University of Kerbala
College of Computer Science & Information Technology
Computer Science Department

Efficient Time Sensitive Routing Protocol for Wireless Sensor Network

A Thesis

Submitted to the Council of the College of Computer Science & Information Technology / University of Kerbala in Partial Fulfillment of the Requirements for the Master Degree in Computer Science

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2023 A.D. 1444 A.H.

بسم الله الرحمن الرحيم

﴿يَعۡلَمُ مَا بَيۡنَ أَيۡدِيهِمۡ وَمَا خَلۡفَهُمۡ وَلَا يُحِيطُونَ بِهِۦ عِلۡمٗا ۞ وَعَنَتِ ٱلۡوُجُوهُ لِلۡحَيِّ
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Dedication

To my father Mr. Khudhayer Abbas, my mother, my loving husband Mr. Haider Jamal for their immense love and support both morally and financially throughout my master's study.

To Dr. Haydar Abdulameer Marhoon, my supervisor, for his patience and support.

To my brother Mr. Farouq Khudhayer Abbas and sisters for their care and support.

Acknowledgement

My heartfelt gratitude goes to Allah, the Most Gracious and Most Merciful for the help and guidance in all my daily undertaking right from the inspection of my studies.

I am heartily grateful to my supervisor, Dr. Haydar Abdulameer Marhoon, whose patient encouragement, guidance and insightful criticism from the beginning to the final level enabled me have a deep understanding of the thesis. I exceedingly appreciate his kindness for welcoming me, introducing me to the world of research, giving me a lot of freedom and delegating several responsibilities to me that I hope I was up to. It was partly through his teaching and advice that I became interested in starting and finishing this study.

My gratitude and admiration also go to Dr. Raaid Alubady for his never-ending support and continual scientific providing, he is the inspiration behind my decision to pursue a career in this research area.

My thanks would not be complete without thanking my parents and siblings for the patience and comprehension they surrounded me with throughout my studies.

I would like to extend my special gratitude to my beloved husband, without whom this study would have never been born, for his moral support, motivation, encouragement, valuable advice and more for the love he has shown me every day, allowing me to build myself as a researcher.

Lastly, I offer my profound regard and blessing to everyone who supported me in any respect during the completion of my thesis.

Abstract

Wireless sensor networks (WSNs) consist of hundreds or thousands of limited sensor devices which have many constraints that affect its performance. The most important concept in WSN is the way to deliver the gathered data from the network nodes to the Base Station. This is called routing techniques. The hierarchical routing topology is used widely by many researchers. Chain-Based and Cluster-Based have many drawbacks separately. To build an efficient routing protocol, the researchers have to pay attention to delay, which is a critical problem in WSNs. In order to reduce the delay of packet delivery as possible, it is essential to create effective routing protocols. This research provides mixed hierarchical routing protocols, which are Chain-Based and Cluster-Based. They are used in a deterministic deployment strategy with a fixed distance between sensor nodes. The proposed routing protocol, called Efficient Time-Sensitive Routing Protocol (ETSRP), has three mechanisms: Cluster-Chain Formation mechanism, Cluster-Head Election mechanism, and Inter-connection mechanism. The basic parameters used to elect the Cluster Heads are distance, remaining energy, and the number of connections in each node. The performance of ETSRP was compared with three routing protocols, which are Grid-Power-Efficient Gathering in Sensor Information Systems (Grid-PEGASIS), Tow Stage Chain Routing Protocol (TSCP), and Deterministic Chain Based Routing Protocol (DCBRP), based on Network simulator NS-3 using End-to-End Delay, power consumption, Cluster Heads power consumption, First Node Die (FND), and Energy× Delay performance metrics. The results of simulation show that the total End -to- End Delay for ETSRP is (0.021) less than the results of DCBRP, TSCP, and Grid-PEGASIS of total End -to- End Delay which are (0.036), (0.99) and (0.085) respectively. ETSRP can be used in many applications in real world to speed up in delivered data such as smart cities, farming and environmental sensing.

Declaration Associated with this Thesis

Some of the works presented in this thesis have been published and accepted as listed below.

i. Y. Khudhayer and H. A. Marhoon, "A Mixed Hierarchical Topology To Ameliorate The Efficiency Of Wireless Sensor Networks: A Survey," 2022 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA), 2022, pp. 1-12, doi: 10.1109 /HORA55278.2022.9800079.

ii. Y. Khudhayer and H. A. Marhoon, "Efficient Time-Sensitive Routing Protocol for Wireless Sensor Network (ETSRP)," 2022 International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), 2022, pp. 1050-1055, doi: 10.1109 /ISMSIT 56059.2022.9932724.

A Mixed Hierarchical Topology To Ameliorate The Efficiency Of Wireless Sensor Networks: A Survey

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***Abstract*—WSNs have a broad spectrum of applications, including military, industrial, security, housing, automobile real-time monitoring, vehicular traffic, and healthcare. Because of sensor nodes in a WSN have limited power, storage, and computational capabilities, various packet forwarding methods have been suggested and tested to prolong the network lifespan as much as possible. The performance of WSNs is effected by the deployment of nodes in the sensed environment area from energy consumption, latency, aggregation methods that used in various routing protocol. In addition the topology that used to build the network such as hierarchical chain-based or cluster-based and election of the node that responsible for aggregation the sensed data and deliver it to the sink node effect on time delivering and the network lifespan. Several different hierarchical routing protocols, such as LEACH, PEGASIS, PDCH, CHIRON, CCBRP, CCM, TSCP, DLRP, DCBRP and others, are discussed in this survey and present a comparison between several chain-based and cluster-based routing protocols**

Keywords*— *WSNs, (Sensor Nodes) SNs, Base station (BS), Cluster Heads and Chain Heads (CH), Routing protocol, Hierarchical, chain-based, cluster-based.

I. Introduction

Recently, one of the most active study areas has been WSNs and continues till now. Devices, methods, and techniques have sprung up quickly as a consequence of the special significance shown by the international literature. Deployment simplicity and broad scope for the application do really deserve such a high level of interest.

Numerous Sensor Nodes in WSN communicate with one another. In addition to observing the environment, actuators allow them to interact with their surroundings. We can make our lives simpler and industrial processes better using sensors since they are tiny and inexpensive and can be readily incorporated into the surroundings. Integrated WSN nodes are a system with few resources: a compact battery, limited, low transmission scope, slow communicating[1]. All of these sensors and actuators may be integrated onto a single basic platform that may use for a many applications such as air conditioning, door control, alarms, etc.

The WSN may be utilized in a variety of situations. Environmental monitoring can help in understanding the migratory patterns of animals. A WSN can quickly and easily identify a fire and notify the fire department. There has been a rise in the popularity of smart cities. The use of temperature and pressure and temperature sensors in conjunction with air conditioning units may help to keep the space at its most comfortable temperature while also reducing energy consumption. Lighting may be turned on and off by sensors connected to an identity system, which prevents illegal entry into restricted areas. Cities throughout the country are embracing WSN in an effort to enhance the quality of life for residents. Sensor networks may be interacted with in a variety of ways. The first is a "pull mode," in which we must search our networks to obtain data. In the second example, SNs transmit data to the sink autonomously[2].

Routing has become a significant issue with WSNs because of the enormous number of nodes they include. WSNs tend to be flat multi-hop networks, which may be challenging to set up, particularly when working with a tight budget. It is necessary to create a routing algorithm with care in order to add the least amount of overhead and to guarantee that energy usage is equitable and minimum. Sensors are commonly installed in locations where human interaction is difficult or impossible. A network's components must be discovered, communication organized, and data effectively delivered. With a high risk of node failures, frequent topological changes, and the effect of the surroundings impossible to forecast, the tasks might be exceedingly tough to execute[3]. The self-organization and self-healing procedures of a WSN must be effective[4]. Routing protocols must take into consideration the asymmetrical connectivity, significant fades, and unreliable communications that might be caused by obstructions like buildings, furniture, and trees. In the modern world, sensors may be supplied in a variety of ways. However, main-powered nodes may potentially be an option in the future. Green sensors which enable batteries to be recharged via harvesting technology like solar panels, are gaining in popularity[5]–[7].

It is important for WSN engineers to keep in mind that in all of these scenarios, energy consumption has a direct impact on system longevity[8]. The WSN is a tough technology that demands meticulous and complicated architecture, and the methodology is arduous because of these limits.

II. WSN Characteristics

Nodes exchange information over a communication network made possible by a variety of different techniques. When it comes to wireless transmission, there is a high likelihood that certain nodes are unavailable at any one moment. Symmetrical connections, in which packet transmission probability vary in the two directions, are often seen in communications. It is feasible to establish clusters with coordinating nodes, however doing so increases control

978-1-6654-6835-0/22/$31.00 ©2022 IEEE

2022 International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT) | 978-1-6654-7013-1/22/$31.00 ©2022 IEEE | DOI: 10.1109/ISMSIT56059.2022.9932724

Efficient Time-Sensitive Routing Protocol for Wireless Sensor Network (ETSRP)

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Abstract— **In the last few years, numerous applications of wireless sensor networks that make use of a variety of data transfer protocols have been created in the commercial and industrial sectors. Because the sensor nodes have a finite amount of energy, it is necessary for wireless sensor networks to implement large data transmission delays to prolong the lifetime of the network. With a WSN, many sensor nodes can be set up in a sensor field, where they can collect data, process it, and then send it on to a designated sink node. Battery power is what keeps sensor nodes going, which is why WSNs rely heavily on routing algorithms. WSNs can be categorized into three distinct types of routing strategies: flat, clustering, and geographic. Clustering routing, of which chain-based routing is a subset, has a wide range of practical applications, including volcanology (area planning), seismology (earthquake measurement), and more. The Deterministic Chain-Based Routing Protocol (DCBRP), the Energy-Efficient Two-Stage Chain Routing Protocol (TSCP), and the Deterministic Power-Efficient Gathering in Sensor Information Systems (PEGASIS) are just a few of the algorithms discussed in this article, along with a new method of data transmission for chain-based routing in WSN. These statistics are transmitted based on the nodes' remaining energy and their distance from the sink node. Efficient Time-Sensitive Routing Protocol (ETSRP) is a newly proposed technology that reduces end-to-end delay while simultaneously reducing energy consumption and extending the lifetime of a network. When compared to other proposed solutions, ETSRP can reduce the network's energy usage and extend the network's lifetime.**

Keywords— WSNs, Routing Protocol, NHC, Chain-based, Cluster-based, Cluster Head (CH), Deterministic deployment.

I. INTRODUCTION

Wireless sensor network is a very helpful network for novel works with martial and civilian purposes. WSN includes many sensor nodes, and these nodes are deployed in the desired location to collect data through sensing of surroundings and forwarding them to the sink node and base station (BS). It's self-organized, organized sensor networks for monitoring physical and or biological circumstances such as vibration, sound, temperature, pressure, & motion, and for collaboratively conveying the data over a network [1]. The WSNs are installed as a network connected to a maximum number of sensor nodes. Each sensor node is surrounded by radio transceivers, gadgets, and other energy components. The resource limitation is the fundamental disadvantage of WSN [2], [3]. The nodes are distributed with a certain design, and every node is self-organized with multi-hop communication [4]. The global WSN system is hierarchical, with the nodes and routers joining to form the gateway [5]. Routers in a wireless sensor network are used to connect nodes in large coverage areas and provide sensing devices in WSN with high reliability [6]. Numerous application fields, including medical, transportation, crisis management, smart spaces, environmental, military, entertainment, and homeland defense, have global access to the WSN. Within ten to fifteen years, the deployment of massive sensor nodes will cover the globe with sensor nodes. In this scenario, the nodes are linked over the Internet. WSN quality of service, security, deployment of nodes, computing energy, and coverage, scalability, size, and energy efficiency encounter numerous challenges [7]. Delay is the most challenging difficulty faced by WSNs; it is a very difficult and significant task to structure transmission data efficiency in WSNs' communication protocols[8].

II. LITERATURE REVIEW

In recent years, numerous ways to chain-based routing have been proposed. Although it may not appear so at first look, low-energy adaptive clustering hierarchy (LEACH) is one of the proposed basic methods for clustering routing classification in WSN to reduce energy usage. In this protocol, nodes are randomly distributed throughout a network. The network is then partitioned dynamically into clusters based on its topology or the number of resources necessary to complete a certain task. One node from each cluster is picked at random as the CH node, and it is the responsibility of this node to collect data from the other nodes in its cluster using the one-hop technique. Figure 1 is an illustration of the LEACH architectural style in operation. There are significant issues with this strategy. This is because, initially, CH nodes will not be selected properly, resulting in a higher death rate compared to other nodes in each cluster. Second, if the source node is distant from the CH node, a great deal of energy is wasted due to the one-hop data transmission approach utilized by this system. Lastly, the network incurs substantial operating expenses.

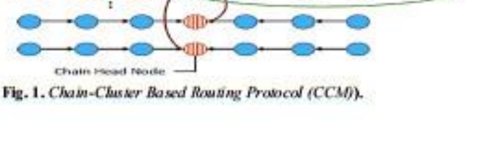

Fig. 1. *Chain-Cluster Based Routing Protocol (CCM)*.

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List of Abbreviations

Abbreviation	Description
BCBRP	Balanced Chain Based Routing Protocol
BCM	Backbone Construction Mechanism
BS	Base Station
BVGF	Bounded Voronoi greedy forwarding
CCBRP	Chain-Chain Based Routing Protocol
CCF	Cluster-Chain Formation mechanism
CCM	Cluster-Chain Mixed
CCMAR	Cluster-Chain Mobile Agent Routing
CCRP	Cluster-Chain Routing Protocol
CH	Chain Head or Cluster Head
CHE	Cluster Head Election
CHIRON	Energy-Efficient Chain-Based Hierarchical Routing Protocol
CHS	Chain Head Selection
C-LEACH	Centralized-Low Energy Adaptive Cluster Hierarchical Routing Protocol
CRBCC	Chain Routing Based on Coordinates-Oriented Cluster Routing Protocol
DCBRP	Deterministic Chain-Based Routing Protocol
DD	Directed Diffusion
DERP	Distance-Based Energy Efficient Routing Protocol
DLEMA	Dijkstra-Based Localized Energy-efficient Multicast Algorithm
DLRP	Direct Line Routing Protocol
DRINA	Data Routing For in-Network Aggregation
D-S PEGASIS	Diamond Shaped Clustering PEGASIS
EAR	Energy-Aware Routing
ECCPTC	Energy Efficient Cluster-Chain Based Protocol for Time Critical Applications
EECPL	Energy Efficient Clustering Protocol
ETSRP	Efficient Time Sensitive Routing Protocol
FND	First Node Die
GAF	Geographical adaptive fidelity

GBR	Gradient-Based Routing
GCH	Grid Clustering Hierarchy (GCH) routing protocol
GH	Green-House
GPSR	Greedy Perimeter Stateless Routing
Grid-PEGASIS	Grid- Power-Efficient Gathering in Sensor Information Systems
PEGASIS	Power-Efficient Gathering in Sensor Information Systems
PEGCP	Power Efficient Grid-Chain routing Protocol.
IP	Internet Protocol
LEACH	Low Energy Adaptive Cluster Hierarchical Routing Protocol
LEACH-DT	LEACH with distance-Based Thresholds
MDR	Multi-Hop Deterministic Energy-Efficient Routing Protocol
MN	Member Nodes
NHC	Next Hop Connection
NoC	Number of Connections
ON	Ordinary Nodes
OSI	Open Systems Interconnection
PDCH	PEGASIS-Double Cluster Head
PEGCP	Power Efficient Grid-Chain routing Protocol
QoS	Quality of Service
REC+	Reliable and Energy-Efficient Cluster-Chain Based Routing Protocol
HNs	Head Nodes
SAR	Sequential Assignment Routing
SN	Sensor Node
SPAN	Coordination of power saving with routing
SPIN	Sensor Protocols for Information via Negotiation
TBF	Trajectory Based Forwarding
TDMA	Time Division Multiple Access
TL-LEACH	Three Layered Routing Protocol Based on LEACH
TSCP	Two-Stage Chain Protocol
WSN	Wireless Sensor Network

CHAPTER ONE:

INTRODUCTION

1.1 Overview

A few years ago, Wireless Sensor Networks (WSNs) were developed for various applications including traffic management, home automation and combat intelligence. Regarding the WSN, routing is a critical task that has to be addressed with extreme prudence. A routing mechanism is needed to transmit data among sensor nodes (SNs) and base stations (BSs). As a result of the evident routing difficulty, the network lifespan is shortened, and power consumption is increased. Consequently, several routing methods have been developed to minimize energy consumption and lengthen the network lifespan [1].

In a WSN, routing is a challenge. Routing protocols have a significant impact on the life of sensor nodes. WSN routing differs from traditional wireless networks because of such specific characteristics of sensor nodes as energy limits, processing accomplishments, and transfer of gathered information from numerous nodes to a single base station. To accommodate such characteristics, many kinds of communication protocols have been developed.

The life duration of an individual sensor node's battery is directly related to how long the network as a whole can last. There is a supply of energy that powers memory, sensing, and transceiver units (power entity). A device's memory and sensing units gather and store information about its surroundings, while the transceiver transmits and receives data from the transceiver's sensors[2]. The three main forms of routing protocols for WSNs are flat [3], location-Based , and hierarchical. Topology is essential, when it comes to reducing various limitations, such as restricted resources, latency and computing resource shortages.

The amount of energy used may be determined, and the length of the path between the nodes affects transmitted energy, but the receiving cost is directly proportional to the packet size[4]. Topology defines the routing channels, whether spread or packets, and the number of packets. Thus, adopting the correct configuration may significantly reduce the number of hops necessary for a particular issue and therefore conserve power. In addition to reducing signal loss, topology may help speed up sensor data transmission. It also increases data consolidation, which decreases processing rounds and power usage, leading to a longer network lifespan. Topologies also determine the size of a cluster, how joined nodes are handled, and how nodes leave the cluster and dealt with. Much power may be saved by maintaining the network architecture effectively. Physical topology has several advantages for WSNs, such as reduced energy consumption, increased lifetime, less interference, and increased scalability[5].

To configure clusters in Low Energy Adaptive Cluster Hierarchical Routing Protocol (LEACH)[6], relying on signal strength, the SNs generate the Cluster Heads (CHs), which are employed as gateways to link with Base Station (BS). In other topology, sensor nodes are arranged in architecture as a string that is Chain-Based [7], with a single-node operating as Chain Head (CH) to transport data to the end server. Examples include a Deterministic Chain-Based Routing Protocol (DCBRP) Cluster-Chain Mixed (CCM) and Two-Stage Chain Protocol (TSCP) with pre-define sensor node deployment[8].

WSN distribution is an important issue because it has a significant impact on the network's performance. Randomized, pre-define and hybrid node deployment are types of distributions offered[9].

The maintaining distributed resource scheduling across the network saves the energy in DCBRP, CCM, TSCP[10], which significantly improves WSN. In this work, devised a Cluster-Chain Based Hierarchical routing protocol[11], which reduces the time it takes to transfer gained sensed data from the SNs to the BS by grouping the nodes in the network into many clusters to reduce the length of the chains.

1.2 Related Work

Hierarchical routing protocols are well-suited to the network model. The nodes aggregate data locally, which reduces the need for central processing. The head nodes combine the data from all other nodes, and then send it to the Base Station (BS). The performance of the hierarchy model is superior to other systems. Further, the WSN's communication component is critical for delivering sensed data from member nodes to the BS in the least time [12]. In this section, present the routing protocols that were proposed to minimize energy consumption and reduce the delay to increase the network lifetime using a pre-define or random deployment of sensor nodes.

A Cluster-Chain routing protocol was proposed to improve the packets delivery over Power-Efficient Gathering in Sensor Information Systems (PEGASIS), called Diamond Shaped Clustering PEGASIS routing protocol (D-S PEGASIS), two head nodes elected every time in multi-layers. All the nodes connect as a chain and the last node delivers the data to the BS as shown in figure (1.1). This routing protocol saves energy level, without taking delay time into consideration [13].

The sensor nodes were deployed as random and divided the nodes into number of levels depends on the distance with BS, each level has unequal number of nodes and to deliver the gathered data until reach BS must across over the chain heads in each level. It had high delay caused by the multi-chain and multi-hops in each round and many elected chain heads.

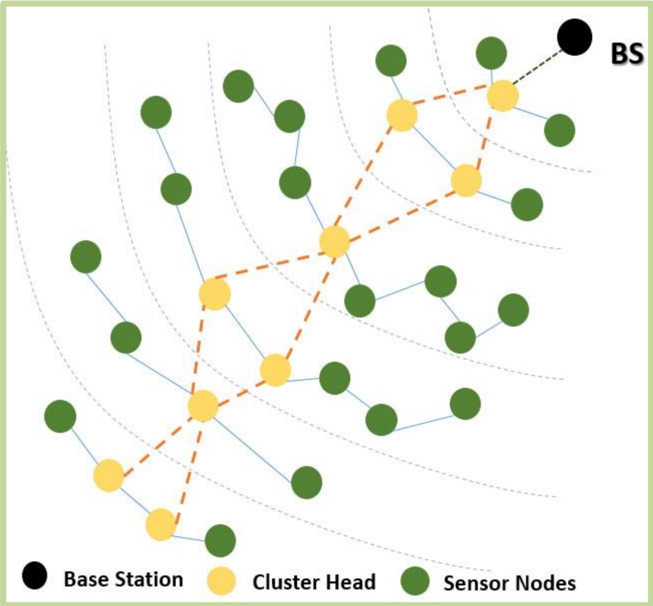


Figure 1.1: Diamond Shaped Clustering PEGASIS (D-S PEGASIS) Routing Protocol[13].

Another routing protocol proposed a mechanism to elect double cluster heads in the same cluster with a Cluster-Chain routing technique to improve the load balance in PEGASIS. This was called PEGASIS–Double Cluster Heads (PDCH)[14], it is shown in figure (1.2). PDCH divided the sensing area into levels of chains, each chain had two or more Cluster Head called main Cluster Head with number of secondary cluster heads connected directly with its one chain main cluster head. Secondary cluster heads help the main cluster heads to save its energy and take the responsibility of gathering and delivering the sensed data to prolong the network life span. The drawbacks of PDCH were the multi-chain with multi-hops in each level in the clusters and chains and election number of cluster heads, all which consume energy and delay.

