study. In summary, the aggregation process considered as a famous routing technology significantly reduces service redundancy, delays, and energy savings [26], [27]. Conversely, it lacks a method for electing an optimum cluster head to enhance the data aggregation efficiency. Furthermore, inefficient cluster head election leads to the high-power consumption of the sensor nodes. Besides, the extensive calculation in the cluster head election process causing in high delays. Also, the repetition of the cluster head election process adds additional overheads which negatively affects energy consumption [25]. To the best of the author's knowledge, the LEACH protocol [100] is the first protocol based on a clustering approach, that uses random selection of cluster heads to distribute the power load equally between network sensors [194]. It also localized coordination to enable scalability and robustness of dynamic networks, also includes data merging in the routing protocol to reduce the amount of information sent to base stations. The results show that LEACH can reduce energy more than 8 times in comparison with conventional routing protocols. Besides, LEACH can distribute power dissipation evenly across the sensors. Although, in the optimum results [195], note the distribution of LEACH's cluster heads is uneven. Similarly, in some areas, the cluster heads are very concentrated. Additionally, LEACH suffers from coverage holes, and connectivity problems, leads to wasting energy in data transmission process. In the same way, the FBCFP protocol uses neuro-fuzzy rule-based clustering concepts to perform cluster-based routing [196]. Energy modeling is utilized to perform cluster formation in WSNs. To insure the weight adjustment, and efficiently routing packets through the machine learning application, a convolutional neural network with fuzzy rules are used. Hence, the network lifetime is prolonged. Nevertheless, the focus on the degree of accuracy for choosing the cluster head by performing complex mathematical operations and measuring multiple factors results in delays and drains the network energy that is supposed to be provided. Similarly, DFLER [197] uses fuzzy logic and the ECATCH algorithm to reduce the workload of the cluster head and produce reliable, accurate results. Nonetheless, sending all sensor data to a specific CH leads to a bottleneck problem. One strength of NCCM-DC [198] is producing a high-performance protocol to enhance energy efficiency and achieve transmission reliability, but a very high load is produced from the synchronization of multi-hop time. Additionally, FEMCHRP [199] elected the cluster heads using the fuzzy logic and Dijkstra algorithm to perform the data transfer process by selecting the shortest energy path. Even so, repetitive use of two methods in the CH election process, at each round, leads to significant energy drain. To enhance the total network lifetime and improve the LEACH protocol, a new node rank based algorithm NR-LEACH was proposed [130]. Conversely, the repetitive calculation for the path cost and the number of links among the nodes in each round depleted the NR-LEACH nodes' energy quickly during the CH election process. Another promising approach from Firefly with Cyclic Randomization (FCR) algorithms is proposed in [131], to enhance an effective CH election method considering energy, delay, and distance in WSNs. Although, the random method used in cluster head election itself results in great delays due to the black hole problems, and the extended amount of time needed to get out from those holes. It is important to highlight that the work in [200] exploits the transmission range for the control messages and the average number of clusters to prolong the network lifetime effectively. On the other hand, repetitive calculations of the transmission range of the control messages and an average number of clusters in each round, cause quick depletion of the network's power and greatly delay the operations. Similarly, RTCP [201] exploits the redundant sensors in the same area and clusters them. To keep the backbone connected, the redundant nodes are stopped, and some active nodes are maintained. The application selected the Tcl value, which affects the number of ready-made groups. When the Tcl is small, few groups are made up. Thus, finding the true Tcl value shows the minimum number of groups, so, when the nodes do not have the same redundancy ratio, it became difficult. On the other hand, DFLCHES [202] introduces an effective CH election that enhanced the network lifetime by exploiting fuzzy clustering and the Genetic Algorithm (GA). Still, the extensive calculation for measurement parameters, such as distance, hop count, centrality measure, and node density, depleted the energy quickly and shortened the network lifetime. Likewise, for performing efficient routing in IoT, a new Cluster Formation based on Neuro-Fuzzy Rule is introduced in [196]. However, many proposed algorithms are using different factors and strategies for selecting cluster heads, and their role is rotating through sensor nodes to attain load balancing, resulting in prolonging the network lifetime. From previous studies, it may be concluded that WSNs are still immature in several aspects and clustering system still suffers from power consumption and delays as a major problem. To solve these downsides in existing proposals available in the related literature, a new Lightweight and Efficient Dynamic Cluster Head Election Routing Protocol for Sensor Networks Wireless (LEDCHE-WSN) is proposed in the next section. Our proposed model is characterized by simplicity, ease, and lightness. The previous characteristics are achieved by avoiding the complexity burdens resulting from intense calculations that are used to ensure the accuracy of the cluster head election process, such as node density, hop count, centrality measure, and messaging, which causes delays and drains the network energy that is supposed to be provided. Experimental results reveal the proposed routing algorithm performs better in terms of packet delivery ratio, energy utilization, network lifetime, and delay.

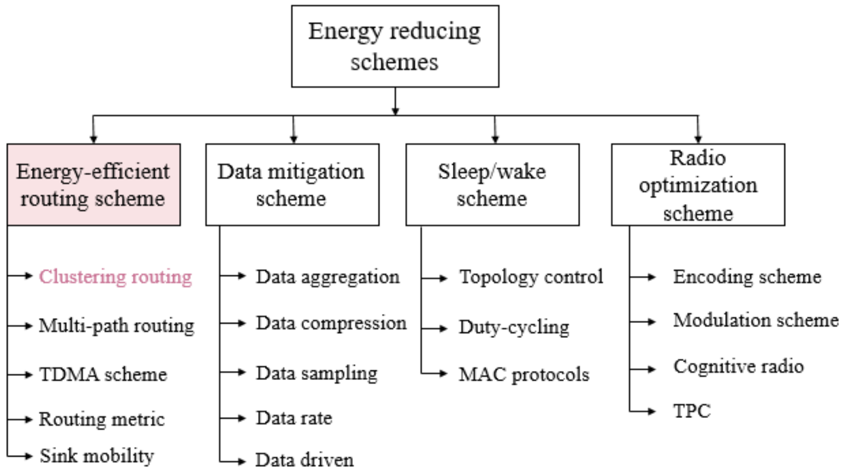

Figure 3.1. Classification of energy reducing schemes in WSNs.

3.2 The Proposed Network Model

The network used to evaluate the proposed clustering protocol is composed of n nodes uniformly distributed in a field $Q \times Q$ square meters. The existence of a link is specified only by the distance among nodes, without taking into account disruptions due to obstructions and interference of wireless signals. A cluster is formed by specifying the cluster head and its cluster members. The cluster member is directly connected to the cluster head. Figure 3.2 illustrates the proposed network architecture.

3.2.1 Nodes Placement

Node deployment patterns make a significant positive impact on the performance of a wireless sensor network. A sensor node is deployed either by placing it in a precise location depending on the application scenario, or by deployed it randomly. A sensor node is also positioned based on the monitored data. For example, in a remote agriculture application, a sensor node is placed manually in the field. If node placement changes continuously, a routing protocol will suffer from the frequent creation and breaking of many links. Moreover, if nodes are deployed densely, a single node has many neighbors that can be directly connected, which will consume more energy and add more burden to the Media Access Control (MAC) protocol due to the repetitive sending to a long range.

To overcome the above issues, topology control is applied. The idea behind using topology control is to control a set of neighbor nodes. Sometimes, a topology is controlled by placing a set of neighbor nodes manually. Topology can also be controlled by creating hierarchies in a network or clustering, by controlling transmission power. A topology is considered based on the used communication technology and the system network requirements. In some scenarios, a hybrid topology is the best option.

The proposed protocol is a hybrid topology, and a combination of centralized and distributed approaches is adopted. Moreover, the topology is controlled by placing a set of neighbor nodes manually. The proposed network model is discussed in more detail in Sections 3.2.2, 3.2.3, and 4.4.

3.2.2 Network Model Assumptions

Regarding the proposed protocol, some basic reasonable assumptions are adopted to define the scope of the proposed network model as follows:

- The network has N sensors distributed in the $Q \times Q$ square field;
- Each node has a unique ID;
- The sink node (SN) location is known by all the sensors and vice versa through the first manually configuration;
- The network nodes are stationary;
- All the network nodes are homogeneous and energy-constrained;
- The SN of each cluster is located at the center of the cluster, so all nodes of the cluster can be connected with it using the single-hop model method;
- The SN has unlimited energy resources, (can be connected to a power grid);
- The BSs are located at the center of each network. The BSs collect their data from rechargeable SNs;
- One BS is used for each $Q \times Q$ m^2 network size;

- Regular sensors can communicate directly with their cluster head (CH);
- The size of a cluster in a network concerning the number of regular sensors is equal;
- In the beginning, all sensor nodes have the same energy level (maximum) and each of them can become the CH or a regular node (due the CH rotation process);
- All the nodes have the capability with appropriate distance to send the information to the sink node.