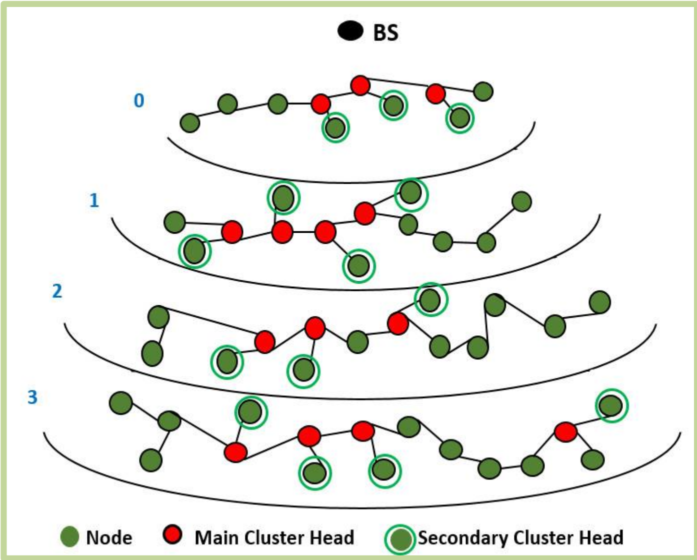


Figure 1.2: PEGASIS-Double Cluster Head (PDCH)[14].

In [15], researchers proposed an Energy-Efficient Chain-Based Hierarchical Routing Protocol (CHIRON) to improve energy saving and prolong the network lifetime by using the Beam Star technique to cluster the sensing area. All elected Chain Heads (CHs) connected with each other in a chain to deliver the sensed data to the BS by the last level node. This is shown in figure (1.3). CHIRON elected cluster heads depending on highest residual energy without taking into account distance with BS that cause delay.

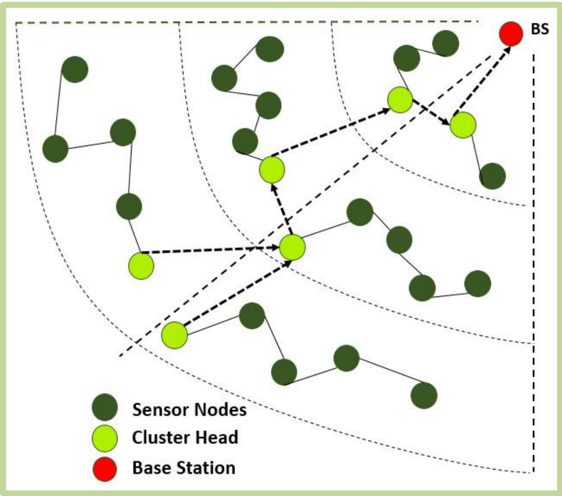


Figure 1.3: Energy-Efficient Chain-Based Hierarchical Routing Protocol CHIRON[15].

A random deployment strategy was employed by many researchers with N sensor nodes using many clustering techniques in the previous and later routing protocols.

In [16], random deployment SNs were used, clustering the sensing area after electing N-cluster heads based on threshold value. This protocol was called Cluster-Chain Routing Protocol (CCRP), it is shown in figure (1.4). All the cluster heads formed a chain and the closest one which had the highest remain energy level will deliver the data to the BS. CCRP doesn't depends on distance to elect the main cluster heads that cause election farthest node from BS with longest distance, and connect with other cluster heads cause Long-Link with multi-hops.

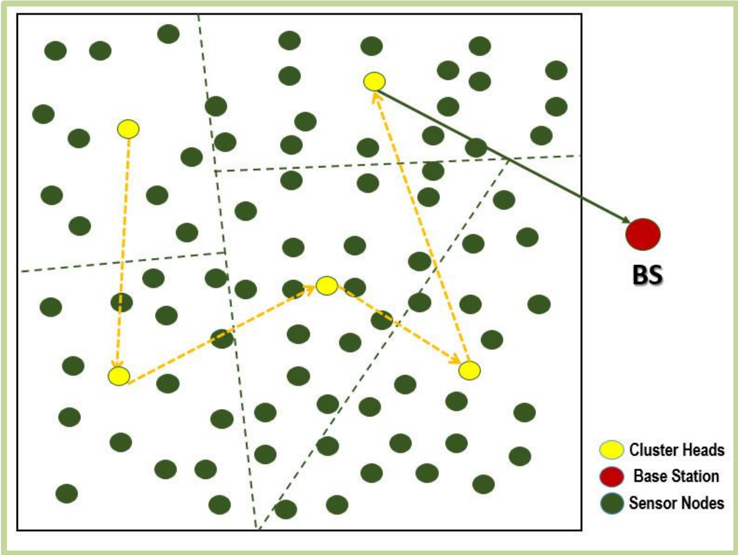


Figure 1.4: Cluster-Chain Routing Protocol (CCRP)[16].

A Cluster-Chain Mobile Agent Routing (CCMAR) was proposed in [17], to improve energy consumption and network life time through clustering. It connects all the sensor nodes in each cluster as a single chain as shown in figure (1.5). One Cluster Head makes use of intra-connection and inter connection methods by employing the advantages of LEACH and PEGASIS [7], [8]. The same drawbacks were presents compared with other random deployment mixed routing protocols of delay and energy consumption caused by long chains in each group and long hops with BS.

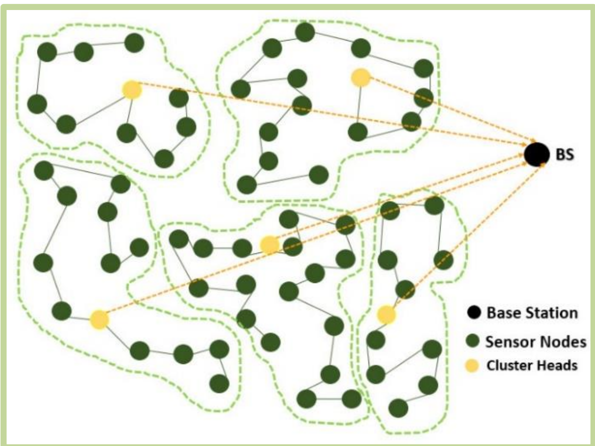


Figure 1.5: Cluster-Chain Mobile Agent Routing Protocol (CCMAR)[17].

In [18], a routing protocol was proposed, called Energy Efficient Cluster-Chain Based Protocol for Time Critical Applications (ECCPTC). It utilized threshold value to reduce the delay in transmitting data to the BS through clustering and connecting the cluster heads in chain form as shown in figure (1.6).

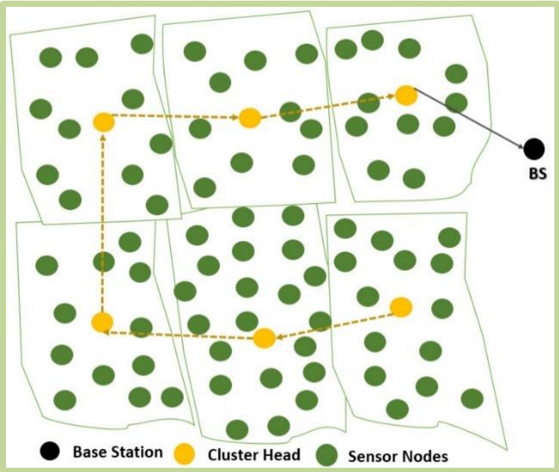


Figure 1.6: An Energy Efficient Cluster-Chain Based Protocol for Time Critical Applications (ECCPTC) Routing Protocol[18].

ECCPTC will give excellent results if uses direct single hop connection with CH in each group instead of long chain, that effect on delay of gathering data.

In[19] , inter and intra connection cluster of data transmission uses a Cluster-Chain protocol called Power Efficient Grid-Chain routing Protocol. (PEGCP) was proposed to extend the network life time through reducing energy consumption by dividing the sensor nodes into clusters. It also formed multiple chains connected to its own Cluster Head in each cluster as shown in figure (1.7), compared with ECCPTC, where the topology of clusters was different with less hops and short distance with BS.

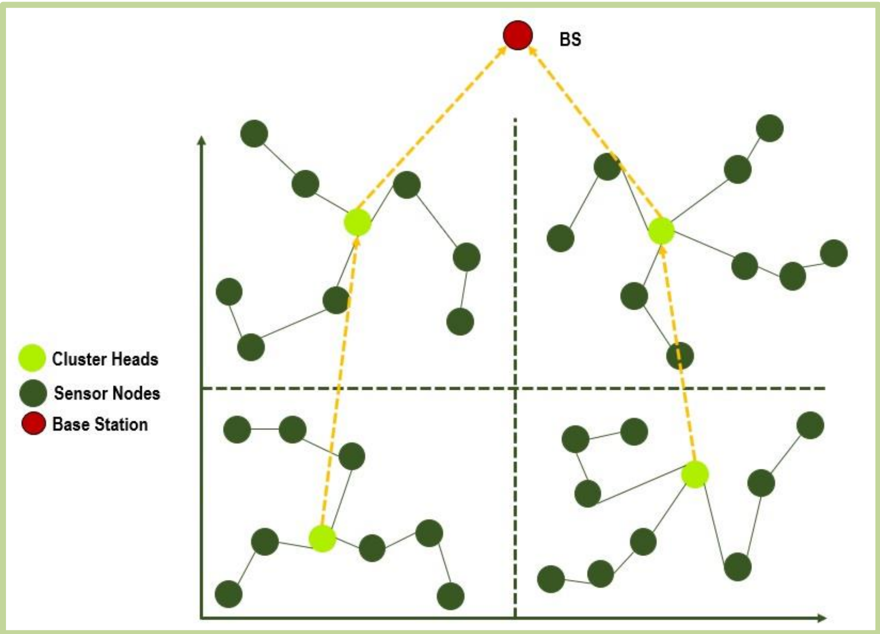


Figure 1.7: Power Efficient Grid-Chain Routing Protocol (PEGCP)[19].

In[20], a Grid Clustering Hierarchy (GCH) routing protocol was proposed to decrease energy consumption. GCH divided the sensor network into grids depending on average energy in current round. It used round schedule methods to elect the cluster heads. The communication between SNs and CHs was the same as in LEACH. The topology is shown in figure (1.8). It used cluster concept of inter and intra-connection with multi-hop for each connection.

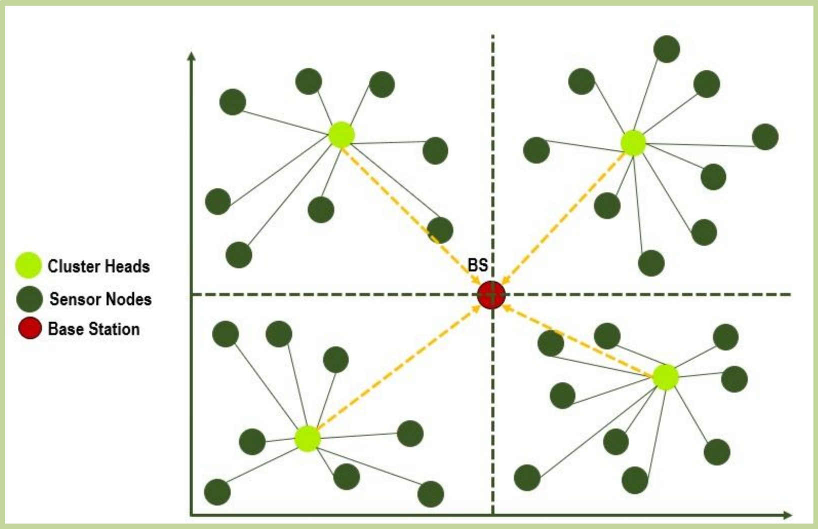


Figure 1.8: Energy Efficient Grid Clustering Hierarchy (GCH) Routing Protocol[20].

In [21], the researchers proposed a Chain-Chain Based routing protocol called (CCBRP) to decrease energy consumption and reduce the latency in delivering data to the BS.

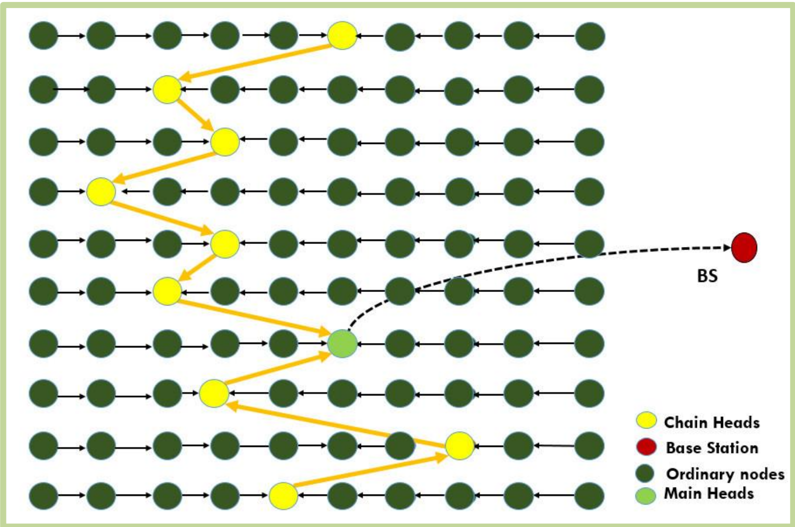


Figure 1.9: Chain-Chain Based Routing Protocol (CCBRP)[21].

It divides the network into multiple chains using the Greedy algorithm and performs it in two stages as shown in figure (1.9). In worst round the election of chain heads in each row cause longest vertical chain, cause highest delay with farthest elected main head cause energy depletion and early die nodes.

Tang et al. proposed a Cluster-Chain Based Mixed routing algorithm (CCM) [22]. The authors used the best features of PEGASIS and LEACH combined into a single system[8] as shown in figure (1.10). In many time sensitive applications, energy and delay measurements were vital. Hence, the main goal was to enhance routing performance in terms of these parameters. Because the radio channel was symmetric, the energy required to transmit a message from one node to another is the same as the energy required to deliver a message in the other direction. The amount of energy required to transmit data was solely dependent on the distance between sender and receiver and the size of the data packet.

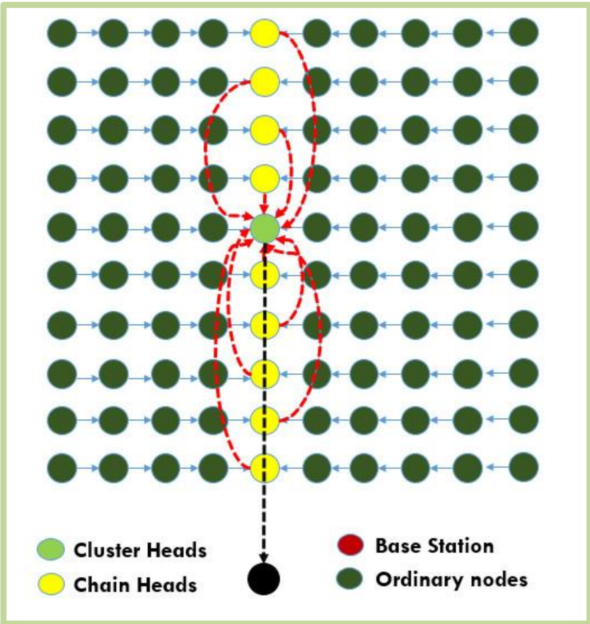


Figure 1.10: Cluster-Chain Based Mixed Routing Protocol (CCM)[22].

There were two stages to the CCM algorithm, namely, Cluster-Based and Chain-Based routing. Using a chain of routers, Chain-Based routing was used to transport data from sensor nodes in each chain to their respective Chain Head in this phase. It had the same drawbacks in CCBRP.

DLRP was a direct line routing protocol proposed [23], to overcome the limitation in DCBRP, which was the high delay. It divided the network into multiple vertical long chains. Each of them had a Chain Head that connects directly to the BS. DLRP shows better performance compared with DCBRP in reducing the delay and saving energy as demonstrated in figure (1.11). The election of nine chain heads in each chain consume more energy than DCBRP and the furthest node of BS elected in next rounds depending on energy remaining cause long link with BS.

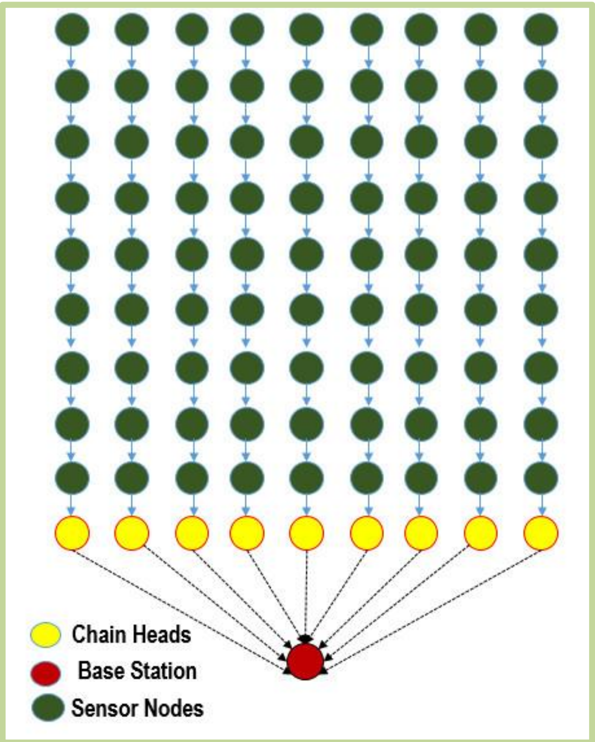


Figure 1.11: Direct Line Routing Protocol (DLRP)[23].

In [24], researchers proposed a grid method to deploy the sensor nodes with fixed distance between them as shown in figure (1.12). They did so to reduce the long hops between nodes and base station. The sensing area was divided into grids, in each grid the sensor nodes formed chain and connecting with neighbour grid' chain, finally all the sensor nodes constructed as single long chain in pre-define deployed in small sensed area. The election of single Chain Head node depended on remaining energy amount to prolong network life time.

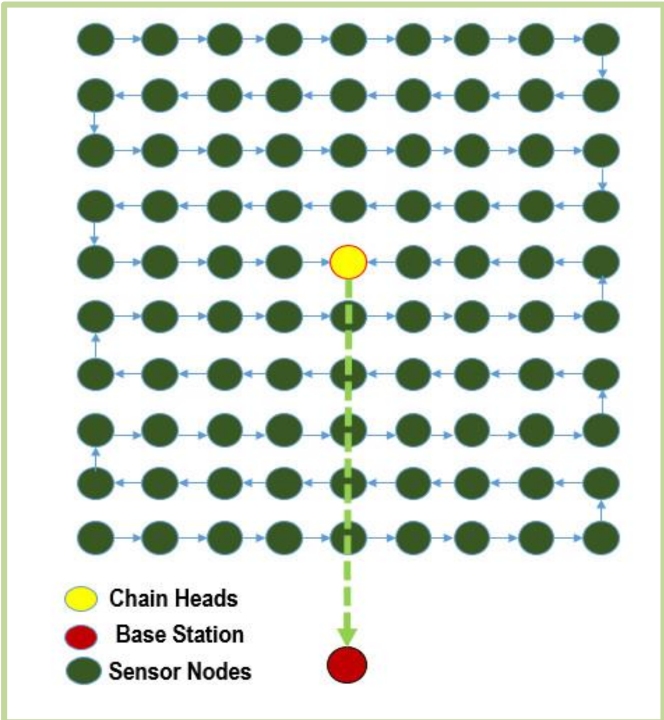


Figure 1.12: Grid Power-Efficient Gathering in Sensor Information Systems (Grid-PEGASIS)[24].

The two-stage chain routing protocol (TSCP) in figure (1.13) was proposed in [25], to reduce the overall energy consumption of network. Its performance was compared with CCM and CCBRP. It was built in two phases, in the first phase, the network was divided into multiple horizontal chains. The second phase was constructed a vertical single chain of all Chain Heads (CH) from all horizontal row chains elected periodically in the same line of the other chain heads.

CCM and TSCP had many limitations. First of all, the multiple long chains caused energy waste due to the random election of the chain heads in the first phase.

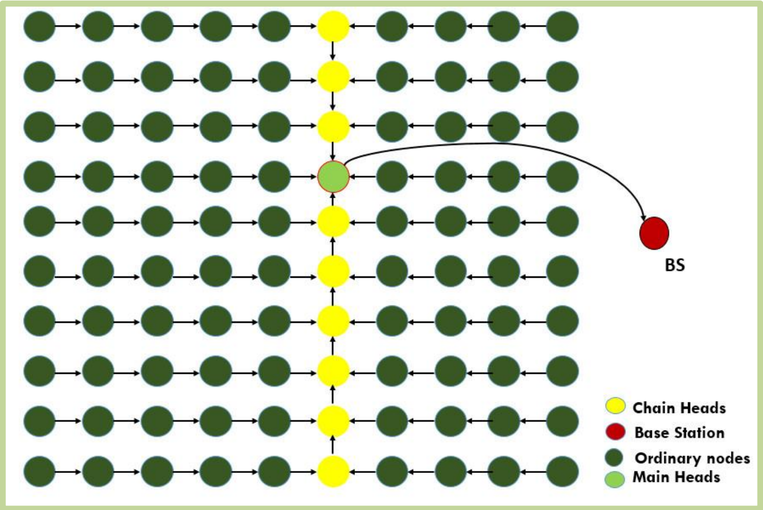


Figure 1.13: Two Stage Chain Routing Protocol (TSCP)[25].

In [26], the researchers proposed a deterministic Chain-Based routing protocol called (DCBRP) to maximize the network lifespan through saving the energy in each node using Next Hop Connection (NHC) in the single chain connection. In DCBRP, the network was divided into three chains, each of which had three columns that connect its nodes using NHC as shown in figure (1.14). There is a single Chain Head (CH) in each chain that delivered the gathered data to the BS directly.

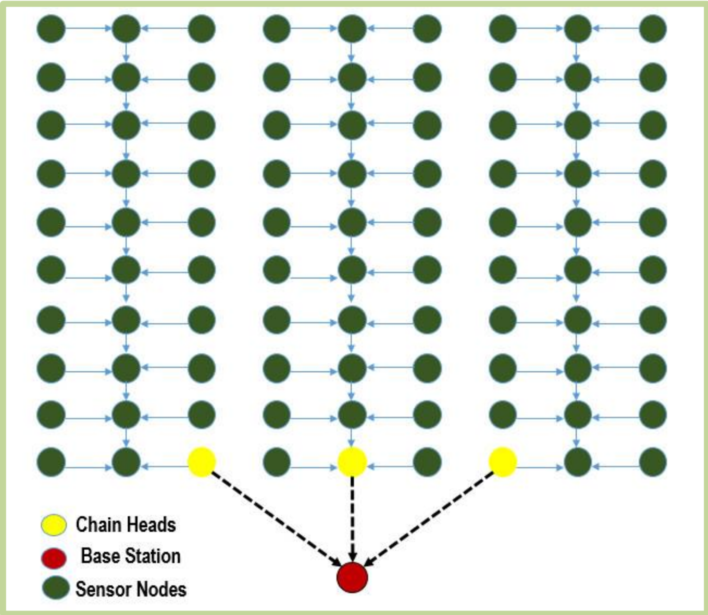


Figure 1.14: Deterministic Chain Based Routing Protocol (DCBRP)[26].

Table 1.1: Details on Related Routing Protocol.

Routing Protocol	**Ref. Year**	**Topology**	**Intra and Inter communication**	**CH Election Method**	**Objective**	**Limitations**	**Deployment of Sensor nodes**
D-S PEGASIS	**[13] 2008**	Cluster-Chain Based	Multi-Hop (Intra) Multi-Hop (Inter)	Elect two head nodes as diamond shape to save energy consumption.	Prolong the network lifespan.	More delay time in data transmission.	Random
PDCH	**[14] 2012**	Cluster-Chain Based	Multi-Hop (Intra) Multi-Hop (Inter)	Using distance to elect cluster heads and branch chain.	Prolong the network lifetime and balance the nodes levels.	More energy consumption.	Random
CHIRON	**[15] 2009**	Chain-Based	Multi-Hop (Intra) Multi-Hop (Inter)	Using maximum residual energy to elect the CHs.	Prolong the network lifetime, reduce the delay in data transmission and redundant paths.	Using BeamStar techniques to cluster the sensor nodes caused unequal cluster size and more delay.	Random
CCRP	**[16] 2008**	Cluster-Chain Based	Multi-Hop (Intra) Multi-Hop (Inter)	Using threshold value and remaining energy for each node to elect CHs.	Improve data transmission from cluster heads to BS.	Using multi-Hop connection in the two construction stages.	Random

Deployment of Sensor nodes	Random	Random	Random	Random	Random
Limitations	More delay in data transmission.	Using multi-hop connection in the two stages.	Increased delay time in data transmission.	Increased Delay in deliver data to BS and overhead in algorithm running.	Using multi-hop connections and election of CHs without consideration of Energy level and distance.
Objective	Propose a distributed fault-tolerant method called (CMATO).	Prolong the network lifetime, minimize transmission delay.	Prolong the network lifetime.	Decrease energy consumption.	To minimize energy consumption and delay.
CH Election Method	Using higher residual energy for Cluster Head election.	Using higher residual energy for Cluster Head election.	Depending on multi-hop in grid clustering technique in inter-intra connection.	Uses round- robin schedule method	Random election of the CHs.
Intra and Inter communication	Multi-Hop (Intra) Single-Hop (Inter)	Multi-Hop (Intra) Multi-Hop (Inter)	Multi-Hop (Intra) Multi-Hop (Inter)	Multi-Hop (Intra) Multi-Hop (Inter)	Multi-Hop (Intra) Multi-Hop (Inter)
Topology	Cluster-Chain Based	Cluster-Chain Based	Cluster-Chain Based	Cluster-Cluster Based	Chain-Chain Based
Ref. Year	**[17] 2018**	**[18] 2012**	**[19] 2021**	**[20] 2016**	**[21] 2011**
Routing Protocol	**CCMAR**	**ECCPTC**	**PEGCP**	**GCH**	**CCBRP**

Routing Protocol	Ref. Year	Topology	Intra and Inter communication	CH Election Method	Objective	Limitations	Deployment of Sensor nodes
CCM	**[22] 2012**	Cluster-Chain Based	Multi-Hop (Intra) Multi-Hop (Inter)	The election of CHs is sequential and the Main-Head elected based on residual energy.	To reduce energy consumption and delay.	The sequential election of CHs in first stage causes disconnection of the networks. Using multi-hop connection.	Deterministic
DLRP	**[23] 2020**	Chain-Based	Multi-Hop (Intra) Single-Hop (Inter)	CHs election depends on energy consumption and remaining energy.	Prolong the network lifetime, minimize transmission delay.	Using multi-Hop connections in the chains.	Deterministic
Grid-PEGASIS	**[24] 2010**	Chain-Based	Multi-Hop (Intra) Single-Hop (Inter)	CHs election depends on remaining energy.	Prolong the network lifetime.	High delay and node dies in early rounds.	Deterministic
TSCP	**[25] 2017**	Chain- Based	Multi-Hop (Intra) Multi-Hop (Inter)	Periodic methods for CHs election. Main head elected by residual energy.	Minimize the total energy consumption, achieve more load balancing.	Using multi-hop connection. The force election of CHs causes low energy saving.	Deterministic
DCBRP	**[26] 2016**	Chain-Based	Multi-Hop (Intra) Multi-Hop (Inter)	The election of CHs depends on energy consumption and remaining energy.	Prolong the network lifetime and reduce energy consumption.	More delay in the data transmission.	Deterministic

1.3 Statement of the Problem

WSNs have a wide range of applications, therefore creating efficient routing protocols is important to extend the network's lifetime and reduce the time of delivering data to the BS.

The fundamental problem of Cluster-Based routing protocol is that the cluster heads are not evenly distributed, and Cluster-Heads (CHs) consume energy in every round, that limits the network's lifetime. In addition, there are no guarantees on the number of nodes in each cluster [27],[28].

While in the Chain-Based approach, choosing the head node is not based on the position of the base station. The main problem is the delay in delivering data to the BS [7],[11].

Further, the Chain-Based routing protocols are designed to prevent energy depletion and extend WSN lifespans[23], [26]. As each CH is prepared to send all cluster packets, this will take a lot of time because of many hops from source to destination.

In some Chain-Based routing protocols, there are n-long chains where the network is divided into multiple chains and in each chain, there is one Chain Head (CH). In other protocols, the network is divided into clusters of n-sensor nodes of long chains and one Chain Head (CH) node with multi-hop between nodes until reaching the BS. This causes considerable delay in data delivery. Therefore, the routing protocols in WSN need a lot of efforts from researchers to reduce the delay and prolong the network lifetime[7].

1.4 Research Questions

- How to divide the network into many small clusters to avoid head nodes overload to deliver all packets?
- How to elect the CHs for each cluster?
- How the network CHs connect to each other till the base station?
- How to evaluate the proposed protocol?

1.5 The Aim of the Thesis

The aim of this research is to design a Cluster-Chain Based routing protocol for the pre-define node deployment in WSNs. The proposed protocol will eliminate the long single chain in Chain-Based topology by clustering (or grouping) the network nodes into multiple clusters. The main goals will be performed with these objectives:

- To develop a Cluster-Chain mechanism by dividing the network to many clusters to avoid long chains and elect a Cluster Head (CH) for each cluster.
- Using inter-connection mechanism to reduce the end-to-end delay.
- Evaluate the ETSRP routing protocol by comparing its performance with DCBRP, Grid-PEGASIS and TSCP routing protocols using suitable performance metrics.

1.6 Research Scope

The study in this thesis covers the hierarchical routing topology and the most relevant recent routing protocols that employ Chain-Based and Cluster-Based routing and makes use of the advantages of both to improve the network performance.

In Chain-Based topology the connection between the sensor nodes saves energy and has high delay because of long link until reach the BS, and when node die in the chain, cause long hops to Chain Head (CH), cause more delay. Otherwise, the Cluster-Based topology it consumes more energy caused by periodically election of cluster heads in each round and grouping sensor nodes to clusters with less delay compared with chain topology and number of head nodes that effect on energy consuming in each round. To simulate a proposed routing protocol in this study, use NS3 simulator with C++ programming language in Eclipse platform. In build the layers of proposed routing protocol the MAC 802.11 protocol is used. The results of simulation used to compare the performance of the proposed routing protocol with other protocols using such performance metrics as End-to-End Delay, Energy consumption, Energy consumption for CHs, and Delay×Energy.

1.7 Thesis Organization

After presenting an overview of the most related routing protocols that used a pre-define deployment method and a general introduction on the proposed routing protocol, more details will be explained in the next chapters. The thesis is organized in five chapters. Below is a layout of these chapters:

First Chapter: In this chapter, an introduction of explanation on WSNs and the importance of routing protocols. Furthermore, discuss the most related routing protocols, their structures and methods. Also summarized the basic idea of the proposed routing protocol and the techniques used in it.

Second Chapter: The second chapter displays WSNs content and characteristics, the applications that using WSNs, the types of the deployment techniques and the election of head nodes. It also explains the importance of routing protocols, their limitations and the details of the structure types of WSNs.

Third Chapter: The proposed routing protocol is explained in detail including phases, structure and mathematical methods to elect the head nodes.

Fourth Chapter: In this chapter, the comparison has been made between proposed routing protocol and other ones using performance metrics through the results of the simulation program NS3 and NetAnim employing C++ programming language in Eclipse platform.

Fifth Chapter: The conclusions will be drawn and propose future work that will help future researchers improve the performance of WSNs with new routing protocols.

CHAPTER TWO:
THEORETICAL BACKGROUND

2.1 Overview

Wireless sensor networks are used in many applications[29]. Due to the sensor devices' compact size, cheap cost, and low power consumption, each sensor node can observe its surroundings for so long. Therefore, they have so much processing capability, and can hold some energy. Large numbers of such nodes with the ability to coordinate with one another provide significant advantages over centralized sensor-Based methods[30]. Wireless Constraints on available resources, asymmetric data flow (many-to-one), and faulty nodes are all hallmarks of sensor networks. Consequently, organizations focus on reducing energy consumption and extending the lifespan of their networks at the expense of improving their speed, capacity, and quality of service. Efficient time routings are the foundation of many existing systems that helps to save the energy through reducing the delay[31].

High dependability close to an individual or structured node is a goal that sensor network routing methods must meet. To provide resilience, there must be many pathways for data to go from the transmitter to the target node. Given that the energy resources available to sensor nodes are limited, and it is usually not feasible to recharge them when they run dry. Conserving energy is a crucial design concern in sensor networks[32]. In contrast to those used in conventional networks, methodologies for sensor networks must place a premium on extending the network's battery life without sacrificing service quality. Energy efficiency and delay in sensor networks have been the subject of many studies in recent years. It is not a good idea to overload the network since it is a very costly activity from an energy consumption standpoint.

2.2 Wireless Sensor Networks Components

Sensor nodes are an essential aspect of a wireless sensor network. One or more sensing devices are often installed on each of the tens, hundreds, or even thousands of relatively tiny nodes that constitute a sensor network. In this configuration, each sensor node connects to a sensor or many. Each node typically has a microprocessor, an electric circuit for communicating with the sensors, a power source (often a battery or an implanted form of energy collection), and a radio transceiver with an internal antenna or link to an external antenna.

A sensor node's price might go anywhere from free to several hundred dollars, depending on the complexities of the various sensor nodes. A number of factors affect sensor node size and price including, but not limited to, energy and its consumption, memory, computing speed, and communications speed. So, resource limits are a direct outcome of the trade-offs necessitated by the small size and low cost of sensor nodes. Depending on the use case, different sensor nodes could be needed to have other qualities of attributes[2], [4].

Another crucial part of a WSN is the base stations. They are an integral part of the WSN and are equipped with additional capabilities such as computing, energy efficiency, and communication to disseminate collected data. In clear words, they act as a connection point for data collected by sensor nodes to be sent to the final consumer. It is common practice to utilize such gateways to transmit data collected by a WSN to a centralized repository.

2.3 Applications of Wireless Sensor Networks

As was previously illustrated, WSNs have attracted a lot of attention since they can be used to a wide variety of problems and have the potential to radically alter our environment in many ways.

WSNs have reportedly been successfully used in a variety of contexts including potential military use. They may be an integral part of military command and control, transportation and computation, civilian monitoring and investigations and targeted capabilities[33].

Between ecological monitoring and control of medical and health care services to other areas like location and tracking, localization, and logistics, the potential applicability of WSNs to every industry on the planet is almost limitless. It cannot be stressed enough how much the advantages and potential uses matter when deciding which wireless tools to use. When an application's specifications have been finalized, the next step is for network architects to choose and implement the hardware that will make those specifications a reality. So, it is crucial to have an understanding of the inner workings, advantages, and challenges of diverse machines. Given the importance of the link between application needs and hardware capabilities, this section will aim to provide a high-level overview of some of the most important uses of WSNs.

Transportation applications collect real time traffic information to inform intelligent transportation models and make observation made of impending congestion challenges.

Moreover, WSNs used in medical/health applications of WSNs such as diagnostics, investigations, drug supervision, functionality support for the disabled, comprehensive hospital monitoring and management, remote monitoring of human sensory data, and in-clinic tracking and monitoring of medical staff or patients[34].

Applications in the environmental sensor networks emerge to include numerous ways in which WSNs have aided environmental and earth scientific research, as shown in figure (2.1).

This includes picking up signals from oceans, seas, glaciers, atmosphere, volcanoes, forests, etc. On the other hand, biosensors are already being used in sustainable agriculture and the environment. Landslide detection and management, Green-House (GH) monitoring and management, and the detection of air pollution are other important factors to consider. Buildings and other infrastructural projects such as flyovers, bridges, roads, embankments, tunnels, etc. can all benefit from the use of WSNs to track their progress, allowing manufacturing and engineering firms to save money by not having to send staff to the sites themselves to keep an eye on things[35].

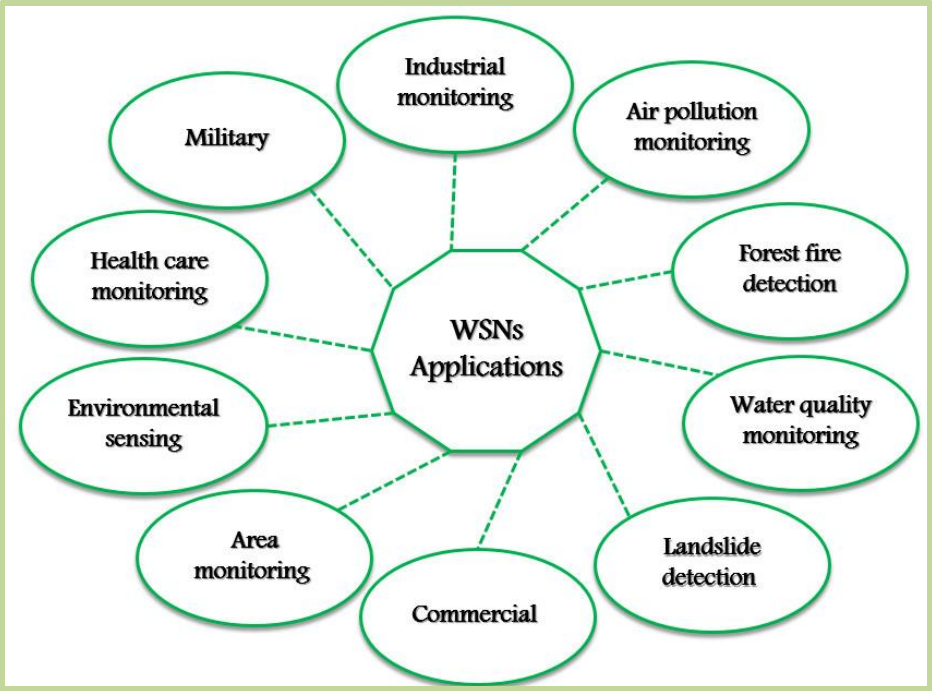


Figure 2.1: Applications of WSNs.

WSNs have been advocated for use in technological condition-based maintenance because of the significant savings and returns on investment they may provide in industrial settings, as well as the new capabilities they make possible. Limitations on sensor placement due to wiring costs are common in wired categories.

The usage of WSNs has been shown to benefit farmers in a number of ways, including the automating of irrigation systems, which allows for more efficient use of water, and the decrease of wastes[36].

2.4 WSN Architecture

Many different types of WSNs such as mobile communications networks, wireless local area networks, Bluetooth networks, Ad-hoc networks, etc. the architecture of WSNs depicts in figure (2.2), the density of sensor deployment, redundant data, unstable SN, insufficient power consumption, bound memory, devices powered by batteries, and software facilities are just some of the attributes that distinguish WSNs. The multilayer nature of the WSN's structure may be seen as a model for the categorization and presentation of related features and services. A WSN's multilayered design may often be seen as representing groupings of similar capabilities. The seven-layer Open Systems Interconnection (OSI) architecture is the standard for networked computers. As a whole, the system's layers work as a suite of interconnected features. Layers include the physical, data link, network, and transport layers in WSNs[37].

The data transfers from one SN to another is only one of the numerous duties of the lowest four levels. After that data has been converted into a signal at the physical layer and then sent down the channel. When two systems are directly linked, the data may be transferred between them through the link layer. Routing is a function of the network layer. The term "routing" refers to any method of communicating and connecting between computers that do not have a direct physical connection. The processes operating on such nodes communicate with one another, and with the rest of the system through the transport layer.

Users are given a means of interacting with software solutions and networking through an interface that is controlled in the application layer.

The three intersecting planes are the power management plane, the mobility management plane and the task management plane. The first controls the sensor node. The second deals with node relocation and where to store and retrieve network data. The third is used to gather data from sensors to complete the mission[38].

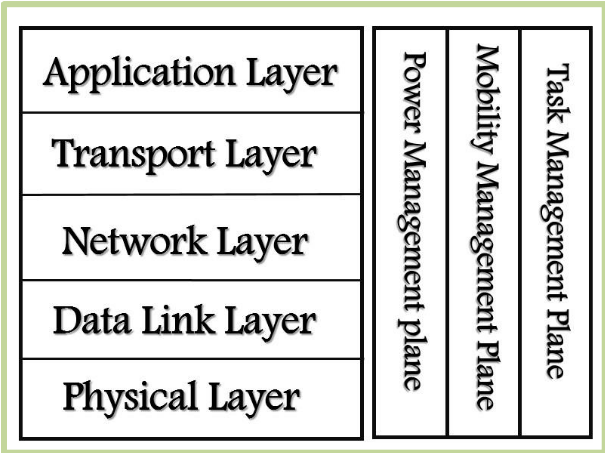


Figure 2.2: WSN Architecture[37].

2.5 Limitations and Important Considerations in Protocols

Considering the many potential uses of WSNs, SNs are limited in packet delivery rate, latency, and power availability. Due to these limitations and the often-high number of SNs deployed, sensor network design and maintenance have faced significant barriers.

In terms of communication and equipment architecture, SNs have their distinct challenges. The primary difficulties start when it comes to setting up sensor networks. It is best to do it in an ad hoc manner, where the SNs are spread out randomly. It is up to the individual nodes to figure out where the network is set up and how it is distributed [39], [40].

Devices should be tough enough to withstand the challenges of deployment in dangerous environments and other areas if the deployment is random. Similarly, the system must be capable of fully configuring itself like the nodes that are set to operate in an unsupported setting [41]–[43].

Since the relayed data must travel across numerous hops, a high level of dependability is required on each connection. Otherwise, the likelihood of data successfully accessing its endpoint is minimal. Many implementations need that packet transfer arrives at their destination within a limited time frame, yet this is a critical component of QoS [44]–[46].

Due to the high level of unpredictability in WSNs, protocol development for such uses is a significant challenge. When the message originator or receiver or both are in motion, this complicates the routing process. A solution to this problem is to either constantly update the routing table or to identify proxy nodes that are in charge of doing so, depending on how far a node has traveled from its initial position, the gateway for that node may also change. There are many different types of attack that may be used against a routing protocol, such as selective forward, black hole, sybil, replay, wormhole, and denial of service [47], [48].

Overload is a major problem in WSNs because it causes packet losses and the need to resend data. This uses up valuable resources and reduces the lifespan of sensor nodes. Huge networks which may handle audio and video and have several BSs are more susceptible to overload [49]. In order to solve the issue of sensed data forwarding in sensor networks, several techniques have been developed.

These routing algorithms were created with SNs features, as well as the needs of the implementation and the overall network topology, in consideration.

2.6 The Role of Routing Protocols in WSNs

The Routing approach is one of the most critical WSN solutions. Managing the route with essential properties in WSN is more challenging than in other competing networks, such as ad hoc. Among the most significant aspects are the constraints on supplies, power generation, and network connectivity. In addition, every SN has an identifier, and maintaining an Internet Protocol (IP) address strategy is a time-consuming task when deployed in large numbers. WSNs are difficult to implement because of the aforementioned drawbacks. In addition, maintaining or updating a significant Internet address is tricky, because of its physical responses, a WSN generates a substantial amount of increased output[50].

Another problem is that in a dynamic context, maintaining routing becomes difficult owing to the constant change of topology and the frequent alteration of the route. The vast quantity of repeating content with a high likelihood owing to data collection from sensor nodes may be addressed by suitable routing protocol architecture. Many-to-one communication is common in Sensor Networks, where numerous SNs send data to a single node. Multicast and peer-to-peer communications are not supported. WSN applications are often constrained by a set time frame for when data may be sent and received. This sort of technology includes a defined long duration data delivery to promptly get around the problems listed above [51]. However, in several scenarios, preserving power is more essential than assessing the Quality of service.

It is vital in almost every field that SN power consumption be taken into account when calculating the lifespan of the WSN. Flat and hierarchical routing protocols are the two primary classes of routing protocols in WSNs. In flat routing, all SNs in the network do the same thing and perform the same functions. WSNs use flooding as a communication method that transmits data hop-by-hop. The sections below demonstrate the different topologies of routing protocols in WSNs used in recent years by many researchers to implement various protocols with different methods [52].