3.2.3 Network architecture Initializing

The network architecture is designed as depicted in the scenario shown in Figure 3.2, and it is configured according to the assumptions mentioned above (Section 3.2.2). The proposed protocol is implemented in the sink node gateway to select an optimum cluster head dynamically. Moreover, the location of the nodes, including the SN, is configured when the network is initialized and the network nodes are stationary. Therefore, when the SN elects the optimum CH, it informs all nodes about the location of the current CH. Nevertheless, to scale the proposed network, only the new cluster is added (with its corresponding SN) in the specified direction to the nearest cluster edge, and the first configuration is performed manually. Furthermore, the network topology list for each cluster in the SN is updated dynamically when dead nodes are deleted during the dynamic re-clustering process. The uniform deployment was essentially adopted to locate the SNs at the center of each cluster, to enable all the regular nodes to communicate with it directly. Each cluster area is appropriate size enough to enable all regular nodes to communicate directly and effectively to each other. Furthermore, the adopted periodic election policy keeps the nodes uniformally deployment view until close to the end of the network's life. The proposed algorithm in Section 4.4 will explain further how to implement the proposed network.

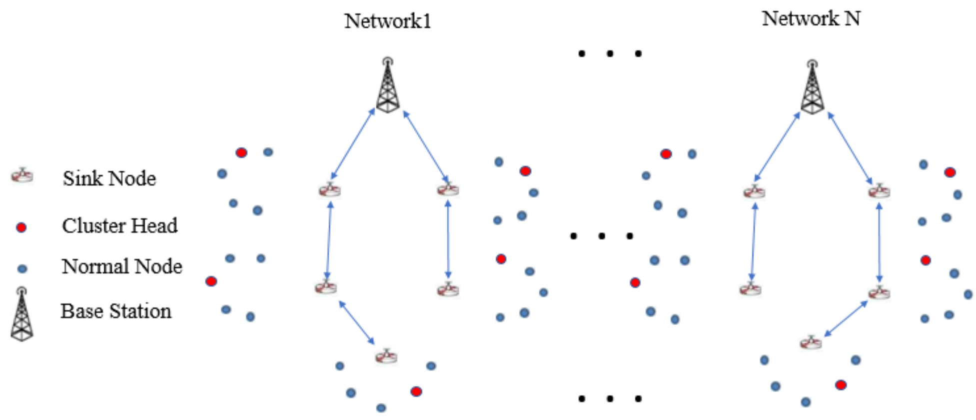

Figure 3.2. Illustration of the LEDCHE-WSN architecture.

Proposed Lightness Architecture and Protocol Efficiency

The philosophy for choosing an appropriate network architecture and its data transmission model has a major impact on the network lightness and efficiency of the proposed protocol. According to the recommendations of a survey conducted in [208], it is clear that the lightest architecture among different architectures is the hybrid architecture, as it acquires the advantages of the distributed and centralized approaches while avoiding their particular limitations. Therefore, the researchers [72], [201] worked to reduce the number of nodes in each cluster to overcome the issue of the energy bottleneck region around the sink node. Similarly, the acceptable number of sink nodes is increased to obtain the advantages of the distributed approach. On the other hand, when the number of clusters is small, intra-cluster distance is becoming too far and it will cause extra power consumption to whole network for data transmission and data loss. In addition, an overlarge number of clusters leads to redundancy when several cluster heads send the same data to the base station (BS) [209]. Experiments should be performed to determine the optimal number of sink nodes and the optimal number of regular sensors in each cluster according to the energy consumption of the whole network lifetime.

A sink node of each cluster is located at the center of the cluster to aggregate data from all the nodes effectively. Furthermore, to make the network lightweight and less power-consuming, to improve the data transmission process, and to ease the deployment, a hybrid-clustering model is adopted. A single-hop clustering model is used in the cluster core (between all the sensor nodes and the elected CH). Nonetheless, its drawback appears when the network size grows in ways such as consuming much more power and increasing the dropping ratio due to the large distances among nodes. Thus, a single-hop method is adopted at the core of the cluster, where nodes are a small size and have a short distance between one another. Conversely, to achieve connectivity and scalability, which the single-hop clustering model does not achieve, the multi-hop clustering model is used in the cluster edge (between the SNs until reaching the BS). The reason for adopting a multi-hop clustering model in the cluster edge comes from the fact that synchronization of multi-hop time in the cluster core produces a very high load and data transmission among nodes, causing more packet delay and packet loss, and therefore, quick energy depletion.

In the same way, to make a network more efficient, the proposed CH election algorithm has avoided the mathematical complexity in the previous studies and many factors considered for precision in electing the optimal CH. They are commonly used, causing much more power consumption and delays. Therefore, the periodic method has been used for electing the cluster head, assuring the node is alive by checking the remaining power without making any accounting or comparing load with other nodes. Due to all these procedures, the network lightness and efficiency of the proposed protocol are guaranteed.

3.3 Proposed Dynamic Cluster Head Election Algorithm

The philosophy of the proposed model is based on improvement in two different directions; the first is designing an appropriate architecture that helps in the lightness of the network and its ease of expansion, which is discussed, in detail, in Section 3.2.3. The second is the enhancement in the algorithm that operates on that architecture, which will be discussed in this section.

The proposed dynamic clustering head election algorithm is structured from two methods. The first is introduced to elect the optimum cluster head, while the second method is introduced to make dynamic self-organization for the clusters when the CH candidate dies or fails. Subsequently, the energy level will be distributed equally among the nodes due to the periodic election policy, the power consumption will be reduced, and, therefore, the lifetime of the network will be improved.

3.3.1 Proposed Optimum Cluster Head Election Method

There is a set of well-known techniques used to select the appropriate cluster head (CH) of each cluster. To explain how the proposed solution works, the description algorithms will focus on a single cluster and then generalize the idea to multiple clusters. Algorithm 1 explains how the proposed method is working in a single cluster.

After the network architecture is designed and its configuration is completed according to the assumptions (Section 3.2.2), the proposed protocol is implemented in the sink node gateway to select an optimum cluster head dynamically.

The basic idea in the proposed method is to distribute the energy level approximately equally among the cluster nodes' in each round/cycle through rotating CH role among the cluster nodes. Along with the random election at the beginning of each round to complexity of tracking the CHs by the attackers.

At the beginning of each round/cycle, the corresponding SN elects the CH candidate randomly (just to determine the CH candidate priority; the election is not finished yet), then the CH candidate power is checked. If the remaining of the CH candidate >zero, that means the CH is alive, the SN elects it as a current CH and informs the other regular nodes. Otherwise means the CH candidate is dead, therefore, the CH candidate is skipped and the next node is checked periodically until the end round is reached. Further, re-organizing the re-clustering process after deleting dead nodes from the topology list will be applied, as illustrated in Section 3.3.2. Accordingly, the regular nodes transmit their data/service to the current CH and, in turn, the current CH transmits the collected data/service to the corresponding SN. After the CH is elected, the SN makes another check to ensure whether the current CH is the last node in this round/cycle or not; that happens when the next node (during the periodic checking) is itself the CH candidate that was elected randomly at beginning of the first round. If the current CH is not the last one in the round, the next CH candidate is checked periodically. Otherwise, it means the first round is finished, and the SN elects the CH candidate for the next round randomly, etc. In the simulation scenario, the rotating of CH among each cluster sensor will done without separating time, and that is to speed up the process of obtaining the simulation results. Whereas, in the real implementation stage, the separating time between the CH rotation may be at each 6 hours or each 12 hours or even 24 hours based on the application natural or the corporation policies. In the same way, the periods in the TDMA system can be extended accordingly. Figure 3.3., shows the proposed Optimum Cluster Head Election method's data flow diagram.

Testing the residual energy of the CH candidate with a specific threshold was ignored, despite it is considered as a one of the common solutions. Because the process of testing these near-death nodes is a waste of time and energy, due to the additional control messages in repetitive testing in each round/cycle for useless nodes if they are not deleted from the topology list, which opens the door for further research to address these challenges effectively. Therefore, this issue is considered as future work, as mentioned in Chapter 6.

Note that the proposed Optimum Cluster Head Election Method lifts from the regular nodes the burden of selecting the next CH node, and the process of notifying the rest of the cluster nodes about the elected CH. Instead, all previous functions were assigned to the rechargeable SN nodes. Contrary to most of the previous studies where the cluster nodes participate in selecting the next CH node and then notify the rest of the cluster nodes to fulfill these roles in these models, cluster nodes keep all the information of the topology list, which leads to a significant and effective drain on cluster nodes' energy.