2.6.1 Flat Topology

The network flow model is used to categorize routing into three distinct categories: flat, hierarchical, and location-Based. All nodes in a network with flat topology serve the same purpose and have the same capabilities [53].

Most WSNs use one of several flat routing protocols, such as Flooding and Gossip, Sensor Protocols for Information via Negotiation (SPIN)[53], Directed Diffusion (DD)[53], Rumor, Greedy Perimeter Stateless Routing (GPSR), Trajectory Based Forwarding (TBF)[54], Energy-Aware Routing (EAR)[55], Gradient-Based Routing (GBR)[51], Sequential Assignment Routing (SAR), etc. Flat routing methods are efficient in low-density networks.

In large-scale networks, when resources are scarce, this is less desirable since more data processing and bandwidth use are generated by more sensor nodes[56].

2.6.2 Location-Based Routing Protocols

Location-Based routing is also known as geographical, geometric, directional, or position-based routing. In Location-Based routing, each sensor knows its own position and the source is aware of the location of the destinations[57]. To decide which neighboring sensor to utilize as a head to send the packet towards the sink, sensors may use their geographic locations (coordinate values). In addition, the intensity of incoming signals may be utilized to roughly estimate the distance between two nearby sensors[58]. Location-Based routing protocols [59] include Geographical adaptive fidelity (GAF), Geographic and energy-aware routing (GEAR) [60], Coordination of power saving with routing (SPAN) [61] , Bounded Voronoi greedy forwarding (BVGF) [62], and Dijkstra-Based Localized Energy-efficient Multicast Algorithm (DLEMA) [63][64].

2.6.3 Hierarchical Routing Protocols

WSN nodes in the hierarchical architecture are often arranged into several clusters according to specified criteria or metrics, and each node execute specialized activities. Each cluster has a 'cluster head' (CH), and other nodes called 'member nodes' (MNs) or 'ordinary nodes' (ONs). CHs may be arranged in a hierarchy with other CHs. For the most part, the higher-energy nodes (CHs) process and transmit data to the BS, whereas the lower-energy nodes (MNs) are responsible for information sensing[12].

Many researchers utilized the form of a chain to connect sensor nodes because of its characteristics[65].

Power Efficient Gathering Sensor in Information System (PEGASIS) was a famous routing protocol that builds the network using a long single chain with one head node, the head node called chain heads (CHs) that responsible for delivering all gathered data. Energy consumption is reduced in this topology compared to other topologies due to the connection of nodes with their closest neighbour nodes and they are set to the sleep phase. Many researchers have improved PEGASIS to save energy in nodes, prolong the network lifetime and reduce the delay in chain communication[66]. In[69], there are many routing protocols that improved the performance of PEGASIS.

The delay in delivering gathered sensed data to the BS is a critical aspect that leads the researcher to improve topology to overcome drawbacks in the network. LEACH[27] was the best known routing protocol to reduce the delay. It divided the network into multiple clusters with one head node in each. In[70],[71], there are many protocols that overcome and improve the performance of LEACH.

The following sections review the technologies, analyzes functional and performance aspects, highlights the hierarchical routing protocol topologies, and presents issues and challenges in WSNs:

2.6.3.1 Chain-Based Routing Protocols

Chain-Based networking is a crucial strategy for arranging sensor node transmission in WSN areas such as the Internet of Vehicles, Medical Services, Intelligent Buildings, etc.

There are numerous researchers that use a chain topology in the random deployment of sensor nodes. Because of the sensor's limited energy supply, most chain protocols are built around the idea of minimizing power use.

In a WSN, each node is connected to its immediate neighbors by a series of identical links in a chain, extending serves to prolong the network's useful life while reducing its overall power consumption and maintenance expenses. The connections in Chain-Based between sensor nodes are multi-hop, but the connection between a head node and the BS may be either single-hop or multi-hop. The long link problem caused high delay and dying nodes through transmitting and caused lost data packets in a chain topology [7]. The issue is addressed by breaking the chain into many smaller chains to avoid the long link connections and using AI algorithms such as greedy algorithm and ant colony optimization algorithm. Among other things, Chain-Based routing protocols with multi-hop/multi-hop communication focus on inter and intra-cluster communication[28], heads choosing, chain formation, and scalability.

The types of Chain-Based routing protocols that successfully improved the WSNs in terms of energy efficient, scalability, and delay-free as mention below:

1. **Power-Efficient Gathering in Sensor Information Systems:**

PEGASIS[70] was the oldest Chain-Based routing protocol. In PEGASIS, each SN connects with its closest neighbour and they deliver their packets from one to another until they reach the head node called ‘chain head’ (CH). Single long chains cause delay but reduce the amount of energy in each round.

2. Chain Routing Based on Coordinates-Oriented Cluster Routing Protocol (CRBCC):

The routing protocol called CRBCC proposed in [71] uses y-coordinates. It creates evenly distributed clusters with about the same number of nodes in each, as shown in figure (2.3). CRBCC redoes the simulated annealing routing algorithm among the top nodes in the chain. The delay was reduced compared to PEGASIS due to dividing the long chain into smaller ones with a chain node in each. The amount of energy consumption increased because of the election of many Chain Head (CH) node.

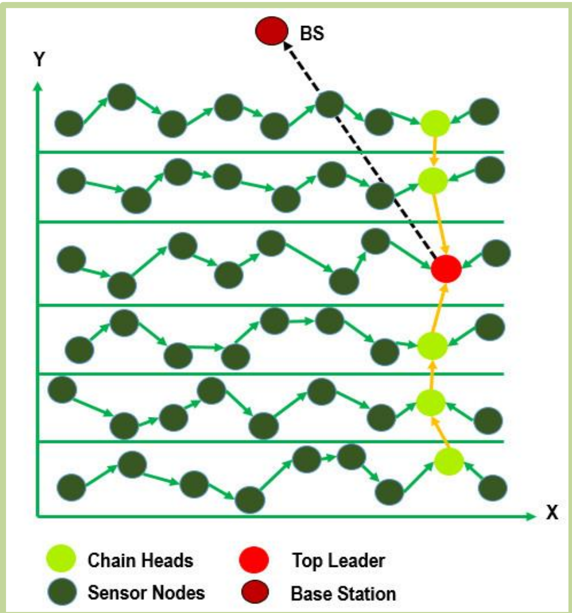


Figure 2.3: Chain Routing Based on Coordinates-Oriented Cluster Routing Protocol (CRBCC)[71].

3. Balanced Chain Based Routing Protocol (BCBRP)

A (BCBRP) [72] was proposed for energy efficiency where equal-sized sections of the overall network area are separated from one another. From each smaller network, it chooses a single representative to act as a bridge.

The spanning-tree algorithm is used in BCBRP where the nodes in each sub-area are linked together to form a chain, then the chains connected using bridge nodes as shown in figure (2.4). As a consequence, the region enclosing the network is smaller; hence, the greatest distance between any two nodes was much less. The BCBRP reduces the total length of the chain link compared to PEGASIS.

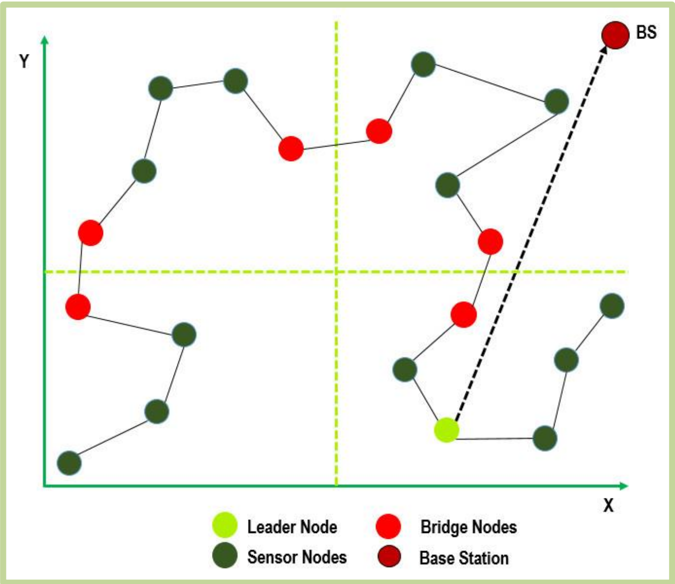


Figure 2.4: Balanced Chain-Based Routing Protocol (BCBRP)[72].

2.6.3.2 Cluster-Based Routing Protocols

There are several routing protocols in WSNs as Cluster-Based [73] routing systems, that becoming increasingly popular among researchers because they may be used to implement a solution that spans several layers. Most clustering techniques divide their work into two parts: the "setup" and "steady-state" phases [74]. The network is partitioned into clusters in the configuration stage by selecting a CH for each one.

For each cluster, a dedicated TDMA slot is assigned by the CH of the setup segment to which member nodes of the cluster submit their identifiable data.

On behalf of its members, the CHs collect and transmit data to the BS. The three stages of cluster protocol are as follows: CH selection, the formation of clusters, and the development of intra-cluster communication. Size, cluster's number, and communication processes inside and across clusters are elements of cluster attributes.

To improve the performance of routing and reduce the delay, many researchers use the clustering topology and elect one or more head nodes in each cluster, below types of Cluster- Based routing protocol:

1. Low Energy Adaptive Clustering Hierarchy (LEACH)

LEACH was a Cluster-Based routing protocol[6] that groups the sensor nodes into clusters as displayed in figure (2.5). To save power, cluster heads "rotate" between sending data to the central hub and receiving it. Turning the cluster heads around this ensures that all of the nodes use the same amount of energy over time, which extends the network's lifespan. It is important to note that LEACH's operation occurs in cycles, there was an initial setup phase, and then a steady-state phase, in each of these cycles. Clusters are arranged and their heads identified during the setup process. The steady-state period is when data is being sent to the BS from the cluster heads.

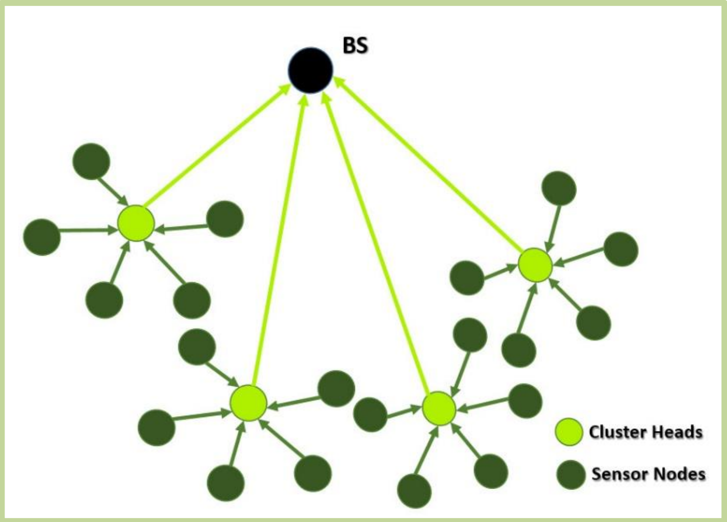


Figure 2.5: Low Energy Adaptive Clustering Hierarchy (LEACH)[6].

2. Three Layered Routing Protocol based on LEACH (TL-LEACH):

Selecting the CH, setting up, and transferring data were the three main TL-LEACH steps[75]. First-level CHs are randomly chosen using an improved threshold like LEACH in the CH selection phase. From the CHs in the first stage, the ones with the lowest energy are chosen to advance to the second as demonstrated in figure (2.6). To begin, nodes outside CHs are invited to join the initial set of CHs as full members.

Following this, the first-level CHs join the second-level CHs with the lowest distance. At the end of the data transmission phase, non-CH nodes send data to the first-level CHs. The consolidated data is then sent from the first-level CHs to the second-level CHs, which in turn send it to a base station[76].

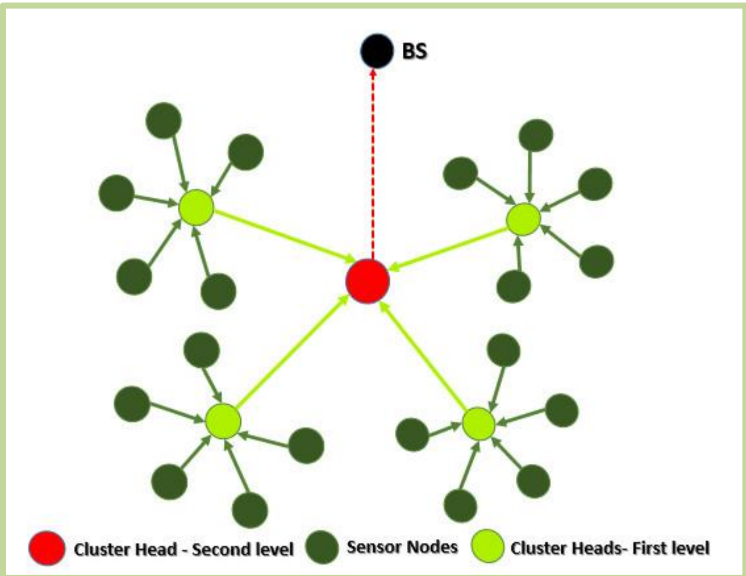


Figure 2.6: Three Layered Routing Protocol based on LEACH (TL-LEACH)[75].

3. LEACH with Distance-Based Thresholds (LEACH-DT):

In LEACH-DT [77], a multi-hop extension was used. The inability of sensors to send signals over great distances requires a multi-hop network rather than a simple one.

In the multi-hop, sensors are organized into distinct sensor groups according to their relative proximity to the BS. To choose the CH, each sensor group executes the suggested single-hop, LEACH-DT as clarified in figure (2.7).

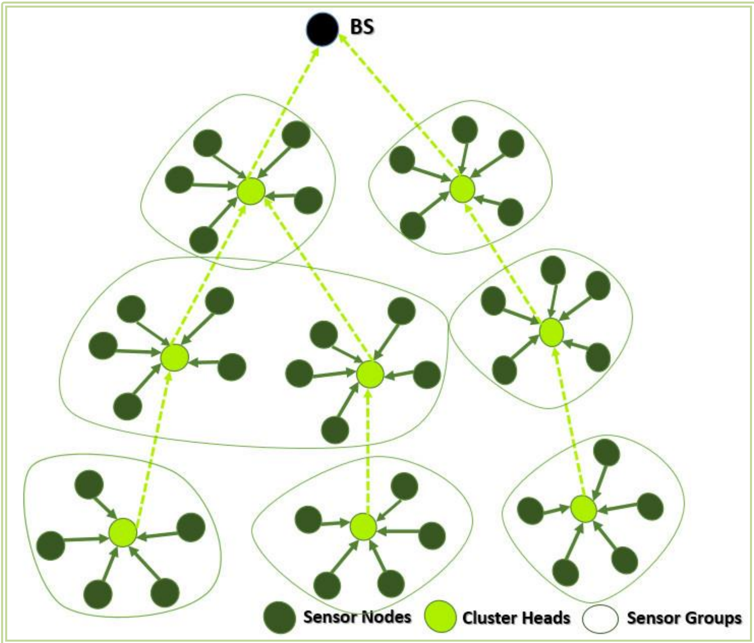


Figure 2.7: LEACH with Distance-Based Thresholds (LEACH-DT) and Multi-Hop Extension[77].

2.6.3.3 Mixed Topologies in WSNs

To overcome the drawbacks in the Cluster-Based and Chain-Based topologies, researchers implement many protocols to improve the performance of WSNs by splitting the sensing area, dividing the single long chains into multi-clusters, connecting the head nodes in one cluster or one chain or reducing the delay using the shortest hop[76], through mixed topologies, many routing protocols used mixed of cluster-chain topology mentioned in below sections:

1. **A Reliable and Energy-Efficient Cluster-Chain Based Routing Protocol (REC+):**

Using the Cluster-Chain topology in some routing protocols by determining where the Cluster Head (CH) should be located and what size and number of clusters should be used, REC+ [78] strived to maximize reliability in multi-hop networks without incurring the high costs of traditional error-control methods as shown in figure (2.8).

REC+ was superior to existing Cluster-Based routing algorithms because it removes the need for several restrictive assumptions that render other algorithms useless in practical WSNs. REC+ was the first cluster chain-based routing algorithm for WSNs that takes into account power efficiency, transmission reliability, and intra-cluster latency while building clusters and choosing CHs. For REC+, the cost of progressively rising delay was too high to justify relaxing the aforementioned premise[79].

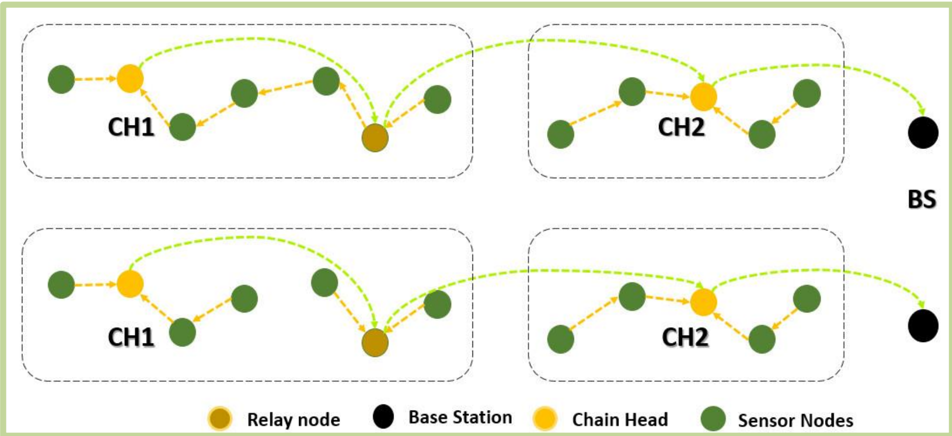


Figure 2.8: Reliable and Energy-Efficient Cluster-Chain Based Routing Protocol (REC+)[78].

2. **Cluster-Chain Based Mixed Routing Protocol (CCM):**

Cluster-Chain Based mixed routing protocol (CCM) [22][80], splits a WSN and proceeds into two phases. In the initial step, sensor nodes in each chain send data to their head node in parallel, utilizing an enhanced chain routing protocol. All Chain Head nodes self-organize into a cluster in the second stage and send fused data to a voted Cluster Head via Cluster-Based routing.

3. **Cluster-Chain Routing Protocol (CCRP):**

Cluster-Chain Routing Protocol (CCRP) is designed for LEACH substitution. Each node in the current round that is acting as a Cluster Head broadcasts a message to all other nodes within its transmission range [81]. At this point, all nodes outside the head make the choice to join the cluster, the reception strength of the broadcast message is used to make this transmission. The leading edges of the clumping clusters link to form a series. The closest base station is the recipient of the compiled data. Connecting the cluster heads in a chain could lessen the energy leak. However, multiple-hop communications between cluster heads exacerbate the latency of the CCRP.

4. **Energy-Efficient Chain-Based Hierarchical Routing Protocol:**

The researcher suggests a new energy-efficient routing for PEGASIS called (CHIRON). The steps of the CHIRON protocol were group formation, chain construction, head node election, and data collection and transmission. They were all energy-intensive, splitting the sensing area into smaller pieces during the first stage allows CHIRON to reduce data propagation time and provide redundant transmission pathways for later phases. CHIRON utilizes Beam Star for its team management needs.

5. **PEGASIS-Double Cluster Head (PDCH):**

The researcher suggests a PDCH [14] routing protocol to eliminate dynamically clustering overhead, lower the durations non-cluster heads must broadcast, minimize the amount of transfers and receptions among all nodes, and deliver only one message to the BS per round.

The Chained transmitting data system makes use of a control token technique. In the branching chain, the primary and second CHs are both in the same chain, albeit they perform distinct duties.

6. **Energy Efficient Clustering Protocol (EECPL):**

(EECPL)[82], shown in the previous chapter figure (2.9), had been proposed as mean of improving WSNs. It aims to decrease power dispersion. During the steady phase, the Cluster Head generates and disseminates the TDMA that specifies the allocated time slots for each cluster member. The time-division multiple-access (TDMA) schedule dictates when a sensor node may transmit and receive data. Cluster nodes use more power than CHs while sending data and communicating directly with the base station.

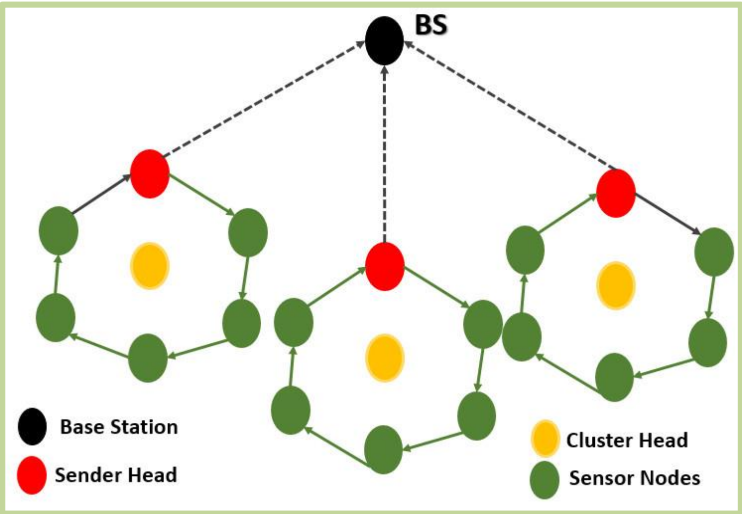


Figure 2.9: Energy Efficient Clustering Protocol EECPL[82].

7. **A Diamond Shaped Clustering PEGASIS (D-S PEGASIS):**

To improve PEGASIS, a diamond-shaped clustering version (D-S PEGASIS) is suggested in [13]. It was ensuring dependability in all situations and the reliability of data transmission is ensured through directive data forwarding.

The data packet will be acknowledged by another head node in the case of a D-S PEGASIS failure. This head node was responsible for transmitting the following data packet to the BS. This method was superior to PEGASIS because data packets are constantly being sent.