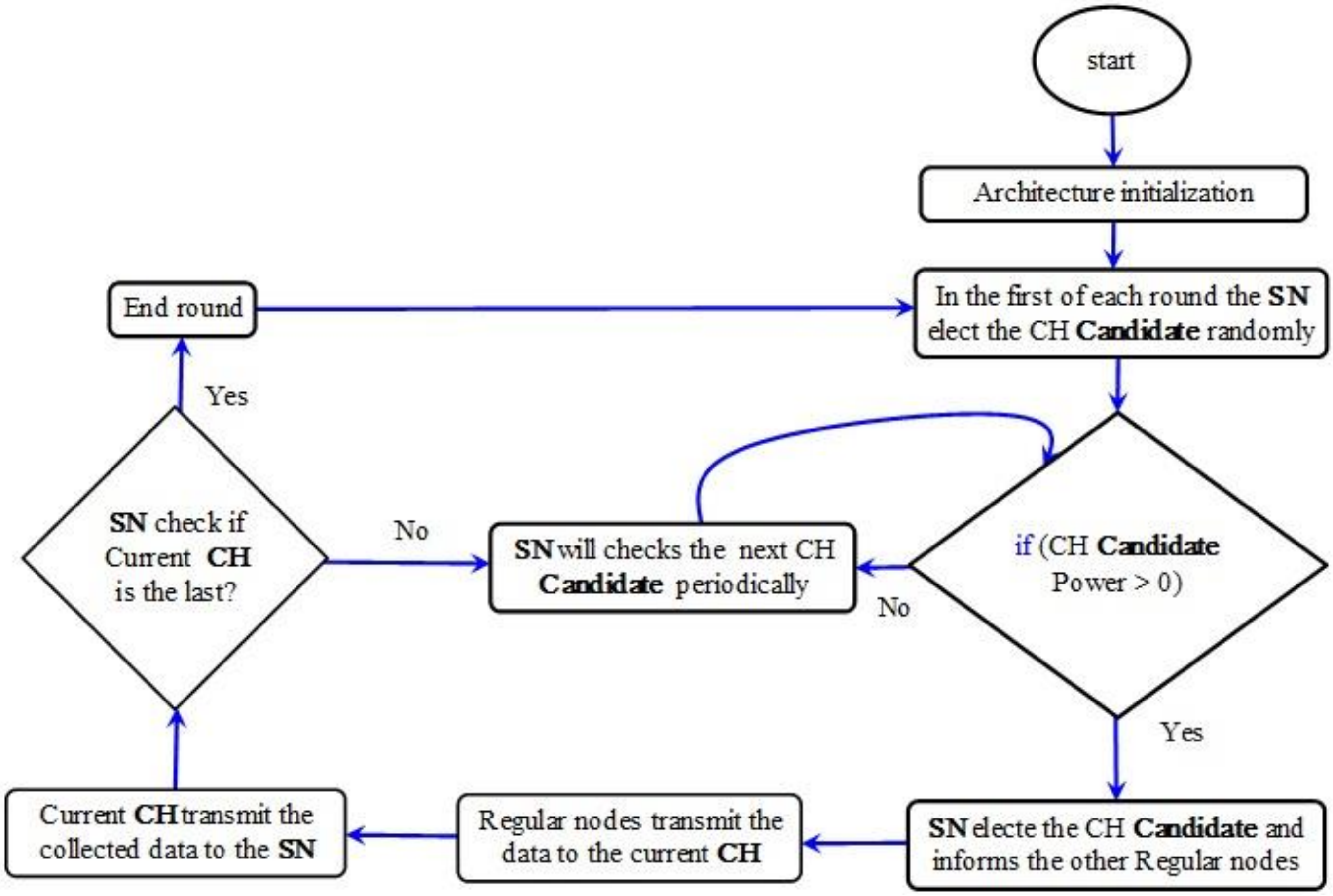

Figure 3.3. The proposed Optimum Cluster Head Election Method's data flow diagram.

In short, the main new ideas of the proposed method can be summarized as follows:

(i) Introduce a new random method to elect a CH candidate; the new method checks the remaining energy for the CH candidate (not the CH itself) which is elected randomly (at the beginning of each round/cycle) to overcome the problems of the black holes. This is contrary to the common random method, which elects the CH randomly and blindly. (ii) Furthermore, the idea behind using the random election method at the beginning of each round is to strengthen the security side and complexity of tracking the CHs by the attackers. Moreover, the random election method is used only at the beginning of each round, and not over the length of the round time. (iii) The next new idea is that, after starting the beginning of the round by using the random method, the rest of the nodes are elected periodically, with checking the remaining energy to skip the dead/failed nodes and save energy and time. Moreover, using the periodic method during the rounds/cycles distribute the energy load equally among network sensors.

Benefits of Random and Periodic Methods Combination

After network creation is completed, the sink node elects the CH candidate randomly at the beginning of each round, to make it difficult for attackers. Moreover, and after the first CH is elected by the SN, the rest of the CHs are elected periodically until the end of the first round, to achieve a good load balance for the network, which prolongs the node life and extends the network lifetime. This combined metric is a good way to overcome the limitation of each one, and at the same time maintain their strengths.

The benefits of mixing the previous two methods (random and periodic) can be summarized as follows:

- Strengthening the security side by electing the CH candidate randomly at the beginning of each round, which complicates the attackers' tasks and attempts as tracking CHs to obtain information;
- Distributing energy among the network nodes fairly, using a periodical election method during each round extending the network lifetime;
- The simplicity, ease, and lightness of the proposed model avoids the complexity burden due to more mathematical operations and messaging for accuracy, which drains the network energy that is supposed to be provided.

Table 3.1: Illustrates measuring the lightness of the proposed model using different factors

Measuring factors	LACH Protocol	FBCFP Protocol	LEDCH-WSN Protocol
1)Repetitive checking to already dead nodes	**Reason:** Random election **Probable: (1 - N)**	**Probable:** Zero	**Probable:** Zero
2) Mathematical Calculations	**Reason:** Calculation **Probable:** Zero	**Reason:** Calculation using 4 factors **Probable:** 4*N	**Reason:** Calculation **Probable:** 1
3) Control messages	**Reason1:** Black holes **Probable:** (1 - N) **Reason1:** Participate in CH election process **Probable:** Zero	**Reason1:** Black holes **Probable:** Zero **Reason1:** Participate in CH election process using 4 factors **Probable:** 4*N	**Reason1:** Black holes **Probable:** Zero **Reason1:** Participate in CH election process **Probable:** Zero
4) Congestion points	**Reason1:** No of Hops (Multi-hop) **Probable:** 2	**Reason1:** No of Hops (Multi-hop) **Probable:** 2	**Reason1:** No of Hops (Multi-hop) **Probable:** 1

Where N is the number of nodes, probable is the probability happen of the procedure. Reason is the reason of the procedure.

According to the Table 3.1, it is so clear that the proposed solution is lowest overhead compared to the two other protocols, in terms of Repetitive checking to already dead nodes, Mathematical Calculations, Control messages, and Congestion points.

Based on our comprehensive and critical survey conducted in [208], researchers have agreed that single-hop model is faster and easy to implement compared to multiple-hop model.

Algorithm 1 Working of the proposed method in a single cluster

Input: *ClusterNumber, DevicePower, DeviceId, Sizeofclusters*

Output: *Assigning the optimum Cluster Head*

```
fn_AssignClusterHead (ClusterNumber, DevicePower)
//Function assign Cluster Heads randomly at the beginning of each cycle and periodically
with the rest//
BEGIN
    R = Generate a random number from [Sizeofclusters]
    FOR all sensor (i) elected randomly R at the beginning of each cycle DO
        DeviceId = ClusterElements [ClusterNumber][i]
        ClusterHeadPower = DevicePower [DeviceId - 1]->dRemainingPower
        IF the candidate CH is a live THEN
                ClusterHeadID = DeviceId
        Else
                CALL fn_DeleteDeadSensors (ClusterNumber, DevicePower)
        END IF
        RETURN ClusterHeadID
    END FOR
END
```

To calculate the energy consumption of the whole network and the formula of its mathematical modeling, it is necessary to calculate the energy consumed for the two sensor points and the formula of its mathematical equation, and then expand the equation to include the whole network. The environmental results sensed by the two sensor points should be sent to the central monitoring unit called the sink node (SN). The energy needed to transmit the data between two sensor points E_{2sens} can be expressed in eq. (1).

$$E_{2sens} = E_{transc}.N_{trans\_dbit} + \varepsilon_{amp}.dis^{\alpha} \quad (1)$$

Where $E_{transc}(j/b)$, is the wasted energy in transceiver operation. N_{trans_dbit}, is the number of transmitted data bits, $\varepsilon_{amp}(J/b/m^2)$ is an amplification coefficient used to ensure the lowest bit error rate due to achieving the reliability of receiver, α is a factor of 2.0 to 5.0, depending on the transmission environment of the networks, and dis refers to the distance between two sensor nodes, which can be expressed as mentioned in Eq. (2).

$$E_{transc} = V_{work}.I_{trans} / T_{trans\_drate} \tag{2}$$

, where V_{work} $Volt_{wrk}$ indicates to working voltage, I_{trans} indicates to current for transmission, and T_{trans_drate} indicates the transmission data rate.