8. **Energy Efficient Cluster-Chain Based Protocol for Time Critical Applications (ECCPTC):**

(ECCPTC) was a Cluster-Chain routing protocol designed in [18], to extend the life of networks by decreasing the amount of power they use. In order to reduce the transmission delay of time-critical data, ECCPTC uses a threshold setting. When a sensor node detects a data value at or above a specified threshold, that information must immediately be sent to the BS. In the proposed protocol, data is sent in a chain topology both inside the cluster and to CHs. Upon startup, the BS sends out a signal to all sensor nodes with the threshold value. Each SN calculates the distance to its neighbors and generates a value for selecting the Cluster Head after the message has been received.

2.7 Deployment Strategies

Wireless Sensor Networks have been regarded as one of the excellent studies in different fields because of their critical significance in wide applications. To process the collected data and send it to different locations, a large number of nodes must be installed in the correct method since deployment is one of the primary challenges in WSNs. Hence, the lowest number of node deployments to get complete coverage is of tremendous value for study. The placement of WSN nodes is a fundamental, but critical factor in determining the network's performance.

There are some nodes that are placed at random, while others are placed at a predetermined location. For a hostile or unfavorable environment, a random deployment of nodes is usually chosen, such important factors as connection, coverage, and energy utilization are taken into consideration in the placement of nodes. In order for a WSN to be considered connected, there must be at least one path to the sink node from all other nodes.

For optimal efficiency, the WSN should have a wide area of coverage and complete connection. Both pre-define and random deployment methods are used to spread the nodes[9], [83], [84].

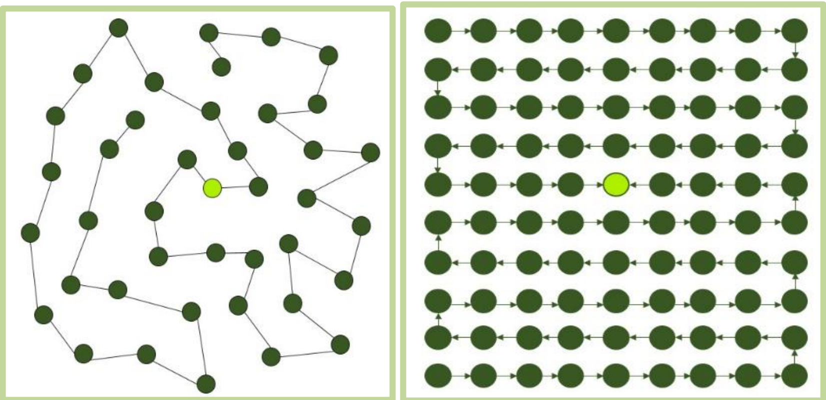
2.7.1 Random Deployment

As the functionality of WSNs relies on their location, the distribution of sensor nodes is crucial to the performance of WSNs in a variety of applications. For example, certain places are sparsely deployed while others are extensively deployed due to the random placement of sensor nodes. Nodes in a field have an equal chance of being put at any time using random deployment. As a result, the nodes are dispersed over unknown terrain. Throwing sensor nodes from an aircraft, for example, may result in such a deployment. In general, it is thought that a uniform random deployment is simple and economical[85], as clarified in figure (2.10) (A).

2.7.2 Pre-Define Deployment

Pre-define techniques are used to predict the performance of a WSN by modeling behavior and building the best approach to meet the user's demands. This is the primary goal of pre-define deployment methods.

The actual deployment of WSNs in the real world is carried out in accordance with the discovered approach. WSNs must be tested to ensure that they meet their stated objectives. There is no established mechanism for deploying a WSN that accomplishes the intended outcomes. When sensors are expensive, pre-define deployment is often employed for indoor applications to ensure the best possible performance of sensors. Pre-define deployment provides the best network configuration compared to random deployment [6],[9],[26].



(A) (B)

Figure 2.10: A) Random Deployment of Sensor Nodes. B) Pre-define (Grid) Deployment of Sensor Nodes.

As demonstrated in figure (2.10) (B), the positions of sensors are pre-calculated in the case of pre-define deployment in order to accomplish such intended objectives as preferred coverage, network connectivity, and network longevity [10], [85], [86].

2.8 Election of Head Sensor Nodes

The election of head nodes is a high-priority stage in WSNs routing protocols. They are responsible for transmitting all data to the BS. The shortest distance between head nodes and the BS affects the communication speed.

Further, the amount of energy consumption is affected by the number of head nodes and SNs that communicate with a head node. The election of head nodes periodically requires substantial energy to ensure that all data is transformed without any possible disconnection. For these reasons, a lot of methods were used in various research papers to select suitable head nodes.

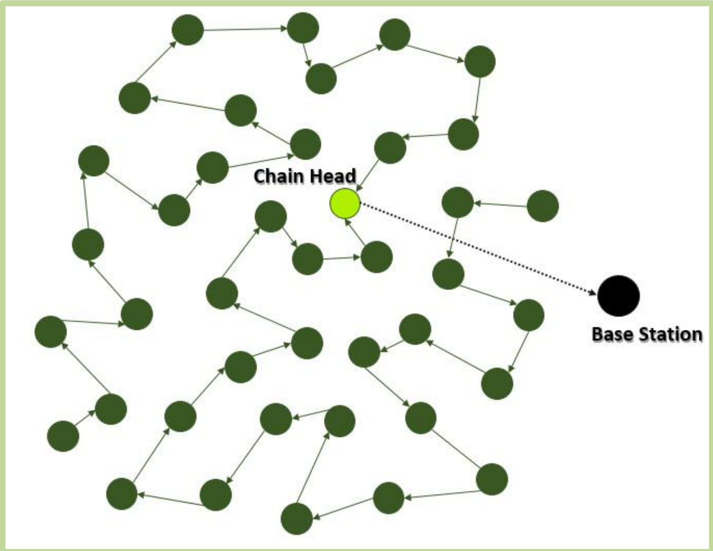


Figure 2.11: Power Efficient Gathering Sensed Information System (PEGASIS)[70].

The first Chain-Based routing protocol was the Power-Efficient Gathering Sensed Information System (PEGASIS) [70] shown in figure (2.11). It is proposed to improve energy consumption in LEACH, which uses a greedy algorithm to construct the chain, and the Chain Head will be elected randomly and connected directly to the BS. In the grid-PEGASIS[24], the CH is elected periodically. This means in every round, SNs will have the responsibility to deliver sensed data to the BS directly.

Using a simulated annealing technique while has been implemented locally in the cluster in the CRBCC routing protocol[71] to determine the x-coordinated order of chain heads and selects one at random. The amount of energy consumption increases because of the election of the chain head node and more delay time.

In BCBRP [72], after dividing the network and electing bridge nodes to connect the sub chains, the SN with a maximum distance from the BS will be the CH node and in the front of the network. In a Cluster-Based routing protocol such as LEACH [6], the sensor nodes detect the events and transmit them to the sink via Cluster Heads (CHs) in the set-up phase of the cluster. However, in stable phases, the cluster was formed and the CH chosen. The CH election procedure was ad hoc, employing random numbers produced in each sensor to choose a new head called a ‘threshold’. LEACH used the intensity of the received signal to have all cluster heads simultaneously advertise their responsibilities to other sensors. The sensors of a Cluster Head connected to its nearby sensors. The LEACH algorithm uses CHs to minimize the quantity of data sent and, as a result, the energy used to transmit it. It was possible that the method's random Cluster Head election may not lead to order distribution over the network and that the algorithm will not be beneficial from a clustering phase technique perspective.

The threshold of LEACH was used in TL-LEACH[75] to elect the CH in the first level. With the lowest energy and lowest distance, they are invited to join the second level CH. The formula below (2.1) was used to elect the CHs in the first level. P is the expected percentage of CH nodes in the population of sensors, whereas r is the current round number. Furthermore, G is a group of nodes which did not turn into a CH in the previous 1/p round (rotation),

$$T(i) = \begin{cases} (r+1) \times mod\ \frac{1}{p} \times p & if\ i \in G \\ 0 & otherwise \end{cases}$$ **(2.1) [75],**

A node's possibility of becoming a CH was based on its distance from the BS. In LEACH-DT [77], to choose the CH, each sensor group executed the suggested single-hop LEACH-DT.

In other routing protocols such as MODLEACH[87], the election of the CH was contingent on the amount of energy wasted in the current round and using a threshold to test the energy level in the sensor nodes. Another method used to elect head nodes depends on the topology used. A lot of routing protocols used a mix of cluster and chain topology.

REC+[78] was a Cluster-Chain protocol that does not make any assumptions about the distances between CHs. Nevertheless, it takes energy and transmission reliability into consideration throughout the clustering process. CH election in REC+ depends on the higher residual energy and initial energy level of the node in the Cluster-Chain formation phase as in the equation (2.2),

$$CH\ election\ = \frac{E^{Residual}}{E^{Initial}} \qquad \textbf{(2.2)[72],}$$

where $E^{Residual}$ is the residual energy amount in elected node, and $E^{initial}$ is the initial value in elected node.

After forming clusters and electing the first Cluster Head (CH), the BS must find the second node and use a higher end-to-end reliability threshold for nodes. The connection between these CHs in the cluster will be long distance. To eliminate this drawback, CHs employ one or more intermediate nodes called Relay-Nodes (RNs). Besides, the BS looks at the maximum transmission range when each CH sends to the BS the maximum power level[72].

PDCH[14] also used more than one head node. It enables the branch chain to live for a short distance because there were two cluster heads, and one on each level, to spread the burden more fairly. The equation is used to choose the cluster heads, the equations (2.3) and (2.4) were utilized to calculate the shortest distance and the election factor of CHs,

$$\boldsymbol{d_i = \sqrt{(x_i - x_{BS})^2 + (y_i - y_{BS})^2}} \qquad \textbf{(2.3),}$$

$$\boldsymbol{Q_i = \frac{E_{res-i}}{d_i}} \qquad \textbf{(2.4) [14],}$$

Where d_i is the distance between the SN and the BS, Q_i is the factor to elect the Cluster Head (CH), while E_{res} is the residual energy, (x_i, y_i) is the coordination of sensor node I and (x_{BS}, y_{BS}) is the coordination of BS.

In the configuration step of D-S PEGASIS[13], two head nodes were available for selection. To save energy, the head nodes generated in a diamond pattern throughout each cycle. This process is continued until all head nodes have been elected. The last head node in the hierarchy transmits the data to the BS.

CCM[80], chain heads were elected periodically to reduce the energy consumed in voting them. The Cluster Head in the last chain head's cluster was elected depending on the maximum residual energy. Otherwise in CCRP[88], it chooses the Cluster Head depending on the node's remaining energy and the number of neighbors by the application of a threshold multiplied by a factor that stands in for the node's remaining energy. The equation below (2.5) was used to elect the cluster head, T(n)' is the value of election of cluster head among other sensor nodes in same cluster, where E_c is the remaining energy of the current node, E_m is the initial energy, p is the probability of being a cluster head, r is the current round and G is the set of nodes that have never been CHs in the last (1/p) rounds,

$$\boldsymbol{T(n)' = \begin{cases} \frac{p}{1-p\left(r \bmod \frac{1}{p}\right)}\left(\frac{E_c}{E_m}\right), if\ n \in G \\ 0, otherwise \end{cases}} \qquad (\mathbf{2.5})[89],$$

In the head sensor node election phase, CHIRON[15] selects a head by looking at the nodes with the highest residual energy values among the group nodes.

The first stages of setting up the energy routing protocol EECPL[82], nodes report their current energy and position to a control hub. This data was used to determine which nodes have enough energy to be considered for roles as cluster heads and cluster senders. The BS guarantees that only such nodes would be chosen. Cluster-senders convey the aggregated data to the BS while the CHs generates and disseminates the TDMA. Once the cluster heads have been discovered, the BS will send out a broadcast with all SN IDs to all SNs in the ring.

ECCPTC[18] had two head nodes, cluster heads in each cluster and one chain head node. Using a non-persistent CSMA MAC protocol, radio ranger selects the node with the highest CHSV among its neighbors as the CH. The BS employs the greedy approach used by PEGASIS to generate a sequence of complete CHs. All cluster heads transmit their data to the chain's head node, and then the head node transmits the data to the base station. The equation (2.6) was used to elect the cluster heads. RE_i is the residual energy of node i and $dis(v_i,v_j)$ is the distance between the two nodes i and j,

$$\boldsymbol{CHSV_i = RE_i * \sum_{j=1}^{number\ of\ neighbors} \frac{1}{dis^2(v_i,v_j)}} \qquad \textbf{(2.6)[18],}$$

Another routing protocol called CCMAR [17] used the weight function to choose the cluster heads. Each cluster had one Cluster Head (CH) directly connected to the BS to send all the gathered data[90]. The weighted equation is displayed (2.7),

$$f(c_{im})_r = r * \frac{|INbr|}{|c_i|} + (1 - r) * \frac{E_{cur}(c_{im})}{E_{max}(c_i)} \qquad \textbf{(2.7) [17],}$$

where c_{im} is the cluster member, C_i is the current cluster, |INbr| is the size of in cluster neighbor, $|C_i|$ is the size of the cluster, $|INbr|/|C_i|$ is the connectivity factor, $E_{cur}(C_{im})$ is residual energy, $E_{max}(C_i)$ is the maximal residual energy among the nodes in the cluster C_i, $E_{cur}(C_{im})/E_{max}(C_i)$ is the energy factor and r is the bias parameter.

2.9 Grouping Sensor Nodes and Communications

In each routing protocol in WSNs, the grouping or clustering of SNs depends on some important characteristics [91]. Clusters number refers to the number of WSN groups formed, which might be fixed or changed depending on the needs of the application. The size of a cluster in a WSN might change. It is possible for several of them to be the same or not. Since the network area is divided into equivalent clusters, the size of the network clusters is consistent throughout. Unequal clustering allows the cluster size to be defined by the distance with the BS as well as by other variables. Because of the greater separation between the cluster and the BS, the cluster grows in size and contains an enormous number of nodes. A smaller cluster with fewer nodes is created when the distance between the cluster and the BS is reduced. Algorithms used to cluster the data may provide various results and types of communication between sensor nodes.

Intra-cluster communication refers to all communication between cluster members and the head nodes. It might be a single or multi-hop route. When used on small size, a single-hop intra-cluster is better to use. While, when used on a big scale, multi-hop is preferred. A WSN lifetime and throughput may be improved with the use of an appropriate intra-cluster communication technique[92].

The application's needs will determine whether inter-cluster communication is single-hop or multi-hop. For small-scale applications, single-hop communication occurs between head nodes and BSs. On the other hand, multi-hop communication is favored for energy-efficient data transfer among several CHs and the BS [93]. Fixed or movable Cluster Head are optional to the application. Only a little distance can be covered by fixed CHs. Moving CHs are more difficult to design than stationary ones as positioning is critical for cluster design in this kind of node.

WSNs employ two distinct clustering strategies, one is centralized, whereas the other is decentralized. A centrally approved BS or super node manages the whole process, including the selection of CHs and building of clusters. For example, when using a dispersed technique, there is no such control permitted from the central authority [37]. Static or dynamic clustering may be used. All these activities are executed regardless of current network conditions in the dynamic process. While, in the static process, these functions are chosen on a case-by-case basis[94] [95].

It is possible to use a proactive, reactive, or hybrid approach while clustering. Sensing data and sending it to the Cluster Head are the tasks of the member nodes. The CH continually communicates data to the BS in a proactive mode. It is called reactive if data is accessible and the CH conveys it to the BS.

In the hybrid technique, the CH sends data to the BS at regular intervals, as well as when the threshold value passes, table (2.1) shows the characteristics of sensor nodes clustering.

In the CH selection process, probabilistic and pre-define methods are used. Selecting the CH may be done at random in a probabilistic method, with no regard to prior considerations. Another option is a mixture of both. Selecting a CH may be pre-define or probabilistic depending on a variety of factors[52][96]. The most important feature is deployment methods. In the pre-define deployment of SNs, they are grouped manually in the simulation programming code by entering the number of SNs and the number of the cluster needed in it. The clusters may be equal in the number of sensor nodes or different in size [10]. In [9] and [23], the deployment of sensor nodes is pre-define and the number of divided chains is fixed and depends on the number of nodes, which is 90.

Table 2.1: The Clustering Characteristics of Routing Protocols in WSNs.

Cluster Characteristics	**Cluster Properties**	**Cluster Size**	**Equal** **Unequal**
		Cluster Number	**Constant** **Variable**
		Intra and Inter communication	**Single-hop** **Multi-hop**
	Cluster Head Properties	**Mobility**	**Static** **Mobile**
		Node type	**Homogeneous** **Hetrogeneous**
		Role	**Relay** **Aggregation**
	Clustering Process	**Method**	**Distributed** **Centralized**
		Cluster Head Selection	**Deterministic** **Propabilistic**
		Dynamism	**Dynamic** **Static**

In DLRP, the network is divided into nine single chains with one Chain Head and ten nodes in each. Further, an algorithm is proposed to construct the chains and the connection between them. CCM[22] and TSCP[25] are other routing protocols that used the grid method and clustering the CHs in every single chain as a cluster that has a main head node responsible for delivering gathered sensed data to the BS. In TSCP, the network is divided into horizontal chains and all the CHs form a vertical chain with one elected node connected directly to the BS. In the random deployment [97], many researchers use the distance equations between adjacent nodes and group the closest sensor nodes together. In this method, the size of clusters and the number of clusters will be different due to the distribution of the sensor nodes as in LEACH[98] and PEGASIS[99]. Many protocols such as the DRINA routing protocol[100] utilized advanced algorithms used in artificial intelligence to build and divide the sensor nodes into clusters and for their intercommunication, and to find the shortest path from member nodes to head ones. A lot of AI algorithms are used in WSNs to cluster the SNs such as the nearest neighbour algorithm and k-mean algorithms[73][101].

2.10 The Energy Model

A popular radio module used in WSN research is the first-order radio model. It is frequently employed for analyzing sensor nodes through simulation. The primary element affecting the energy consumption of the sensor nodes during wireless data transmission is distance. According to what we know, the crucial part of a sensor node that uses the most energy is its wireless communication component. The first-order radio model assesses the energy used per cycle by a sensor node during transmission or reception.

The radio model features power control and can use the least amount of energy necessary to reach its target audience shown in figure (2.12). For example, when a k-bit message is transmitted through a distance (d), the required energy can be expressed in equation (2.8), and the energy consumed at the reception is illustrated in equation (2.9).

Transmitting the k-bit of data packets:

$$\boldsymbol{E_{TX} = E_{TX-elec} \times k + E_{TX-amp}\,(d^2 \times k) = \begin{cases} kE_{elec} + k_{\varepsilon_{fs}} d^2, & d < d_0 \\ kE_{elec} + k_{\varepsilon_{mp}} d^4, & d \geq d_0 \end{cases}}$$

(2.8)[111],

Receiving the k-bit of data packets:

$$\boldsymbol{E_{RX}(k) = E_{RX-elec} \times k} \qquad \textbf{(2.9)[111]},$$

Where $E_{TX-elec}$ and $E_{RX-elec}$ are the energy dissipated per bit of the transmitter and receiver, respectively. ε_{fs} and ε_{mp} depend on the transmitter amplifier model used, and *d* is the distance between the sender and receiver. $k_{\varepsilon_{fs}} d^2$, the distance between nodes must be less than the threshold d_0 , and $k_{\varepsilon_{mp}} d^4$ uses the multipath model. In this work, we assumed the radio model dissipates E_{elec} = 50 nJ/bit , ε_{fs}= 10 pJ/ bit/m^2 and ε_{mp}= 100 pJ/bit/m^2. And d_0 is denotes the threshold distance between two nodes in equation (2.10),

$$\boldsymbol{d_0 = \sqrt{(\varepsilon_{fs}/\varepsilon_{mp})} \cong \sqrt{\frac{10}{0.0013}} \cong 87.705802} \qquad \textbf{(2.10)[111]},$$

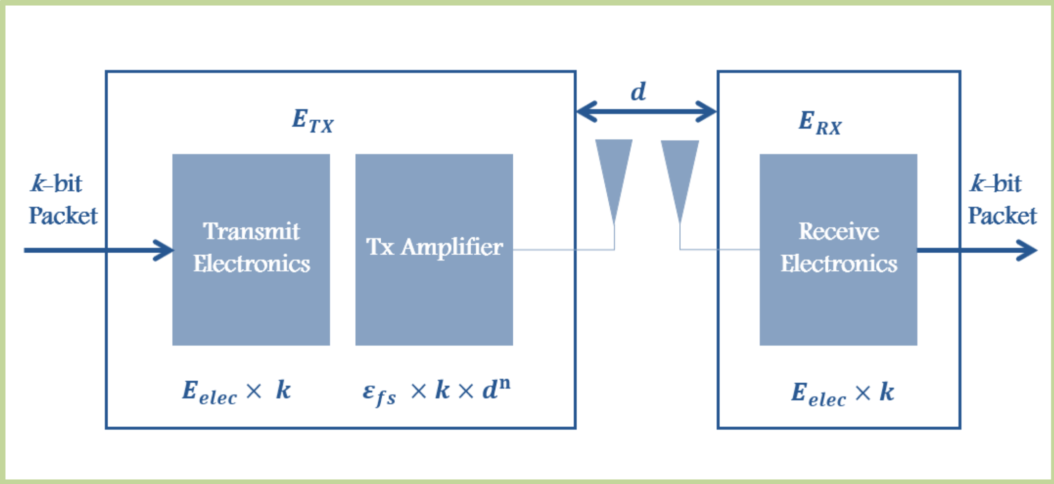


Figure 2.12: First Order Radio Model[111].

CHAPTER THREE:

PROPOSED ROUTING PROTOCOL (ETSRP)

3.1 Overview

In a hierarchical routing protocol, various methods and structures can be built. These methods are used to improve the performance of WSNs, such as the connections between SNs, methods for clustering the sensing area, election of head nodes or Head nodes (RNs) employed in the aggregation and compression of data before delivering it to the BS.

Dividing SNs depends on the deployment method, the number of SNs in the network, and the sensing area size.

The efficiency of a routing protocol is determined by the topology used, the suitable parameters used to elect the head nodes and the connection with other SNs.

Each topology has its own advantages and drawbacks. To overcome the drawbacks, mix more than one topology and come up with new parameters to build an efficient routing protocol.

The research methodology and the three mechanisms that used in this work explained in the diagram (3.1) starting with the investigations about WSNs and its application, researcher papers and the methods that used to present different routing techniques until reach the proposed routing protocol with using the CCF, CHE and Inter- connection mechanism then implement the code in NS3, and last evaluate the performance using different performance metrics.

In this chapter, the methodology of proposed routing protocol and the construction phases are introduced in section (3.2).

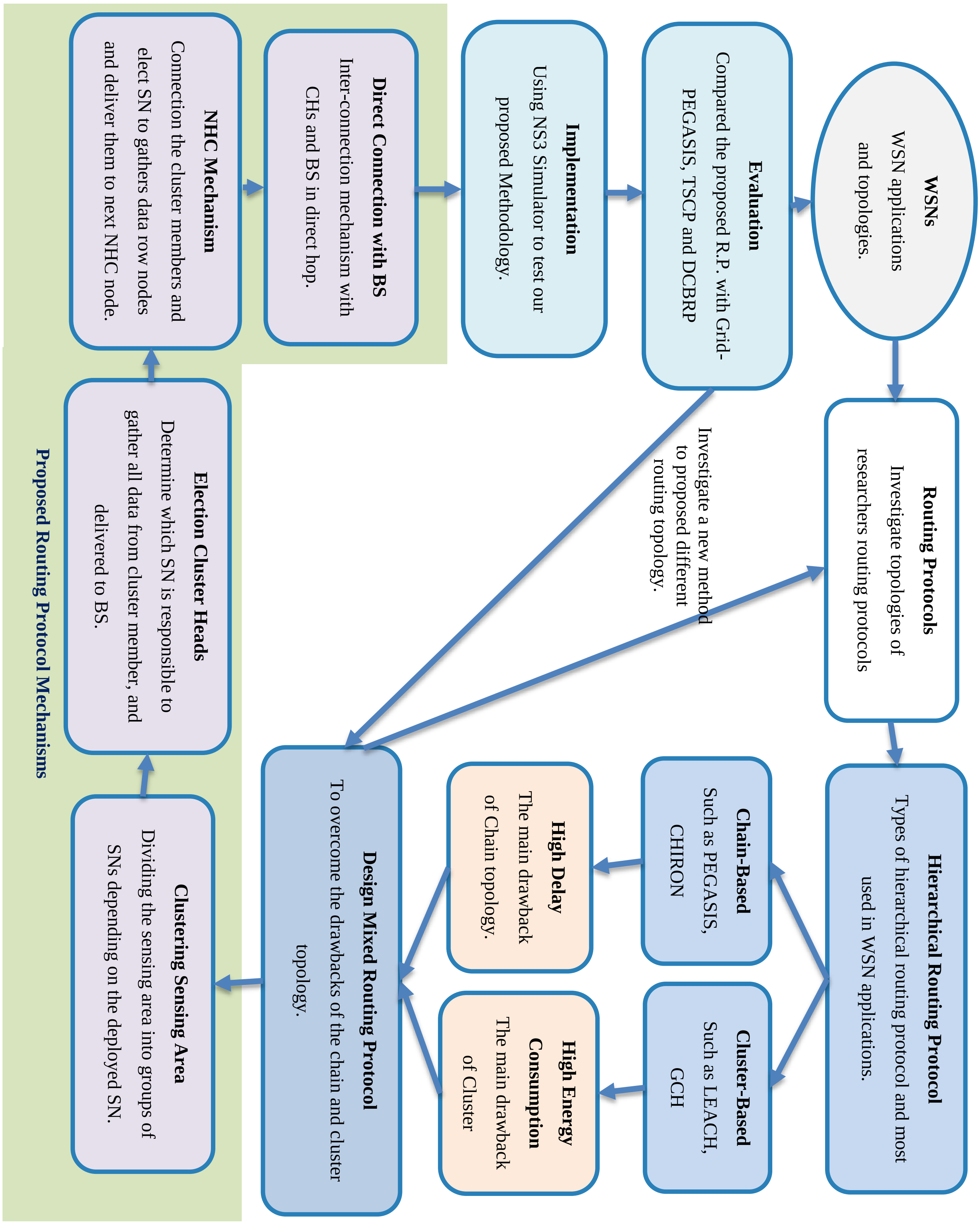


Figure 3.1: Diagram of Research Methodology of Proposed Routing Protocol.

3.2 The Proposed Routing Protocol

Grouping strategies, communications, and election methods of CHs help to reduce delay and extend the life of nodes. Numerous algorithms have been developed to speed up delivering data to the destination, optimize energy consumption, and ensure that nodes are evenly distributed over a WSN during data transfer. This research proposed a new pre-define Cluster-Chain Based routing protocol to improve the time of delivering sensed data from the furthest SNs to those closest to the BS, called Efficient Time Sensitive Routing Protocol (ETSRP).

First phase of ETSRP is divide the network into multi-clusters depends on the sensor nodes number that deployed with equal distance in pre-define methods to prevent the long link connection that happened in random deployment that caused high delay and deplete energy. In NS-3 simulator, the ETSRP deployed nodes in (10 × 9) grid field, divided in six clusters with 15 nodes. All nodes are static has recognized position (x,y) by BS. Base station is located in fixed location far away from the sensing area in location (50,120). All nodes have energy value equal to (2.0J), and minimized in each round by the effect of energy consumption equation of transmitting and receiving. The distance between nodes is determined to 10 meters. In each cluster, there is one Cluster Head (CH) elected to take the role of gathered and delivered all packets to BS.

The connection between the nodes in each cluster depend on the arrangement of the sensor nodes. SNs arranged as three columns, each two nodes communicate with the middle node that gathered data with its own, and delivered it to the highest energy remaining nodes in its really row, this called next hop connection technique that used by many researchers to save energy of nodes[23], [26].

Next phase, the cluster heads are elected depending on the energy remaining, distance and number of connections. At last, when all the sensed data are gathered by the cluster heads, the connection with BS done directly in Inter-connection technique to send the all data to BS in single hop. The three mechanisms of ETSRP are explained with details in below sections. Figure (3.2) shows conceptual model flowchart of ETSRP. The main objective of this research is to improve the network performance by deliver the sensed data in efficient time.

ETSRP includes three main mechanisms start with Cluster-Chain Formation: that divided the network into clusters with the knowledge of sensor nodes number, number of clusters, number of nodes in each cluster and the distance between nodes are basic to build the connection between nodes. The second mechanism is Cluster Head Election mechanism that improves the time delivery due to the distance, and energy remaining, and number of connections, the distance between elected node and BS effect has the large impact on delivery time.

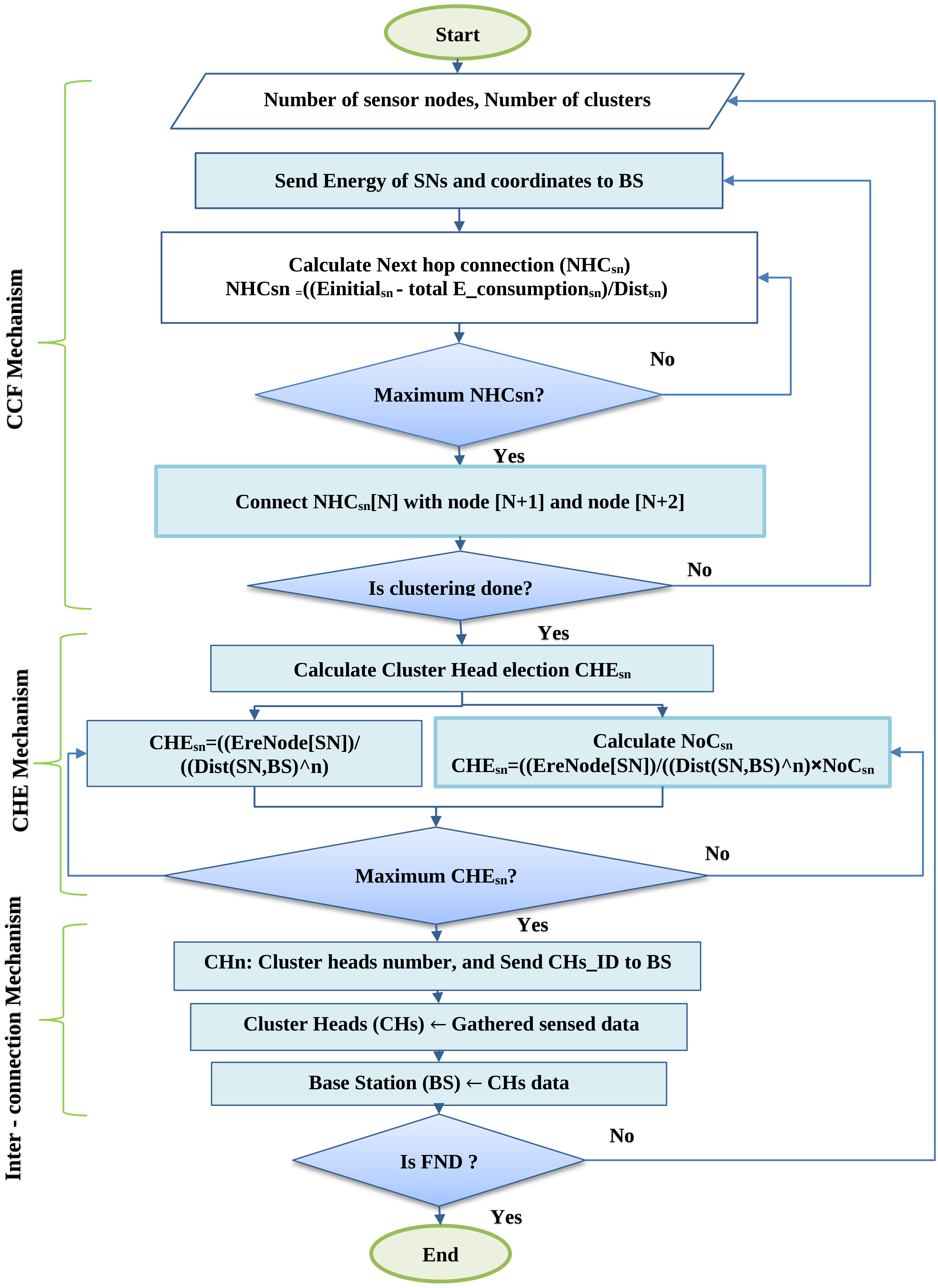


Figure 3.2: The Conceptual Model of ETSRP.

The last mechanism, is Inter-Connection mechanism that used to prevent multi-hop connections between CHs and BS, and help to decreases the overall delay of ETSRP.

3.2.1 Cluster-Chain Formation (CCF) Mechanism

The first phase in proposed protocol is deployed the sensor nodes then grouped each 15 nodes as 3 column × 5 rows with 10 meter distance as shown in figure (3.3). The 3 nodes in each row communicate with each other through elect one node from them to gather their packets plus its own, and delivered to the next nodes in next row.

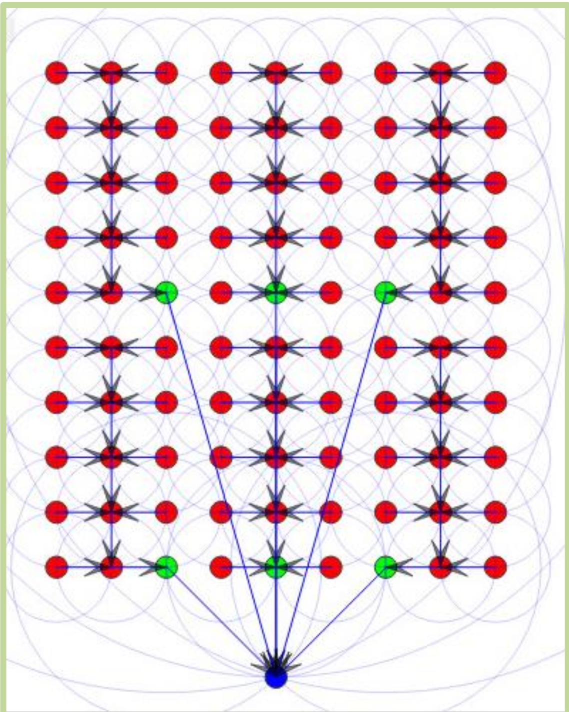


Figure 3.3: The ETSRP Simulation Dividing into Clusters and Next-Hop Connection Mechanism.

Each row elects that node depending on the equation (3.1) for next hop connection mechanism.

$$NHC_{factor} = \frac{E_{initial} - \sum_{0}^{current\ round} E_{consumption}}{\sqrt[2]{(Y_B - Y_A)^2 + (X_B - X_A)^2}} \qquad \textbf{(3.1)[23],}$$

NHC_{factor} is responsible for decide which node will be the main node to elect the data from its neighbour nodes, $E_{initial}$ is the initial energy amount in sensor node, $E_{consumption}$ is the amount of energy consumed in current round, and the (X_B , Y_B) is the coordinate of Base Station and (X_A , Y_A) is the coordinate of sensor node.

There are many probabilities to divide the deterministically deployed sensor nodes and the number of clusters depends on the number of sensor nodes in each cluster. The limitation in WSN is the delay in delivering packets because of the long connections in a column in different topologies.

Each sensor nodes and BS have static position in algorithm, in the algorithm (3.1), the main parameters that must give at the beginning are number of sensor nodes, number of clusters, the distance between nodes, and the number of columns in clusters to calculate the number of rows and build the connection between them and calculate the next hop node in each row. The clusters number depends on the total number of nodes, and the number nodes in each cluster depend on number of clusters and number of total nodes Clm in the above algorithm of CCF, after building the cluster, elect the next node in each row to gather the data and send it to next node using NHC_{sn} equation, after that transform to build next cluster. These steps done in each round and in each round different nodes elect to be next hop node depends on energy remaining and distance $Dist_{sn}$.

Algorithm (3.1): The CCF Mechanism of the ETSRP Algorithm:

Declarations:

SN: Number of sensor nodes
Cn: Number of clusters
Dist: 10
Clm: Number of nodes in each cluster

Nc: Number of columns in each cluster
Sm: Number of nodes in each column

```
Begin
1    Input SN
2    Input Cn
3    Calculate Clm ← (SN/Cn)
4    Sm ← (Clm/Nc)
5    While i <= Cn  do
6        For j <= Sm do
7            Set [i] ← (x,y);
8            Set[i+1] ← (x, y+Dist)
9             i←i+1
10            j←j+1
11            Dist_sn ← (Dist_sn , Dist_BS)
12       For d <= Cn  do
13           For e <= Sm  do
14               NHC_(e) ← ((Einitial_(e) - total E_consumption_(e) )/Dist_(e))
15               For c<= Nc  do
16                   NHC_(c) ← ((Einitial_(c) - total_consumption_(c))/Dist_(c))
17                    If  NHC_(c) < NHC_(e)  then
18                         NHC_(c) ← NHC_(e)
19                        NHCx ← c
20                    End if
21                   Connect(SNode[NHC_X[N],SNode[N+], Node[N+2])
22               End for
23           End for
24       End for
25   End for
26   Set next cluster (x+Dist,y) Goto step 5
27   End while
End
```

3.2.2 Cluster Head Election (CHE) Mechanism

There are two methods for electing CHs. Many parameters could be used to elect CHs, such as energy, distance, number of hops, density, overlapping degree, distance from neighboring nodes, intra-cluster distance, and number of neighboring nodes. In the proposed electing mechanism, the work depends on energy remaining, distance between the SN and BS and the number of connections with each node. In any routing protocol, to improve the performance of WSNs, the distance between the SN and BS is an essential concept that affects in reducing the delay. Furthermore, network lifetime is a very important concept that has an effective impact on the network by reducing the energy consumption in each round. The energy level should be taken into consideration.

- **Energy Calculation**

In WSNs communication, sensing, delivering, and receiving packets depend on the energy in sensor networks. In the proposed routing protocol, the remaining energy is the first parameter to prolong the network lifespan as long as possible.

- **Distance Calculation**

The most important parameter that is calculated in equation (3.2) is the distance between SNs and the BS. It directly affects the delivery time. The sensor node will be elected as a Cluster Head (CH) if it has the shortest distance to the BS among other SNs.

$$\boldsymbol{Distance}_{(\boldsymbol{SN},\boldsymbol{BS})} = \sqrt[2]{(\boldsymbol{Y}_{\boldsymbol{BS}} - \boldsymbol{Y}_{\boldsymbol{SN}})^2 + (\boldsymbol{X}_{\boldsymbol{BS}} - \boldsymbol{X}_{\boldsymbol{SN}})^2} \qquad \textbf{(3.2)[26],}$$

Distance $_{(SN, BS)}$ is the distance between the SN and BS, (X_{BS}, Y_{BS}) is the location coordinate of the base station, and (X_{SN}, Y_{SN}) is the location coordinate of the sensor node.

- **Calculation of Number of Connections**

In each round, the sensor network senses the area and delivers the packet to its closest neighbour node or to an intermediate node that delivers the packets to the CHs. The time of delivering packets from one node to other increases depending on the number of hops until reaching the CHs. The number of connections has its influence on decreasing the delivery time from multi nodes to one. The election of the intermediate nodes in rows depends on the NHC mechanism calculated by the maximum remaining energy value and closest distance from the BS. As shown in figure (3.4), node (d2) is elected in the first round to be a Cluster Head because it has the highest remaining energy level, shortest distance from the BS and three connections with other nodes from (a1-d1) and (a3-d3). In other rounds, the energy levels are decreased for each SN. In the figure below, the (b1) is elected as a Cluster Head depending on the NHC mechanism and it has three connections. The (c2) node has the probability to be the next Cluster Head due to energy level.

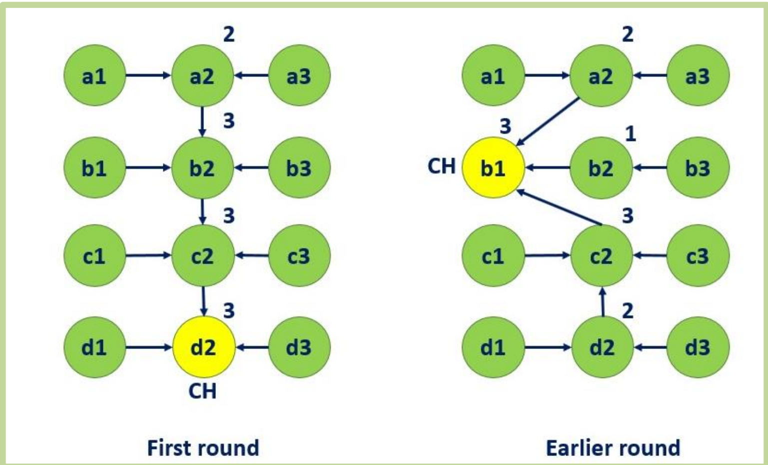


Figure 3.4: Number of Connections in Sensor Network.

3.2.2.1 Election of Cluster Heads without Number of Connections

To elect the suitable cluster heads in each cluster, the energy remaining in each node is decreased in each round. It is affected by how many times the SN is elected as a Cluster Head and its role to transmit its own packets and receive packets from other sensor nodes in the same cluster. Distance has a massive effect in CH election. CHs are elected when a SN has the maximum value of equation (3.3) compared to other sensor nodes in the same cluster, the CHE mechanism is explained in (3.2) algorithm.

$$\boldsymbol{CHE = \frac{Energy_{remaining(SN)}}{Distance_{(SN,BS)}}} \qquad \textbf{(3.3),}$$

Where *CHE* is the factor to elect the maximum sensor nodes value in each cluster to be the Cluster Heads depending on $Energy_{remaining(SN)}$ parameter which is the remaining energy in sensor node and the parameter $Distance_{(SN,BS)}$ which is the distance between sensor node and Base Station.

Algorithm (3.2): ETSRP without NoC Algorithm for CHE Mechanism:

Declarations:

SNodes← 90
NClusters←6
Eelc← 0.00000005
Eamp← 0.0000000001
K←1024 bit
Dist: distance between SN
EnrgyTx← (Eelc * k) + (Eamp * k * (Dist ^ n))
EnrgyRx← Eelc* k

Begin

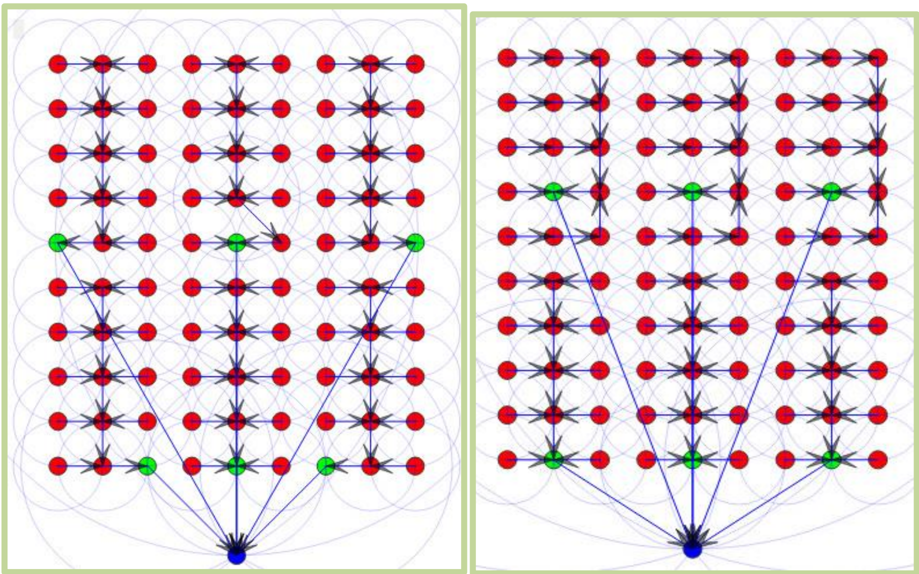
```
For SN ∈ SNodes do
Econ←0.0;
   dist[SN]←10.0
   EreNode[SN]←2.0
   live[SN]←1
End for
Calculate CHE← ((EreNode[SN])/((Dist(SN,BS)^n)
For  CL ∈ NClusters do
  For Ni ∈ CL do
    If ((EreNode[Ni])/((dist(Ni,BS)^n) >  CHE  then
       CHE←((EreNode[Ni])/(sqrt(dist(Ni,BS)
    End if
    If Ni=CHE then
    Econ[Ni]←EreNode1[Ni]-EnrgyTx((PacketSize*dist1[BS]);
    Else EreNode[Ni]← EreNode[Ni] - EnrgyTx ((PacketSize ), 10);
    End if
  End for
End for
End
```

3.2.2.2 Election of Cluster Heads with Number of Connections

Another parameter that influences network performance in delivery time is the number of connections with SNs in equation (3.4). The number of hops from the SN to the CH has its impact on the number of packets gathered in each round and on the delay of transmission to the BS. The algorithm (3.3) explain that number of connections will have a higher priority than distance that shows in the simulation results in figure (3.5).

$$\boldsymbol{CHE} = \left(\frac{\boldsymbol{Energy_{remaining(SN)}}}{\boldsymbol{Distance_{(SN,BS)}}}\right) * \boldsymbol{NoC_{SN}} \qquad \textbf{(3.4),}$$

Where *CHE* is the factor to elect the maximum sensor nodes value in each cluster to be the Cluster Heads depending on $Energy_{remaining(SN)}$ parameter which is the remaining energy in sensor node and the parameter $Distance_{(SN,BS)}$ which is the distance between sensor node and Base Station. NoC_{SN} is the number of connections with the current SN that will be elected as CH. The number of connections ensures that the node with the highest connection will be a cluster head. This means that the number of packets received from neighbors' is higher than others and reduces the distance and the number of hops in the next rounds.