In contrast, we can express the energy consumed to receive the data from the other side $E_{reciv-data}$ as:

$$E_{reciv} = E_{transc}.N_{trans\_dbits} \tag{3}$$

Equation (1) reveals that the consumed energy in the fixed distance is directly proportional to the number of transmitted data bits. Conversely, the greater distance between the two nodes means more energy has been consumed.

Schemes of Sensing

The process of supplying power and ensuring the proper operation of WSN becomes very difficult. Hence, building structures of effective wireless networks for energy efficiency networks is critical [210].

By the network scheme switching, power is saved substantially at the network level. Two different network schemes are reviewed as follows:

Scheme 1 (Single Cluster Algorithm):

The data points obtained from all sensor nodes are transmitted to the CH, and $E_{allSens-CH}$ energy consumption can be calculated, in this case, as:

$$E_{allsens\_CH} = \sum_{i=1}^{N} [(E_{transc} + \varepsilon_{amp}.dist_{i-CH}^{\alpha}).N_{trans\_dbits}] \quad (4)$$

Where N indicates the number of nodes, $dist_{i-CH}$ indicates the distance between nodes and the CH, and N_{trans_dbit} indicates the obtained data bits.

3.3.2 Proposed Dynamic Re-clustering and Self-Organization Method

During the process of the proposed Optimum Cluster Head Election Method, and when the SN checks the CH candidate, a result greater than zero means it is alive and, hence, the SN elects it as a current CH and informs the other nodes. Otherwise means the CH candidate is dead or failed. Thus, the SN deletes the CH candidate from the topology list, sends a report/feedback to the Base Station (BS) to do the appropriate, and re-organizes the cluster dynamically by re-arranging the node's ID accordingly. Furthermore, any node that cannot transmit their status are considered as dead/failed nodes, so they will also be skipped and deleted from the topology list; the checking of the rest of the nodes will continue periodically. In short, the new idea of the proposed method is that, when the CH candidate is dead/failed, the proposed protocol skips the node and deletes it from the topology list to address the black holes and routing delay problems. Which causes the waste of time and energy, due to additional control messages for useless nodes, which are not deleted from the topology list. Next, the proposed method reorders the nodes and sends feedback to replace the node or do the appropriate. Figure 3.4 shows the proposed Dynamic Cluster Self-Organization Method's data flow diagram.

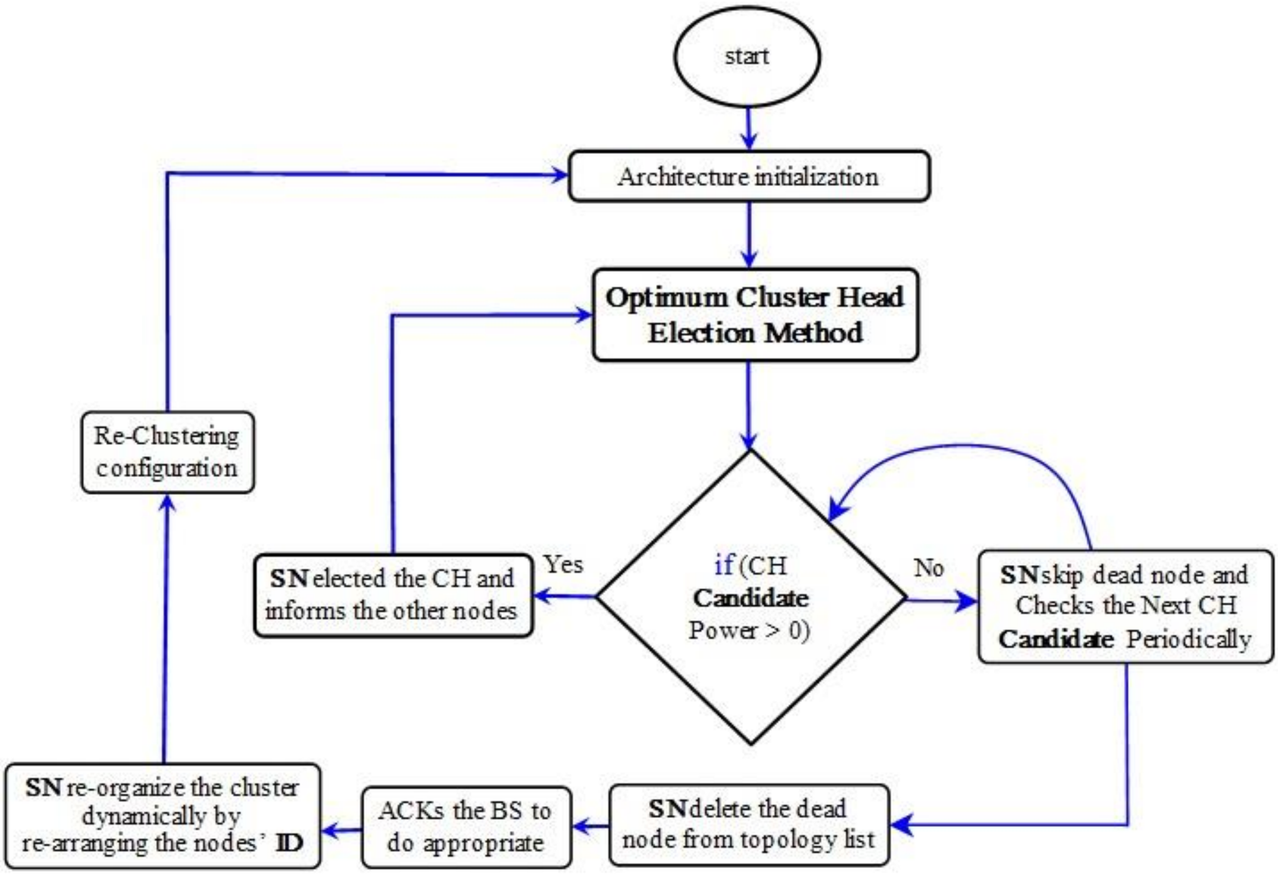

Figure 3.4. The proposed Dynamic Cluster Self-Organization Method's Data Flow Diagram.

3.3.2.1 Mitigation of Energy Consumption during Cluster Reconfiguration

Occasionally, the CH consumes more energy due to the cluster preparation stage and many data transfers. Re-clustering is proposed to distribute the CH role among the sensor nodes equally and extend the network lifetime. Although, re-clustering increases power consumption, due to additional control messages, and delays real-time data transmission [211], [212]. The proposed solution overcome this limitation as detailed in the coming section (3.3.2.2).

3.3.2.2 Dead Nodes and Re-Clustering Organization

During the verification of the remaining energy of each node, after discovering a dead node the proposed algorithm provides a solution that involves deleting dead or failed nodes from clusters' topology list and then notifies the Base Station. Thus, overcoming the false election problem (black holes), which saves wasted energy in sending messages to a dead or failed node. It also saves wasted time to get out of the false election of the failed nodes (black holes). Consequently, it will not consider dead or failed nodes in the upcoming cluster reconfiguration process. Algorithm 2 shows how to delete the dead nodes from the topology list, and the processes of Base Station notification and re-clustering configuration.

Algorithm 2 Deletes the Dead Sensors from the Cluster

```
Input: ClusterNumber, DevicePower, Sizeofclusters
Output: Delete the Dead Sensors from the Cluster
fn_DeleteDeadSensors (ClusterNumber, DevicePower)
// Function delete the Dead Sensors from the Cluster and sends a report to the BS //
BEGIN
    FOR each sensor i starting from the dead sensor DO
        Delete the Dead Sensors by Copy next element value to current
        element
        ClusterElements [ClusterNumber][i] =   ClusterElements
        [ClusterNumber] [i + 1]
    END FOR
        Decrement Sizeofclusters by 1
        ClusterElements [ClusterNumber] [Sizeofclusters--]
        Send a report telling the Base Station that the DeviceId (in the
        ClusterNumber) is dead
END
```

3.3.2.3 Multiple Cluster Organization

The previous operations were concerning a single cluster, whereas in the case of multiple clusters, the cluster is determined to elect the appropriate CH first, then move among the rest of the clusters to apply the same scenario. Moreover, data of all the clusters are sent to the sink node. Algorithm 3 presents how to move between the other Clusters to elect the appropriate CH for each one.

3.3.2.4 Data Collection Phase

After selecting the CH, the sink node uses a Time Division Multiple Access system (TDMA), giving a time limit for each node to transmit its data to the elected CH. In the second stage, the elected CH transmits the received data to the sink node as scheduled (TDMA). Consequently, the cluster head before transmitting the data, will avoids data collision problems. The coming mathematical model and analysis illustrate these ideas precisely. Algorithm 4 shows how to determine the current cluster for each sensor, while Algorithm 5 shows how to transmit all clusters' data to the sink node (SN).

Algorithm 3 Multiple Cluster Algorithm

Input: DevicePower, NUMBEROFCLUSTERS

Output: Moving between the Clusters to elect the optimum CH for each

```
FOR each Cluster i of the network DO
    IF (CHcount[i] == NUMBEROFCLUSTERS) THEN
      CH [i] = CALL  f_AssignClusterHead (i, DevicePower) RETURNING
     elected CH
      prevCH[i] = CH[i]
     CHcount[i] = 0
    ELSE
       CHcount[i]++
       IF (prevCH [i]! = 0)
            CH[i] = prevCH[i]
    END IF
END FOR
```

Algorithm 4 Identify the cluster of each sensor

Input: *DeviceId, ClusterElements*

Output: *Identify the cluster of each sensor*

```
fn_IdentifyCluster (DeviceId)
BEGIN
For each Cluster i of the network DO
        For each sensor j of the Cluster DO
            IF (DeviceId == ClusterElements[i][j]) THEN
              RETURN i
        END FOR
END FOR
END
```

Algorithm 5 Data Transmission Phase

Input: *ClusterNumber, DevicePower, DeviceId*

Output: *Transmit all Clusters data to the Sink Node*

```
IF the sensor is the Cluster Head THEN
forwards all the collected data to the corresponding Sink Node
Else
Identify the Cluster and the current CH will be the NextHop for the data transmission
process
ClusterId = fn_IdentifyCluster(DeviceId)
nextHop = CH[ClusterId]
END IF
```

Scheme 2 (Multiple Cluster Algorithm):

The sensor network is split into different groups; the data is collected from the sensor nodes in each group and transmitted to the corresponding cluster head. In turn, the head of the group sends the collected data to the central management unit sink node. In this case, the energy consumed can be calculated as:

$$E_{CH-SN} = \sum_{m=1}^{M} \begin{bmatrix} \sum_{i=1}^{N_m - 1} \left(E_{transc} + \varepsilon_{amp}.dist_i^{\alpha} + E_{reciv} \right).N_{trans\_dbits} \\ + \qquad \left(E_{transc} + \varepsilon_{amp}.dist_m^{\alpha} \right).N_{trans\_dbits} \end{bmatrix} \tag{5}$$

Where M indicates the cluster's number, N_m indicates the nodes' number in the corresponding cluster, $dist_i$ indicates the distance between the node and its CH, $dist_m$ indicates the distance between the CH and the SN, and $N_{trans\_dbits_m}$ indicates the number of data bits in the transmitted packet data.

For example, Figure 2.5 also illustrates the Multiple Cluster Algorithm, which is a process of managing and monitoring the precision agriculture platform, where the network divides into different groups. Each agriculture platform in this scheme is identified as a cluster. The rest of the sensors transmit the obtained data to the elected cluster head, then the cluster head transmits the data (service and commands) to the corresponding sink node.

3.4 Summary

In this chapter, a clustering approach is investigated, with presen a taxonomy of an energy-reducing scheme. Moreover, a Lightweight and Efficient Dynamic Cluster Head Election Routing (LEDCHE-WSN) Protocol is proposed to enhance energy efficiency, reduce delays, and extend network life for wireless sensor networks. The proposed routing algorithm comprises two integrated methods, electing the optimum cluster head, and organizing the re-clustering process dynamically. Finally, the proposed algorithm's flowchart, pseudo-codes, and their mathematical models are presented and discussed.

CHAPTER IV

SIMULATION TOOL AND ITS DEPLOYMENT

4.1 NetSim simulator

NetSim is a network simulation tool that allows users to create network scenarios, model traffic, design protocols, and analyze network performance. Users can study the behavior of a network by testing combinations of network parameters. NetSim enables users to simulate protocols that function in various networks and is organized as Internetworks, Legacy Networks, Advanced Routing, Advanced Wireless Networks, Cellular Networks, Wireless Sensor Networks, Personal Area Networks, LTE/LTE-A Networks, Cognitive Radio Networks, Internet of Things and VANETs.[NetSim_Experiment_Manual]

4.2 Simulation Setup

In the simulation setup, 100 sensor nodes are scattered uniformly in a $100m^2$ region. The simulation study uses NetSim simulator. The proposed network has been divided into 5 clusters, and each cluster includes 20 nodes. Moreover, each cluster is connected to the corresponding sink node, therefore, the number of SNs is also 5. The SN of each cluster is located at the center of the cluster, to aggregate data from all the sensor nodes effectively. Therefore, all nodes of the cluster can be connected with it using the single-hop model method. Besides that, sink nodes are distributed to make the network more scalable. Additionally, the BS is located at the center of each network. The BSs collect their data from rechargeable SNs. To be more specific, in the proposed protocol there are 5 SNs in a $100m \times 100m$ network size. To easier the calculation, suppose that each cluster takes a square shape. Consequently, there is one SN in each 44.7m × 44.7m. Thus, means the distance between the neighbor regular nodes is approximately 9m (sensors are distributed at the square perimeter). According to an assumptions, each SN is at the center of each cluster, meaning the distance between the regular nodes and the SN is approximately is 22m. Therefore, the nodes are not far from the SN. Moreover, the BS is at the center of the 5 SNs, in the same way; the distances become closer. Hence, good architecture design makes the connectivity more simple and flexible. Table 4.1 shows the network parameters and corresponding values.

Table 4.1: Network Simulation Parameters.

Value	**Parameter**
100 × 100 m	Network size
Sensor	Device Type
100	Number of sensor nodes
1460	MTU (bytes)
DSR	WSNs Routing Protocols
PHY IEEE802.15.4	MAC Layer Protocol
512 bits	Control packet size
4000 bits	Data packet size
6J = 6000 m J	Initial Energy
50 nj/bit	Eelect
CARRIER_SENSE_ONLY	CCA
−95	Packet Reception Power Threshold (dBm)
−85	Receiver Sensitivity (dBm)
100	Sensor Range (m)
250	Data Rate (Kbps)
1200	Simulation Time (sec)
NetSim	Simulator

The existence of a link is specified only by the distance among nodes, without taking into account disruptions due to obstructions and interference of wireless signals.

The network architecture is designed as depicted in the scenario shown in Figure 3.2, and it is configured according to the assumptions mentioned above (Section 3.2.2). The proposed protocol is implemented in the sink node gateway to select an optimum cluster head dynamically. Moreover, the location of the nodes, including the SN, is configured when the network is initialized and the network nodes are stationary. Therefore, when the SN elects the optimum CH, it informs all nodes about the location of the current CH. To scale the proposed network, only the new cluster is added (with its corresponding SN) in the specified direction to the nearest cluster edge, and the first configuration is performed manually. Furthermore, the network topology list for each cluster in the SN is updated dynamically when dead nodes are deleted during the dynamic re-clustering process. The uniform deployment was essentially adopted to locate the SNs at the center of each cluster, to enable all the regular nodes to communicate to it directly. Additionally, the area of each cluster is an appropriate size to enable all regular nodes to communicate with one another directly and effectively. Furthermore, the adopted periodic election policy keeps the view of the uniform deployment of nodes until close to the end of the network's life.

4.3 Summary

In this chapter, simulation definition and its needs are discussed in detail. Furthermore, a brief overview is given for the NetSim simulator, which is used to evaluate and validate the performance of the proposed protocol, as well as, simulation setup has been also presented.

CHAPTER V

PERFORMANCE EVALUATION AND RESULTS ANALYSIS

5.1 Introduction

The LEACH protocol is chosen to perform the comparison due to the considerable number of protocols based on it, such as FBCFP [18] or FL-EEC/D [16].

In this chapter, the performance efficiency and precision of the proposed protocol assumptions are validated by using NetSim simulation and compared with the LEACH and FBCFP protocols in terms of energy consumption, latency, loss ratio, and network lifetime. To provide highly efficient communication paths, routing protocols use one or more known metrics. Three factors are used to evaluate the performance of the proposed protocol as described below.

5.2 Results Analysis

The proposed LEDCHE-WSN protocol is evaluated and compared with the LEACH and FBCFP protocols in terms of energy consumption, mean package delay, and total packets dropped (loss ratio). Additionally, it is compared with existing HEED and FLCFP performance in terms of network lifetime.