(A) **(B)**

Figure 3.5: The Two Scenarios of CH Election. A) Without NoC. B) With NoC.

<u>Algorithm (3.3): ETSRP with NoC Algorithm for CHE Mechanism:</u>

<u>Declarations:</u>

SNodes← 90

NClusters←6

Eelc← 0.00000005

```
Eamp← 0.0000000001
K←1024 bit
Dist: distance between SN
EnrgyTx← (Eelc * k) + (Eamp * k * (Dist ^ n))
EnrgyRx← Eelc* k
Begin
    For SN ∈ SNodes do
    dist[SN] ←10.0
    EreNode[SN] ←2.0
    live[SN] ←1
    SN←SN+1
    End for
    For i ∈ SNodes do
        Calculate NoC[i]
         i←i+1
    End for
    CHE← (((EreNode[SN])/((dist(SN,BS)^n)*NoC[SN]
    For  CL ∈ NClusters
       For Ni ∈ CL do
         If ((EreNode[Ni])/(dist(Ni,BS)^n)*Noc[Ni]>  CHE
              CHE←((EreNode[Ni])/(dist(Ni,BS)^n)*NoC[Ni]
          CL←CL+1
         End if
    If Ni=CHE then
      Econ[Ni]←EreNode1[Ni]-EnrgyTx((PacketSize*dist1[BS]);
      Else EreNode[Ni]← EreNode[Ni] - EnrgyTx ((PacketSize), 10);
      End if
     End for
    End for
End
```

3.2.3 Inter-Connection Mechanism

All the packets must be delivered to the BS after being gathered from all sensor nodes by CHs. The connection method with single or multi-hop affects the routing energy and latency.

In this research, the single-hop inter-connection costs less delay than other routing protocols, the only effect is the deployment method used. When nodes die, the topology and the distance between SNs will change. The proposed protocol divided the sensor nodes into six cluster, each have fifteen sensor nodes with one cluster head. After elect the cluster heads in each cluster, all the sensor nodes sensed the area and delivered its packets to the next hop sensor node then to the cluster heads depends on the highest remaining energy, the role of cluster heads starts. All the cluster heads send the gathered packets to the BS in single hop as inter connection and the number of connection (NoC) helps to elect the nodes that has max number of links than other in same cluster with the effect of energy remaining and distance- in early rounds to saves energy and prolong the ETSRP lifetime.

The inter connection mechanism used to eliminate the multiple hops that used in chain topology and prevent the latency in delivering packets. The only effected on the delay is the distance from cluster heads to BS where the position of cluster heads in clusters has huge impact on ETSRP performance [23][26].

3.3 Summery

WSN has many constraints effected by sensor nodes limitations, such as power that supply all the sensor device unit which are processing, sensing, communication units. To overcome these constraints, built suitable routing protocol with mixed topology (chain and cluster formation). In this thesis, ETSRP divided the sensed area into clusters, with three columns in each using next hop connection mechanism to save the nodes energy as long as possible. Using most effect parameters to reduce delay and extend the network life time through reduce the energy consumption, that parameters are distance, energy remaining and new parameters that effect on elect the cluster heads which is Number of Connections (NoC). Using inter-connection mechanism that reduce the delay much more because of direct connection with BS to deliver the all packets.

CHAPTER FOUR:

RESULTS AND DISCUSSION

4.1 Overview

The performance evaluation and results of simulation will be presented in this chapter. The evaluation of ETSRP to Cluster Head election without the number of connections in equation (3.9) and the election methods with the number of connections in equation (3.10) in the previous chapter.

Moreover, summarize the simulation programs and programming requirements in section (4.2), the parameters in section (4.3), and list the performance metrics in section (4.5), and the results of ETSRP.

4.2 Simulation Parameters

There is a basic parameter required to evaluate the performance of ETSRP and compares its results of simulation with other routing protocols using the NS-3.22 and C++ programming language as demonstrated in the table (4.1).

4.3 Validation and Evaluation of ETSRP

The proposed mechanisms of ETSRP are validated and evaluated by executing them in NS-3.22 using the C++ programming language explained in section (3.5) in the previous chapter. In addition, the evaluation is done through six performance metrics (Delay, Total power consumption, Average power consumption, CHs power consumption, (Energy×Delay), and Average (Energy×Delay)). The results are compared with DCBRP, TSCP and Grid-PEGASIS.

Table 4.1: Simulation Parameters.

PARAMETERS	DETAILS
Topology	Grid size (9 × 10)
Sensor Nodes Type	Homogenous
Number Of Sensor Nodes	90
BS Location Coordinate	(50,120)
Initial Energy	2.0 J
Packet Size	1024 bit
Deployment Methods	Deterministic
Distance Between Adjacent SNs	10 m
Energy Channel	Symmetric for the energy required in transmission from A to B is the same as from B to A.
Energy to Open the Electronic Circuit (E_{elec})	50 nJ/bit
(ε_{fs})	10 pJ/ bit/m^2
(ε_{mp})	100 pJ/bit/m^2

4.4 ETSRP Performance Evaluation

The performance metrics are used to evaluate the performance of ETSRP with the Grid-PEGASIS, TSCP and DCBRP. The results of performance metrics computed until First Node Die (FND). Many researchers such as [102], [103] used this parameter to compare their results. This is because after the first node dies, the topology will be different from what made before, and the connection between SNs will be wrong and not give a good performance in the next round.

4.4.1 End-to-End Delay

Chain-Based routing protocols have a main drawback, namely, delay. To calculate the delay time in each round, the End-to-End Delay metric is most important in equation (4.1). The delay in transmitting and receiving the packets depends on the number of chains or clusters and the way of connection between SNs.

$$End - to - End\ Delay_r = \sum_{packet=1}^{last\ packet} (Time_{Resived} - T_{transmit}) \qquad (4.1)[46],$$

Average Delay: The average delay is calculated by dividing the total delay in each round until first node die (FND) by the number of packets that is equal to 90 packets in equation (4.2).

$$Average\ Delay = \frac{\sum_{r=1}^{r=FND} End\text{-}to\text{-}End\ Delay_r}{Number\ of\ packets} \qquad (4.2)\ [46],$$

The election of CHs depends on the energy remaining and the distance between the SNs and BS. The End -to- End Delay in DCBRP in round (1861) where FND is (0.0413291), in Grid-PEGASIS in round (171) is higher (0.306484) and in TSCP (0.105456) in round (652).

But in ETSRP without NoC is much less (0.0233239) where FND in round (1567). Figures (4.1) show the End -to- End Delay metrics results.

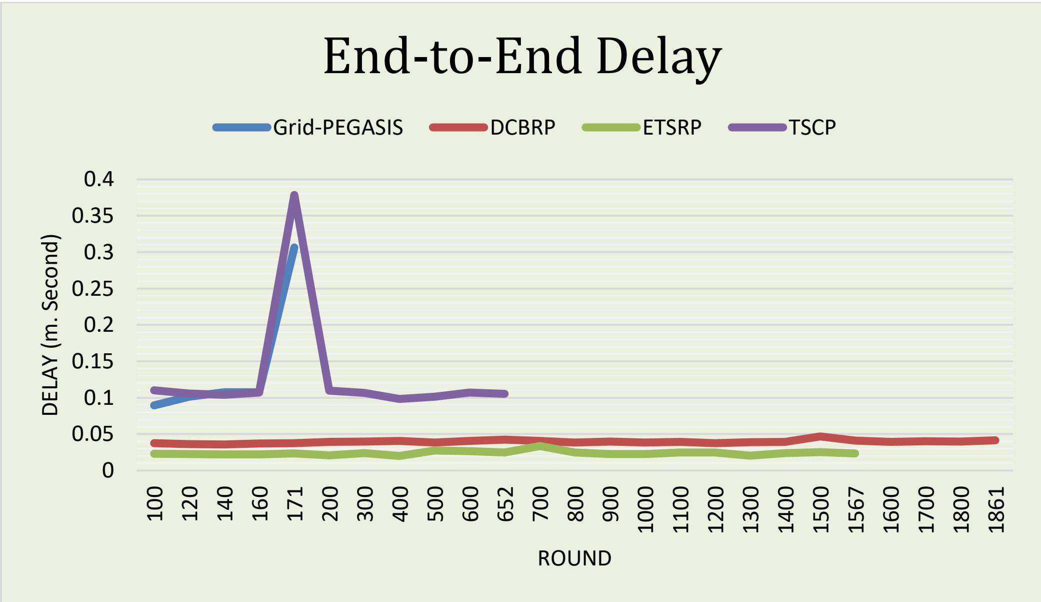


Figure 4.1: End-to-End Delay Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP.

Adding the parameter of number of connections in sensor nodes to the CHE mechanism has several effects. First, the FND in ETSRP-Noc in round (1614), that is, the nodes that have a higher number of connections will be elected many times as CHs in the same cluster, this will cause more energy consumption in it, but the energy remaining parameter will affect to improve on reducing of election the same Cluster Head many times.

The End -to- End Delay in ETSRP-NoC shows lower results than in DCBRP, TSCP and Grid-PEGASIS as demonstrated in figure (4.2). The results are (0.306484) in round (171), (0.105456) in round (652), (0.0413291) in round (181) and (0.0215624) in round (1614) for Grid-PEGASIS, TSCP, DCBRP and ETSRP-NoC respectively.

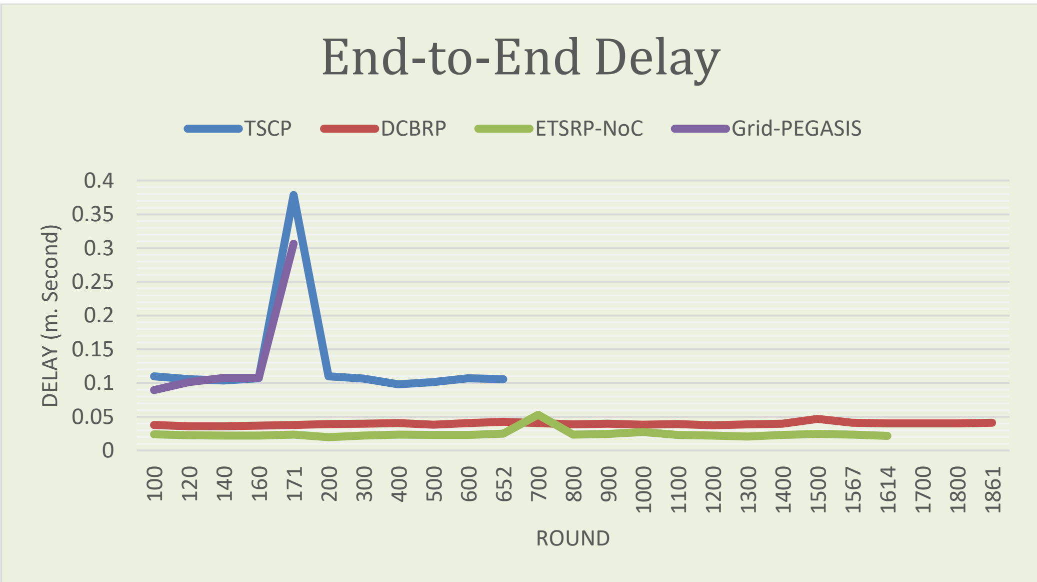


Figure 4.2: End-to-End Delay Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP-Noc.

4.4.2 Total Energy Consumption

Energy consumption is a very important metric that shows the energy spent in each SN in each round as clarified in equation (4.3).

$$Total\ E.Cosnsumption_r = \sum_{n=1}^{no.Nodes} E_{consumption\ in\ node\ (i)} \quad (4.3)[26],$$

Because of the energy constraints of SNs batteries, energy consumption is a significant barrier in these networks and should be avoided to enhance the lifetime of WSNs. Many researchers have proposed and developed routing protocols with different mechanisms that will increase the network life span and reduce the energy depletion in each SN, the results show the network life time for each routing, the energy consumption and in which rounds is the FND as demonstrated in figure (4.3).

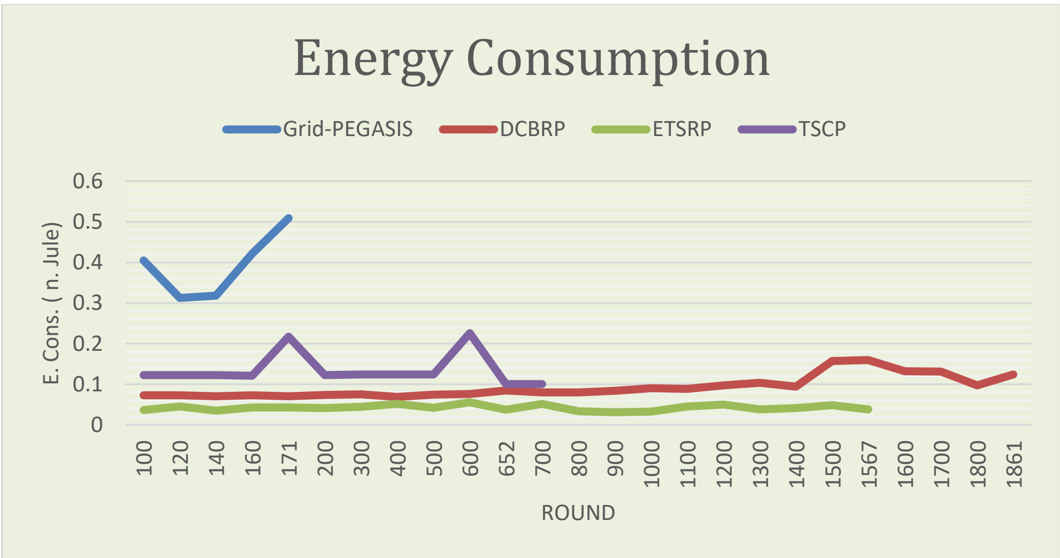


Figure 4.3: Total Energy Consumption Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP.

The election of CHs in each cluster by adding the parameter NoC, effect by election the CH that has highest energy remaining amount and highest number of connections that prolong the network life time more without NoC parameter, the results shown in figure (4.4).

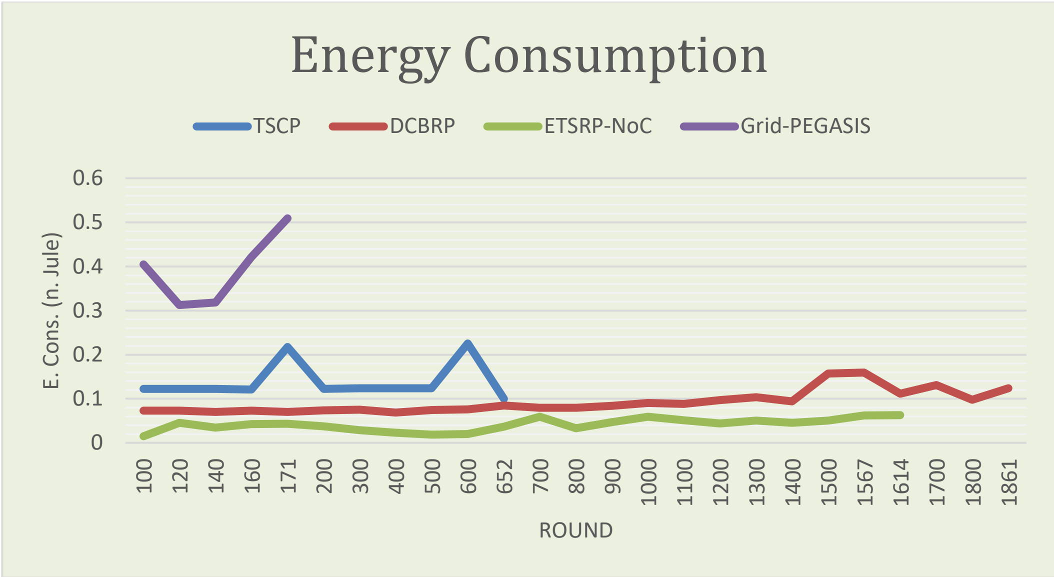


Figure 4.4: Total Energy Consumption Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP-NoC.

4.4.3 Average Energy Consumption

Until first node dies (FND), the summation of all Energy consumption is divided by 90 packets as in equation (4.4).

The ETSRP gives less energy consumption caused by the connection method between the SNs in each cluster which is next hop connection, that depends on the energy and distance, by elect the responsible SN has higher energy remaining to gather the packets from upper SNs row in each cluster and then deliver them to CH. The results shown in figure (4.5) and first node dies in round (1567).

$$Average\ E.Consumption = \sum_{r=1}^{r=FND} \frac{Total\ E.consumption}{number\ of\ packets} \qquad (4.4)[26],$$

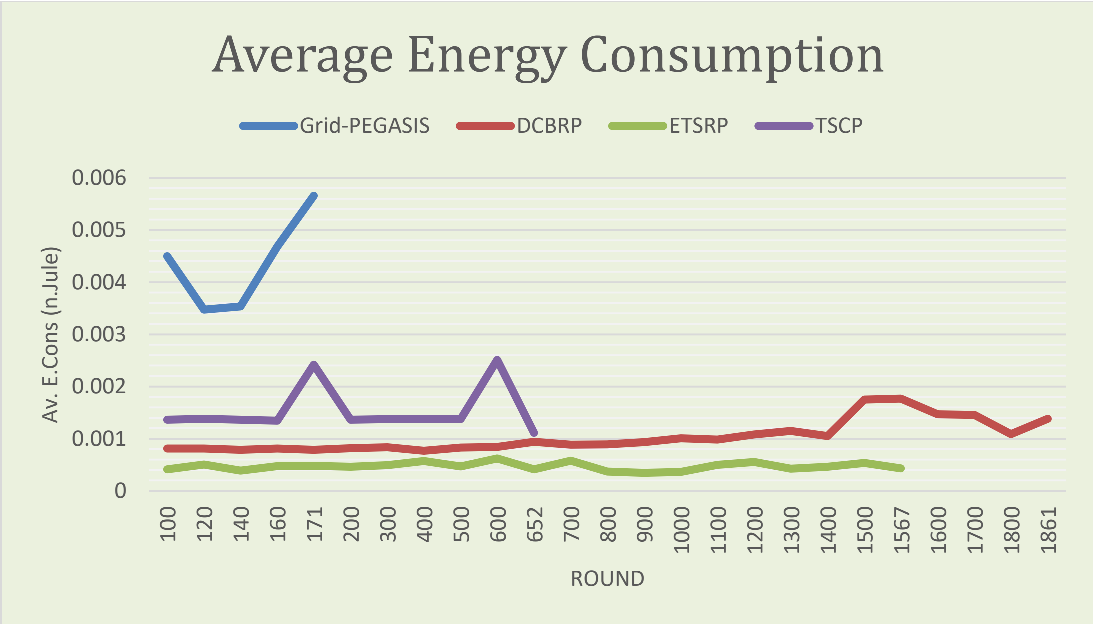


Figure 4.5: Average Energy Consumption Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP.

The results in figure (4.6), shows that ETSRP-NoC deplete less energy than Grid-PEGASIS, TSCP and DCBRP and extend the network lifespan where the first node die in round (1614).

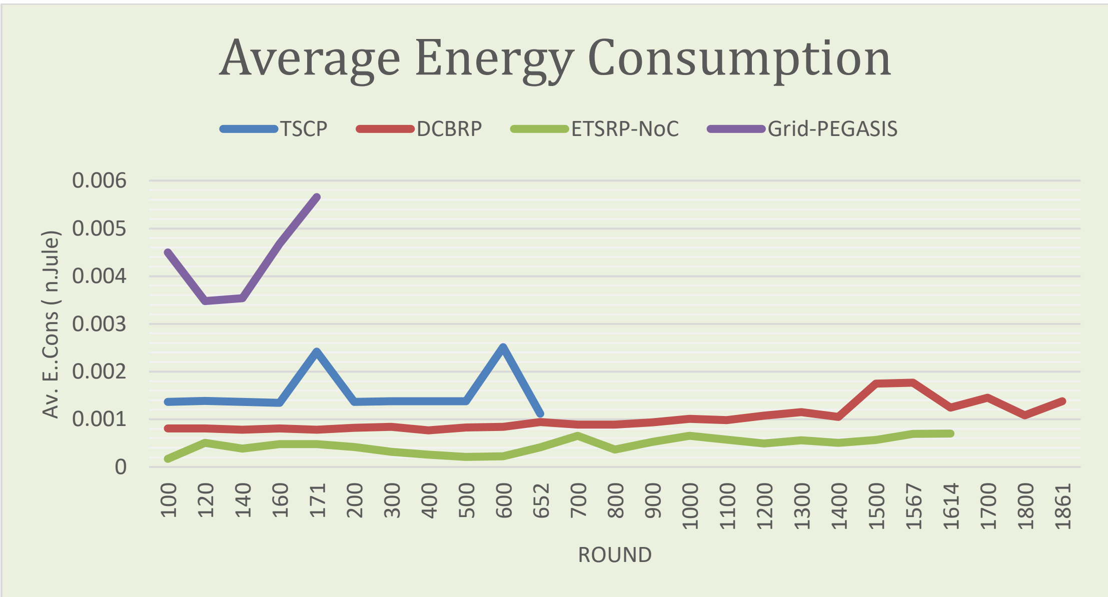


Figure 4.6: Average Energy Consumption Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP-NoC.