The proposed algorithm is characterized by simplicity, ease, and lightness as pointed out in the thesis title. The computational complexity burden was avoided in the proposed algorithm compared with other protocols. Most of the previous studies, including the FBCFP and LEACH protocols, adopted a heavy measuring method in choosing the optimum cluster head, such as measuring the signal strength, residual energy, node density, hop count, and the distance among nodes and base station which causes delays, increasing loss ratio, and draining the network energy that is supposed to be provided. More precisely, the FBCFP protocol makes extensive calculations in the cluster head election process, such as node density, CH degree count, traffic level, and bandwidth availability. On the other hand, the LEACH protocol calculates and compares the remaining energy for a CH candidate with all other sensor nodes, causing a shortening of the network lifetime and adding more burdens to the network. On the other hand, the LEDCHE-WSN algorithm checks the remaining energy only to ensure that a CH candidate is alive, without adding a burden in calculation and comparison for the remaining energy of the CH candidate with all the other sensor nodes. As a result, the experiments in the coming sections prove the simplicity and lightness of the proposed algorithm compared to the most recent studies.

5.2.1 Energy Consumption and Network Lifetime

The total energy consumption measures the energy consumed by each node in forwarding packets to sink nodes, which indicates the network lifetime wasted by the protocols. The calculation of Average Energy Consumption uses Equation (6).

$$Avg_{E_J} = \frac{\sum_{j=1}^{N} E_{sens_j}}{\sum_{n=1}^{k} N_{reciv\_pk_n}} \tag{1}$$

Where Avg_{E_J} is the Average Energy Consumption, E_{sens_j} is the Energy Consumed by each packet, $N_{reciv\_pk_n}$ is the Number of received packets

Figure 5.1 plots the total energy consumption per node, including the nodes ID. As may be seen, it can be noted that the proposed LEDCHE-WSN protocol reduced the total energy consumption of the sensor nodes by approximately 32% when compared to the LEACH protocol, and 8% when compared to the FBCFP protocol for the 100 × 100 m network size. This can occur for several reasons.

First, it can occur due to deleting failed or dead nodes from the network topology during the re-clustering process to address the black holes and routing delay problems, which causes a waste of time and energy due to additional control messages for useless nodes, if they are not deleted from the topology list. Second, it can happen due to releasing the regular nodes from the processes of selecting the next CH node (cluster formation process). Instead, the rechargeable SN will do all the previous jobs. Contrary to what happened in the most previous studies, especially in the FBCFP protocol. Second, the reduced energy consumption could be because, checking the remaining energy in LEDCHE-WSN is performed only to ensure that, the CH candidate is alive. Whereas the FBCFP and LEACH protocols calculate and compare the remaining energy for a CH candidate with all other sensor nodes, causing in shortening the network lifetime and adding more burdens to the network. Finally, this figure presents the total energy consumption for each node when the last node of the LEACH protocol is dead, and the simulation time is finished (1200 s is the simulation time, as shown in Table 4.1). A good load balance is estimated inside the proposed protocol by monitoring the total energy consumption for each node. From Figure 5.1, it is observed that the total energy consumption in the proposed protocol, until the simulation time is finished, is much more regular and the energy is distributed more equally among network sensors than total energy consumption for the benchmarks, which means energy distribution in the proposed protocol is better, therefore, proves the efficiency of the proposed protocol.

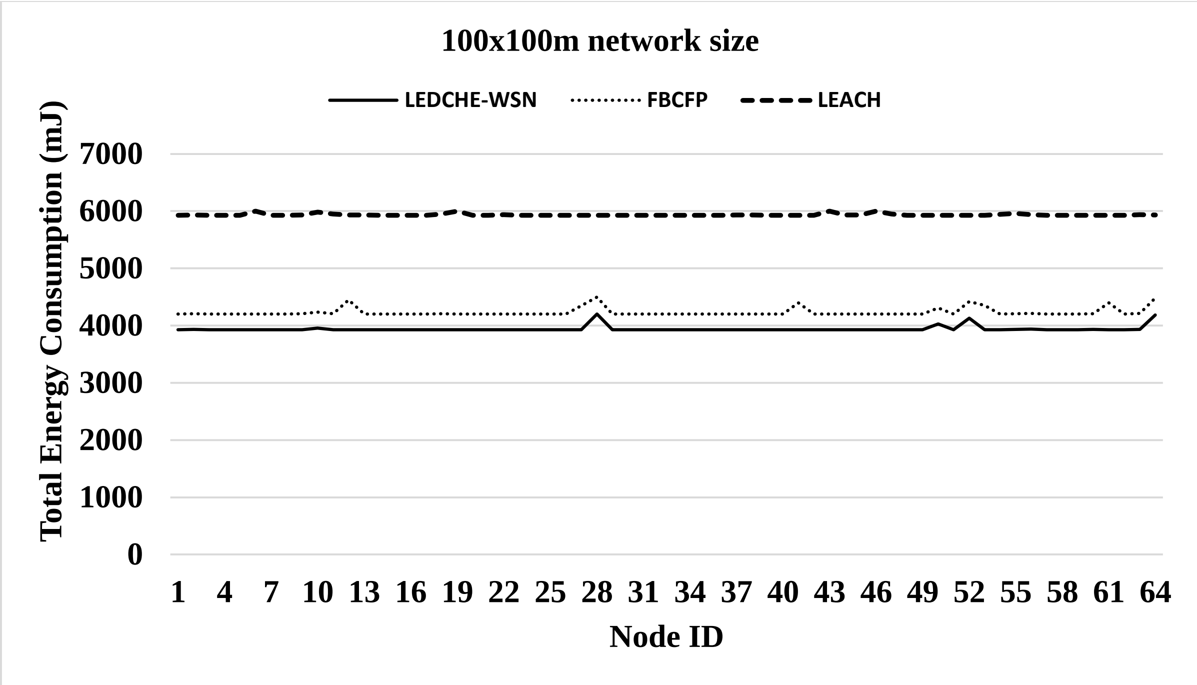

Figure 5.1**.** Total energy consumption for each node considering a 100 m ×100 m network size for LEACH, FBCFP, and LEDCHE-WSN protocols.

According to [18], considering results for 100 nodes, the HEED protocol improves the LEACH protocol network lifetime by 8%, the FLCFP protocol improves the LEACH by 10%, and the FBCFP protocol improves the LEACH by 25%. This means that the proposed protocol LEDCHE-WSN overcomes the performances of LEACH, HEED, FLCFP, and FBCFP in terms of network lifetime.

5.2.2 Mean Package Delay

Mean delay $\left(\mu_{dely}\right)$ is the sum of Queuing Delay (Que_{dely}), Total Transmission Time (T_{trans}), and Total Routing Delay $\left(Rout_{dely}\right)$. Mean Package delay can be calculated by Equation (7).

$$\mu_{dely_i} = \sum_{i=1}^{N} (Que_{dely_i} + T_{trans_i} + Rout_{dely_i}) \tag{7}$$

The Total expected Queuing Time is as in equation (8):

ρ is the utilization given as follows, $\rho = \frac{\lambda}{\mu}$ (8)

Where: $\mu =$ service rate, i.e., the rate is taken to service each packet.

$\lambda =$ Arrival time, i.e., the time at which packets arrive.

Total Transmission Time is the sum of transmission time through each link.

Transmission time through each link is the same as presented in Equation (9):

$$Transmission\ time\ through\ each\ link = \frac{Payload\ size\quad (Bytes) \times 8}{Uplink\ speed\quad (bps)} \tag{2}$$

Where the payload size is the sum of packet size and the overhead as presented in Equation (10):

$$Payload\ size\quad = Packet\ Size + Overhead \tag{10}$$

Where the overhead is the content of each packet as presented in Equation (11):

$$Overhead = Head + Trail \tag{11}$$

Routing Delay is approximately 1 micro sec and can be calculated from the event trace file. It is the difference between “Physical In” and “Physical Out” time [213].

Figure 5.2 plots (μ_{dely}) considering the round’s number. From Figure 5.2, it can be observed that the proposed protocol improves (μ_{dely}) by more than 42% compared to the LEACH protocol, and more than 15% compared to the FBCFP protocol; this is a consequence of using the single-hop clustering model at the cluster core, resulting in the fast delivery process and making it much more simple and lightweight. The LEACH and FBCFP protocols adopted a multi-hop model and synchronization of multi-hop nodes' time in the cluster core, producing a very high load and data transmission among nodes, causing much more packet delay and packet loss, and therefore quick energy depletion. Similarly, using the random method in the LEACH protocol during the CH election process causes much more delay, due to the false election of the failure (black holes) and much more time needed to get out of those holes. Additionally, the extensive calculation in the CH election process, such as node density, CH degree count, traffic level, and bandwidth availability in the FBCFP protocol results in more delays and increased complexity, as detailed in Section 5.2. (Results Analysis). On the other hand, the LEDCHE-WSN protocol checks nodes are alive before the election process to overcome the black holes problem. Furthermore, by locating the sink node at the center of the cluster, the distance between nodes and the sink nodes will reduced. Consequently, the mean package delay is improved, and data aggregation from all sensor nodes is performed effectively.

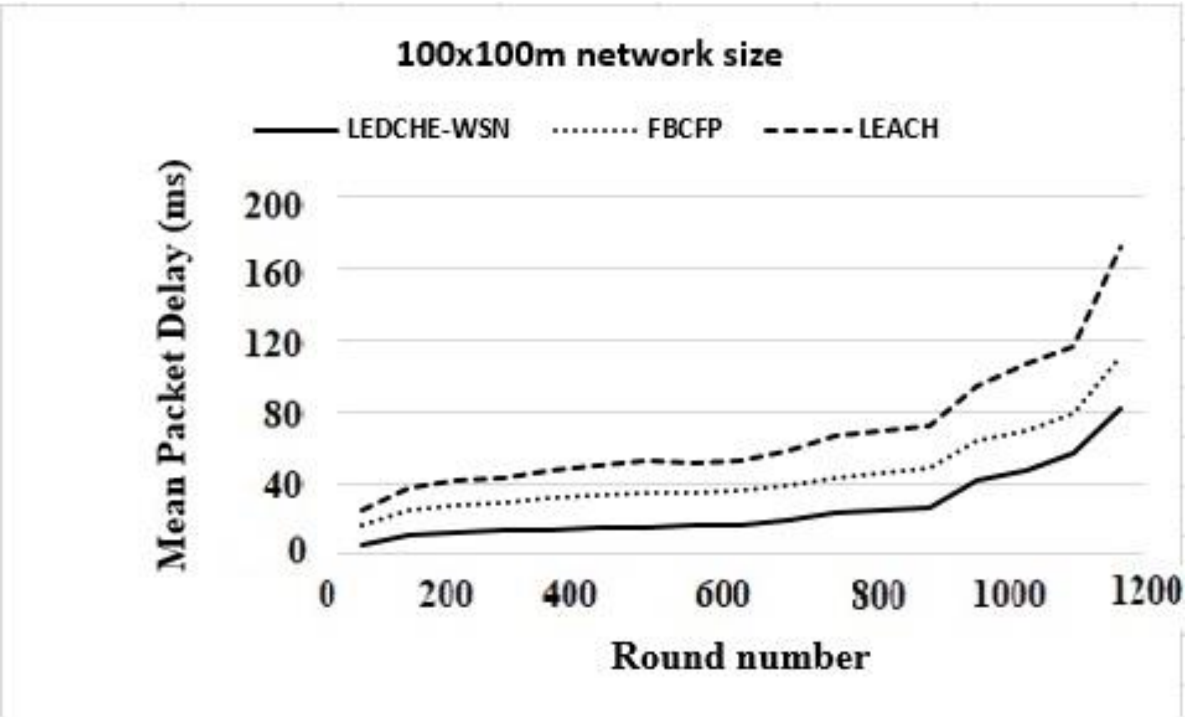

Figure 5.2. Mean package delay considering 100 × 100 m network size for LEACH, FBCFP, and LEDCHE-WSN protocols.

Despite the efficiency of the proposed protocol, the plots shows the accelerating and infinite increase of the Mean Delay, which may cause the network to collapse rapidly at the end. As it appears that, this continue increase is not only in the proposed protocol, but also in the other two protocols (LEACH and FBCFP) which means that they suffered the same effect. After referring to the data obtained from the simulation results, we found that the elected CH was exposed to a stream/burst of data - coming from regular nodes - that exceeded its ability to transmit, which created a critical bottleneck. Thus, it negatively affected the network performance in terms of mean delay and loss ratio.

5.2.3 Total Packets Dropped (Loss Ratio)

Considering packet loss in the selection of the best communication path has a significant impact on reducing energy consumption and increasing the network throughput. Moreover, it is used as a measure to determine the efficiency of routing protocols. The loss ratio can be calculated using Equation (12).

$$\text{Total}_{packt\_dely_{(i,j)}} = \sum_{i=1}^{N} \text{Packt Sent}_i - \sum_{j=1}^{M} \text{Packt Reciv}_j \qquad (12)$$

Where, Packt Sent_i is the packets Sent, while, Packt Reciv_j is the packets Received, where $j \in i$.

Figure 5.3 shows the total packets dropped (loss ratio) considering the round's number. As may be observed, the proposed LEDCHE-WSN protocol reduced the loss ratio by more than 46% compared to the LEACH protocol, and more than 25% compared to the FBCFP protocol. This is due to adopting the single-hop clustering model that is easy to implement and fast to deliver, but its main drawback appears when the network size grows. To overcome this problem, LEDCHE-WSN architecture is enhanced by using a single-hop model at the cluster core where its nodes are a small size have a short distance between one another. Moreover, using a multiple-hop model at the cluster core causes multiple congestion points in the cluster, which in turn results in increasing the packet loss ratio, and quick node energy depletion. Consequently, the core becomes lightweight and the loss ratio is improved. The LEACH FBCFP protocols adopted a multiple-hop model at cluster core, producing a very high load and data transmission among nodes, causing more packet delay, packet loss, and, therefore, quick energy depletion. Furthermore, repetitive checking at each round/cycle for dead nodes, in the LEACH and FBCFP protocols, caused more delays and increased the loss ratio. The proposed LEDCHE-WSN protocol is distinguished by deleting the failure and/or dead nodes from the network topology during the re-clustering process to address the black holes and routing delay problems.

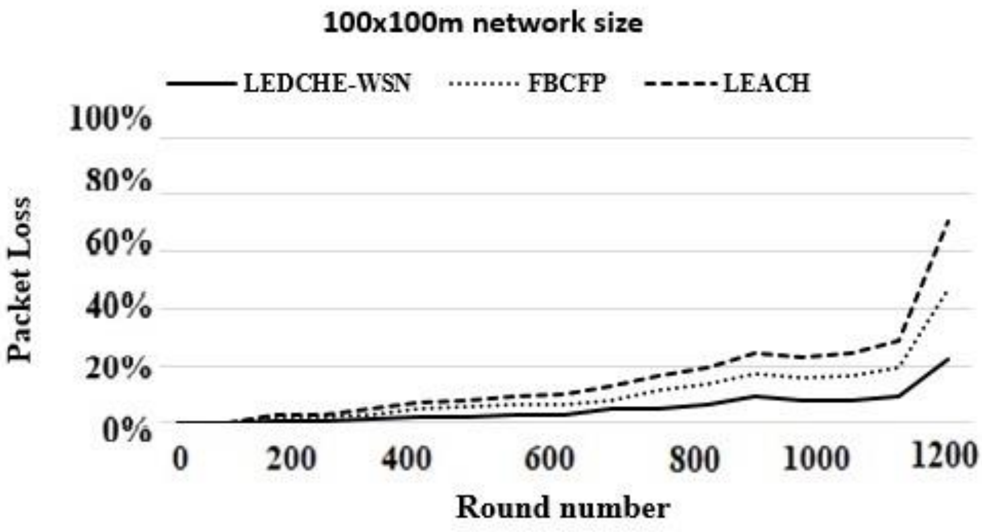

Figure 5.3. Percentage of packets loss ratio for the 100 × 100 m network size for LEACH, FBCFP, and LEDCHE-WSN protocols.

Although the TDMA system is used to preventing packets collisions problem. However, it can be seen in the figure that the Loss Ratio also increase continuously, which directly affects at the network performance negatively. This is for the same reason that mentioned about the problem of the steady rise in the Mean Delay, which leads to this increasing in the loss ratio. Therefore, in the upcoming experiments consideration should be taken about the appropriate amount of transmitted data to the CH.

5.3 Proposed Protocol Strength Points Compared with LEACH and FBCFP Protocols

The proposed LEDCHE-WSN protocol is preferable to the benchmark LEACH and FBCFP protocols, taking into account the following aspects:

- The LEDCHE-WSN protocol adopted a hybrid clustering model. A single-hop model is used at the cluster core, where the nodes are a small size and have a short distance between one another, making it more simple, fast, lightweight, and easy to deploy. On the other hand, a multi-hop model is used at the cluster edge to make it more connective and scalable. LEACH and FBCFP protocols use the multi-hop model at the cluster core. Despite the fact a multi-hop model can improve connectivity and extend network coverage, it causes more packet delay and packet loss, especially at the cluster core. As is well-known, the direct routing approach (single-hop model) is easy to deploy and provides fast delivery, but its drawback appears when the network size grows. Therefore, this problem was overcome by improving the LEDCHE-WSN architecture through distributing sink nodes, and using the multi-hop model at the edge of the cluster to make it much more connective and scalable;
- The LEACH protocol elects the cluster-head randomly, which results in an unbalanced energy level and thus dissipates the total network energy. The proposed algorithm performs a periodical election by excluding failed or dead nodes, which leads to a balanced energy level;
- The proposed algorithm works randomly only at the beginning of each round, to enhance the privacy of location, minimize hackers' chances of successive packets, and further complicate guessing the next packet;
- The random method in the LEACH protocol caused much more delay, due to the false election of the failure nodes (black holes) and much more time needed to get out of those holes. On the other hand, the proposed protocol

ensures the living of the node by checking the remaining power during the random election for the CH candidate to overcome the black holes problem, and that happened only at the beginning of each round;

- The LEACH protocol calculates the remaining energy and times of being elected as a cluster head for each sensor node adds more burden to the network. Moreover, the FBCFP protocol is more complicated, focusing on the degree of accuracy to choose the cluster head performing complex mathematical operations and measuring multiple factors (such as node density, CH degree count, traffic level, and bandwidth availability), causing more delays and increasing complexity. The LEDCHE-WSN algorithm checks the remaining energy just to ensure that a CH candidate is alive, without adding a burden in calculation and comparison for the remaining energy of the CH candidate with all the other sensor nodes as detailed in Section 5.2. (Results Analysis);
- More importantly, the LEDCHE-WSN protocol relieved regular sensors from the processes of selecting the next CH node and notifying the rest of the cluster nodes accordingly. Instead, it assigned all previous jobs to the rechargeable SN nodes, contrary to what happened in most of the previous studies including the FBCFP protocol. In this protocol, cluster nodes participate in selecting the next CH node and, then, notify the rest of the cluster nodes. It keeps all the information of the topology list, leading to a significant and effective drain on cluster nodes' energy;
- The proposed method is distinguished from the LEACH and FBCFP protocols by addressing the problem of re-electing a failed or dead node, checking the status of the node, and then deleting the failed and/or dead nodes from the network topology list, resulting in extending the overall network lifetime.

5.4 Summary

This chapter evaluates and validates the performance of the proposed protocol using NetSim simulation and compared it with the LEACH protocol and the best approaches available in the literature using different scenarios. Experimental results reveal that the proposed routing algorithm results in better network performance in terms of packet delivery ratio, energy utilization, network lifetime, and delay. Moreover, proposed protocol strength points compared with LEACH and FBCFP Protocols are presented.

CHAPTER VI

CONCLUSION AND FUTURE WORK

This chapter summarizes the contributions and findings of the research work and presents suggestions and recommendations for future study. This study primarily investigates the importance of introducing a lightweight and efficient routing protocol for achieving efficient applications services for WSNs.

6.1 The Proposed Method

The proposed method introduces a simple, light, and easy to deploy cluster head election algorithm in WSNs, due to reducing the power consumption with minimum packet delay, loss, and routing overhead than the inefficient ones. The idea to achieve that is to distribute the energy load equally among the network nodes. Moreover, the proposed algorithm deletes the dead/failed nodes from the topology list, and then updated it dynamically by reordering the nodes and sending feedback to replace the dead node or do the appropriate during the dynamic re-clustering process.

6.2 Contribution of the Research

As mentioned above in the previous section. The main goal of this thesis is to propose a new lightweight and efficient dynamic cluster head election routing protocol for wireless sensor networks to enhance the cluster-based networks in terms of energy consumption, latency, loss ratio, and network lifetime. The highlight of this thesis is that two integrated methods are introduced, electing the optimum cluster head, and organizing the re-clustering process dynamically. Therefore, this study reaches several contributions to reduce power consumption, enhance the network delay, and strengthen the security side. Major activities corresponding to contributions are summarized as follows:

- **i.** Review the state of the art of service discovery and cluster-based routing protocols, applications, strategies, and mechanisms with focusing on the CH election mechanisms.
- **ii.** Proposing a new method to elect the optimum cluster head dynamically in Cluster -Based routing protocols of the WSNs, which enhance the data aggregation efficiency.
- **iii.** The proposed method is distinguished by deleting the failure and/or dead nodes from the network topology during the re-clustering process, to address the black holes and routing delay problems. In turn, results in a waste of time and energy, due to additional control messages in repetitive checking in each round/cycle for useless nodes if they are not deleted from the topology list.

6.3 Future Work

Future trends of this research study may include how to face the challenge of elected CH node failure while performing its work (considering the challenges of the threshold idea as a common solution). A scenario of scattering a considerable number of sensor nodes randomly and evaluating the effect of packet loss in the routing process using the obtained measurements. Moreover, experiments should be performed to determine the optimal number of sink nodes and the optimal number of regular nodes in each cluster. Furthermore, for future work, it is necessary to evaluate this work using the metrics of the first death, half of the live nodes, and last death. The challenges of routing and data transmission between the sink nodes and the corresponding BS is also left for future work. Ultimately, the mobility of sensor nodes will be considered and extended this work to the Internet of Things world.

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Appendixes

Proposed algorithms Simulation Codes

Single Cluster Algorithm:

```
int fn_AssignClusterHead (int ClusterNumber, POWER **pstruDevicePower)
//Function assign Cluster Heads Periodically with deleting the dead sensors from the
//each cluster.

{
        int ClusterHeadID, j, i, DeviceId, Num_of_Devices;
        double ClusterHeadPower;
        Num_of_Devices = Sizeofclusters;

        ClusterHeadID = DeviceId;

        for (i = 0; i< Num_of_Devices; i++)
        {
                DeviceId = ClusterElements [ClusterNumber][i];
                ClusterHeadPower = pstruDevicePower [DeviceId - 1]->dRemainingPower;
```

```
                    if (ClusterHeadPower > 0)
                    {

                              ClusterHeadID = DeviceId;


                    }
                    else
                  // Code for delete the Dead or failure Sensors from the Cluster
.
.
.
          }
          return ClusterHeadID;
}
```

How to delete the Dead node from the Topology list and the processes of Base Station notification and re-clustering configuration:

```
int fn_AssignClusterHead(int ClusterNumber, POWER **pstruDevicePower)
{
.
.
.
                    else
// Pseudo code for delete the Dead or failure Sensors from the Cluster

               // This block delete the Dead Sensors from the Cluster
                    {
                              for (j = i; j < Num_of_Devices; j++)
                              {
               /* Copy next element value to current element */
                              ClusterElements [ClusterNumber][i] =   ClusterElements [ClusterNumber] [i + 1];
                              }
                              /* Decrement array size by 1 */
                              ClusterElements [ClusterNumber] [ Num_of_Devices--];
                        /*Send msg telling the network monitor that the DeviceId (in the ClusterNumber) is dead*/
                  fprintf (stderr, "\n The Sensor %d is deleted from the Cluster %d\n", DeviceId, ClusterNumber);
                    }
          }
          return ClusterHeadID;
}
```

Multiple Cluster Algorithm:

```
for (i = 0; i<NUMBEROFCLUSTERS; i++)
          {
                    if (CHcount[i] == NUMBEROFCLUSTERS)
                    {
                              CH[i] = f_AssignClusterHead (i, pstruDevicePower);
                              prevCH[i] = CH[i];
                              CHcount[i] = 0;
                    }
                    else
                    {
                              CHcount[i]++;
```

```
                if (prevCH [i]! = 0)
                        CH[i] = prevCH[i];
        }
}
```

Identify the Cluster:

```
int fn_IdentifyCluster (int DeviceId)
//Function to identify the cluster of the sensor.
{
        int i, j;
        for (i = 0; i<NUMBEROFCLUSTERS; i++)
        {
                for (j = 0; j<Sizeofclusters; j++)
                {
                        if (DeviceId == ClusterElements[i][j])
                                return i;
                }
        }
}
```

How to send all Clusters data to the Sink Node (SN):

```
        /*If the sensor is the Cluster Head, it forwards it to the Sink node. Otherwise, it forwards the packet to
        the Cluster Head of its cluster. */
        if (pstruEventDetails->pPacket->nSourceId == pstruEventDetails->nDeviceId)
          //mean if the packet from the source
        {

          //Identify the Cluster and the CH of the current Cluster will be the nextHop
                ClusterId = fn_IdentifyCluster(pstruEventDetails->nDeviceId);
                        nextHop = CH[ClusterId];
        }
        else
        {
                nextHop = get_first_dest_from_packet(pstruEventDetails->pPacket);
        }
```