4.4.4 Average Cluster Heads Energy Consumption

To save the energy consumption in each SN, CHE methods are proposed, depends on the distance, remaining energy and number of connections. Equation (4.5) shows the Average of all CHs power consumption until FND by the number of elected CHs in network.

$$Average\ CHs\ E.consumption = \frac{\sum_{i=1}^{i=FND} E\ consumption\ of\ CHs}{number\ of\ CHs} \quad (4.5)[26],$$

The number of chain heads or cluster heads which are responsible for gathering all packets and send them to the BS affects the network life time. The energy spent by CHs can be calculated by the performance metric CHs Power Consumption. The figure (4.7) shows the results of the energy consumption of each CH in routing protocols.

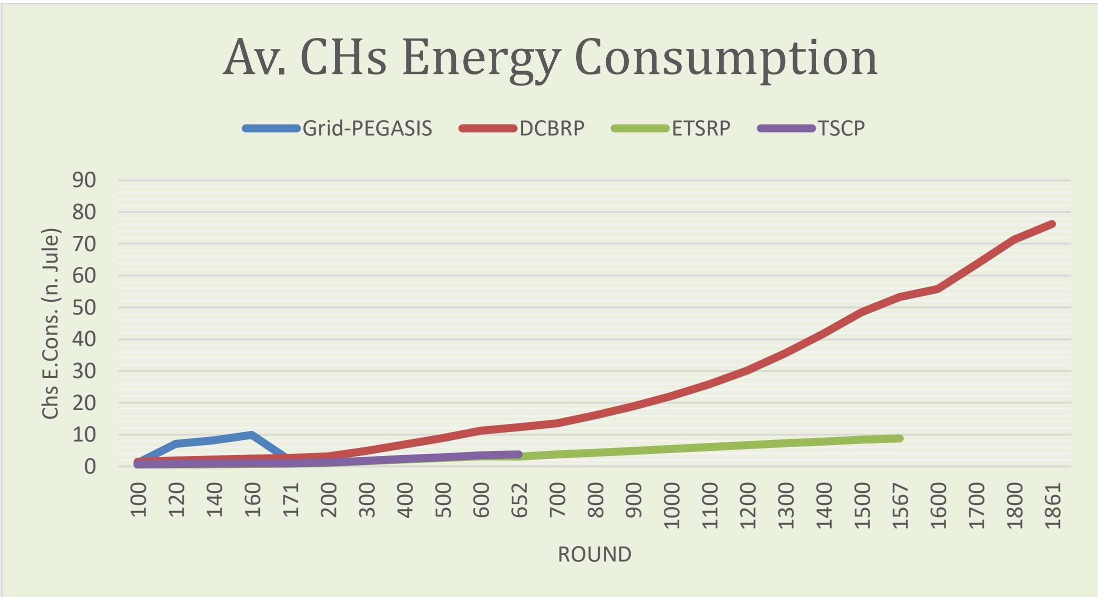


Figure 4.7: Average CHs Energy Consumption Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP.

The number of chain heads in DCBRP is three. It has a higher value in the rounds of simulation where the CH is responsible for gathering 30 packets from 30 nodes and delivering them to the BS. This causes more energy consumption. In ETSRP, the cluster heads are equal to the number of the clusters, they are 6 both. Each CH has to gather 15 packets from 15 nodes in one cluster and deliver them to the BS directly in a single hop. This causes less energy consumption than in DCBRP.

In round (652), TSCP has CHs energy consumption equal to (3.76945), lower than DCBRP which has (12.3829) in the same round. ETSRP shows lower results than them equal to (3.06496).

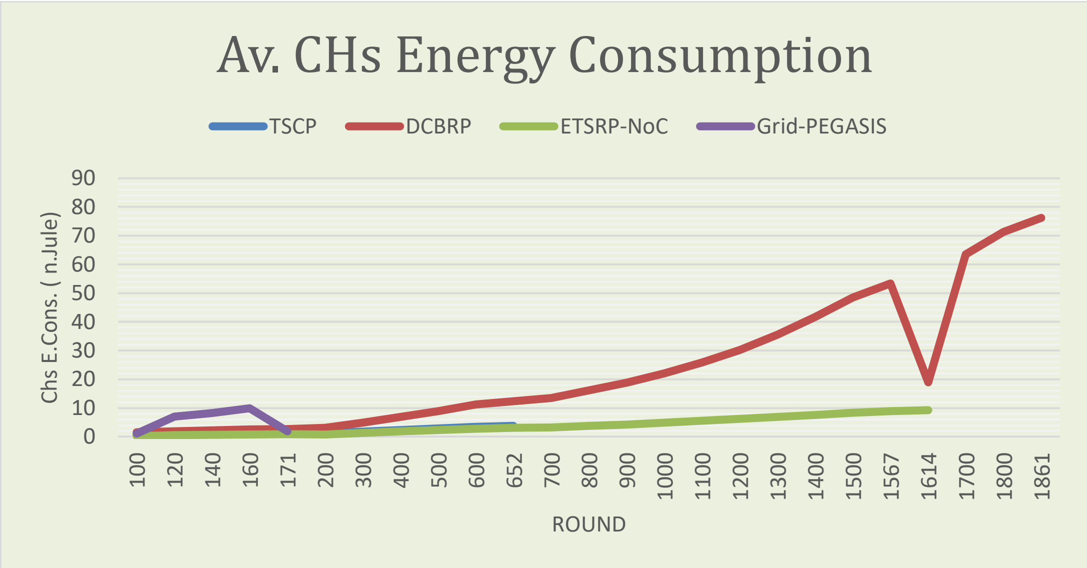


Figure 4.8: Average CHs Energy Consumption Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP-NoC.

In round (171), TSCP has CHs power consumption equal to (0.977715), lower than that in DCBRP which is (2.68244) in the same round. ETSRP-NoC shows lower results equal to (0.860547) as displayed in figure (4.8). Table (4.2) shows the results in round (171).

4.4.5 Energy × Delay

This metric was used for the first time by [104]. Delay and Energy are the most important effects on Chain-Based routing protocols. Equation (4.6) compacts the effect of both metrics.

$$Energy \times Delay = \ Total\ E.Cosnsumption_r \times End - to - End\ Delay_r \quad (4.6)[23],$$

The Energy×Delay metric is used by many researchers such as [23], [26], [94], [104], [105]. This metric gives better results. Where delay affects the energy results, this metric gives different results that can compared with the other. Figure (4.9) shows that DCBRP and Grid-PEGASIS have higher results than ETSRP and TSCP. In round (171), the result of Energy×Delay is (0.00186927) for ETSRP without NOC, (0.00511328) for DCBRP, (0.000914915) for TSCP and Grid-PEGASIS has (0.0917009). Figure (4.10), however, shows different results affected by the number of nodes and FND in each routing protocol. It gives us different values. In the rounds where FND, the results are (0.0010189), (0.00000130425), (0.00115481), and (0.000181852) for Grid-PEGASIS, TSCP, DCBRP, and ETSRP without NoC respectively.

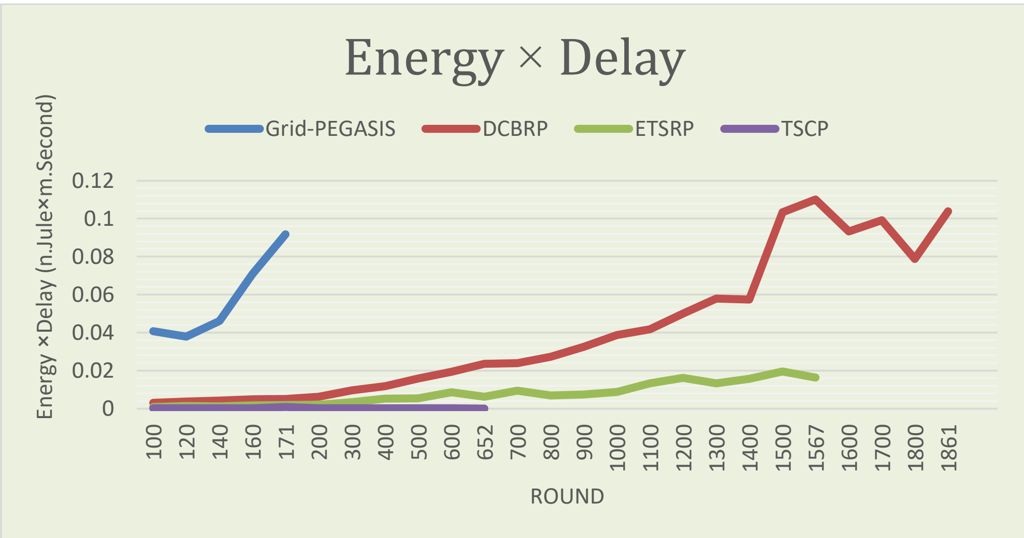


Figure 4.9: Energy×Delay Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP

Figure (4.9) shows that DCBRP and Grid-PEGASIS have higher results than ETSRP and TSCP affected by the energy value. In round (171), the Energy×Delay result is (0.00186927) in ETSRP-NOC, (0.00511328) in DCBRP, (0.000914915) in TSCP, and (0.0917009) in Grid-PEGASIS. While in figure (4.10), the results are (0.0010189), (0.0000101657), (0.0000568142), and (0.0000207697) for Grid-PEGASIS, TSCP, DCBRP, and ETSRP- NoC respectively.

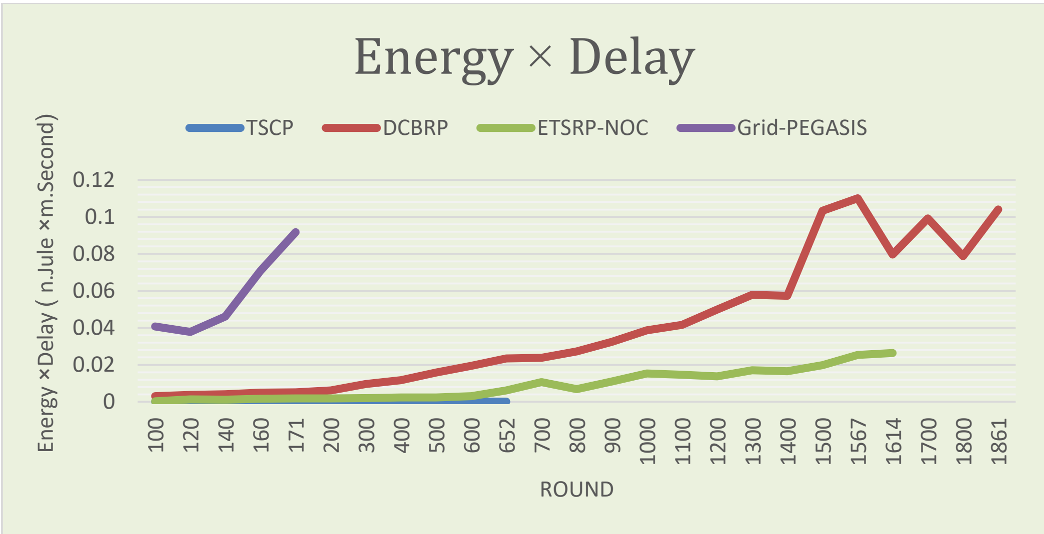


Figure 4.10: Energy×Delay Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP-NoC

4.4.6 Average (Energy×Delay)

The two metrics can be calculated to evaluate the performance of the ETSRP routing protocol by multiple the effect of Average Delay and Average Energy consumption until first node die as in equation (4.7).

$$Average\ (Energy \times Delay) = \ Average\ Delay \times \ Average\ E.Consumption \quad (4.7)[105],$$

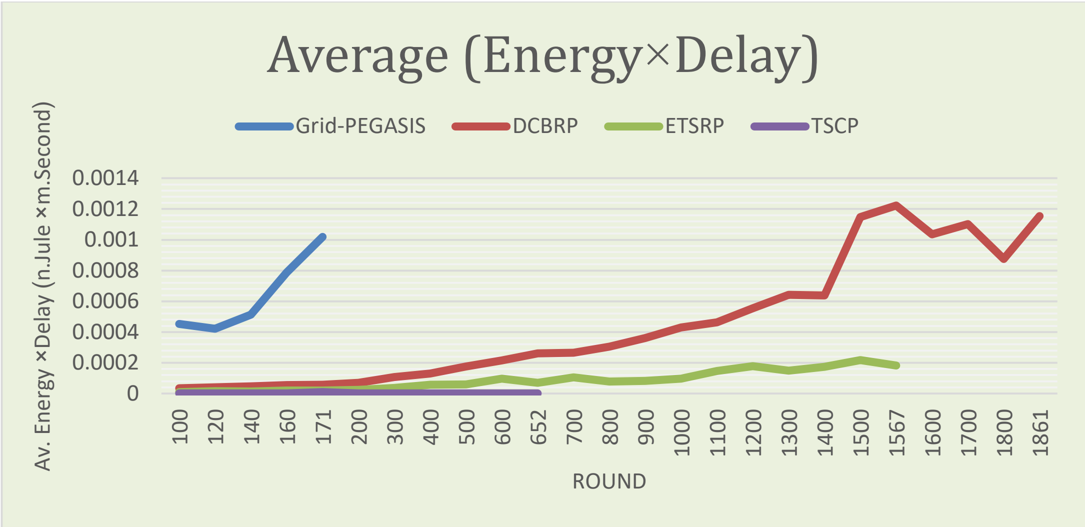


Figure 4.11: Average (Energy×Delay) Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP.

In figure (4.11), ETSRP has (0.0000207697) and with NoC is (0.0000207697), that results less than DCBRP and Grid-PEGASIS, but TSCP shows lower results than all other protocols effected by the number of Chain Heads (CHs) in figure (4.12). Table (4.2) explain the results of performance metrics for ETSRP, TSCP, Grid-PEGASIS and DCBRP in round (171).

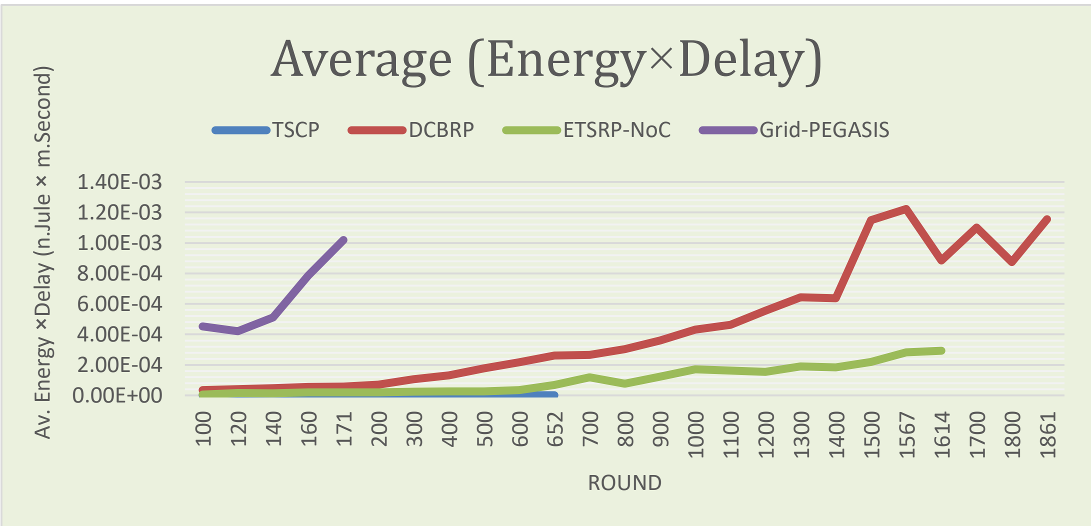


Figure 4.12: Average (Energy×Delay) Metric with Grid-PEGASIS, TSCP, DCBRP and ETSRP-NoC

Table 4.2: The Simulation Results of ETSRP.

Routing protocol	E-to-E Delay	T. Energy consumption	Av. Energy consumption	CHs Energy consumption	Energy × Delay	Av. (Energy × Delay)	FND
TSCP	0.37859	0.217498	0.00241664	0.977715	0.000914915	0.0000101657	652
DCBRP	0.037626	0.0705638	0.000784043	2.68244	0.00511328	0.0000568142	1861
Grid-PEGASIS	0.306484	0.509102	0.00565669	1.86025	0.0917009	0.0010189	171
ETSRP	**0.0233989**	**0.0431411**	**0.000479346**	**0.860547**	**0.00186927**	**0.0000207697**	**1567**
ETSRP-NoC	**0.0233989**	**0.0431411**	**0.000479346**	**0.860547**	**0.00186927**	**0.0000207697**	**1614**

4.5 Simulation Requirements

Every simulator program needs a specific hardware requirement. The device specifications used in this work have core-i7 with 1.80GHz – 2.30GHz processor and 20.0 GB RAM. The VMware allocated more than 8 GB memory and with one tera HDD and 250 GB SSD of two hard disk.

4.5.1 Ubuntu

The use of the Linux operating system is increasing in the research area although it is limited in personal computers. In this study, the operating system used is Ubuntu Linux as a visual image installed on VMware workstation v.16 Pro. The first version of the Ubuntu operating system was Ubuntu version 4.0 released in 2004. Ubuntu releases a new version every 6 months. The Long Term Support (LTS) version was released with a support timeframe of five years[106][107]. The version of Ubuntu used in this research is Ubuntu16.04 LTS.

4.5.2 Eclipse Platforms

Providing a well-organized and secure platform for vendors of commercial tools is one of Eclipse's main objectives. Furthermore, the Eclipse foundation never stops trying to lower barriers to license the platform for commercial use. C, C++, Java, and other source language development are supported by the Eclipse platform, which is very extendable. The Eclipse C/C++ Programming tool is the name of the C/ C++ development environment. There are many libraries needed to be installed for Eclipse to work with Ubuntu Linux depending on the Ubuntu version.

4.5.3 The NS-3 Simulator

NS-3 is an open computer network simulation environment based on discrete-event simulation. Each event in such a simulator is connected with its execution time, and the simulation continues by executing events in the temporal sequence of simulation time. Events are consumed while the simulation runs, although new events may (or may not) be created.

When there are no more events in the event queue, or when a specific "End" event is identified, the simulation will stop automatically[108][109][110]. To run and execute the simulation and routing structure, the animation program required in NS-3.22 is NetAnim-3.105 version. NS-3 is a powerful simulation program that builds the components of network, deals with them as real parts with protocol layers and communicates with the nodes as devices through internet addresses (IP). The layers are programmed in C++ in Eclipse for each sensor node as instruction lines which are YansWifiChannelHelper, WifiHelper, NqosWifiMacHelper, NetDeviceContainer, Ipv4AddressHelper, and set the Ipv4GlobalRoutingHelper at last to guarantee the connection with the nodes. MAC layer of the wireless sensor network application followed one of the IEEE standards (802.11).

4.6 Summery

The sensor nodes are deployed in pre-define way over the sensing area with ten-meter distance between each adjacent node. The distance and number of nodes in each cluster effect on the energy consumed by each cluster head. The outcomes of performance metrics for all routing protocols are taken in round (171) where the FND of Grid-PEGASIS, the End-to-End Delay in ETSRP is reduced compared to other routing protocol. The energy consumed by CHs are variant between the protocol depends on number of cluster heads or chain heads elected, In ETSRP the CHs power consumption is (0.860547) because of using next hop connection instead of chains with multi-hop.

CHAPTER FIVE:

CONCLUSIONS AND FUTURE WORK

5.1 Overview

The goal of this work is to improve WSN transmission time through building a Cluster-Chain routing protocol for a pre-define deployment of sensor nodes in WSNs. In addition, this study compares the performance evaluation of the ETSRP routing protocol with other protocols.

This chapter provides the conclusion of the research phases and objectives, as well as future work for other researchers in sections (5.2) and (5.3) respectively.

5.2 Research Conclusions

This research reviews in chapter two the previous studies that use various topologies to improve the routing techniques in WSNs. The routing protocols that used different topologies with the same networks have more efficient performance than others depending on deployment methods and applications. ETSRP uses pre-define (grid) methods to deploy sensor nodes used in many applications. Therefore, the main contribution of ETSRP can be summarized in three phases. The first phase is the Cluster-Chain Formation Mechanism (CCF) used to divide the networks into six clusters. The NHC mechanism is used to communicate with cluster sensor nodes depending on the distance and remaining energy parameters. The second phase is Cluster Head Election (CHE). It is used to elect the Cluster Heads in each cluster depending on energy remaining, distance and number of connections to reduce the delay in transmitting data from SNs to the BS. The last phase is the Inter-Connection Method.

It is the connection of CHs with the BS that reduces the delay through electing the suitable CH with a maximum number of connections in addition to the consideration of energy level and distance from the BS. Therefore, the main objectives of ETSRP are:

i. Chain-Based routing protocols seem interesting in WSN applications although the delays are a major issue for packet delivery and duplication.
ii. Clustering the WSN area into groups of SNs and improving the DCBRP performance.
iii. Reducing the delay and power consumption in CHs nodes and lowering the number of nodes in the same chain by dividing it into clusters.
iv. ETSRP outperforms DCBRP, TSCP, and Grid-PEGASIS in the performance metrics and the results of the simulation.

5.3 Future Work

This study proposes a distinct idea that may be developed by other researchers to come up with a new improved routing protocol. It suggests a mixed topology, reducing delay and energy consumption. The following are some useful guidelines:

i. Devising routing protocols with random deployment methods that use the number of connections after clustering the area of WSN using AI algorithms.
ii. Changing the base station (BS) location in each round, which can give a better-improved performance used in other applications.
iii. Using Machine Learning techniques to elect the head nodes in the network.

iv. Proposed an algorithm to make the WSNs more scalable in pre-define deployment method using NS-3 simulator.

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الخُلاصَة

شبكة المتحسسات اللاسلكية تتكون من المئات او آلاف من أجهزة المتحسسات المحدودة الموارد والتي تملك العديد من القيود التي تؤثر على أداء الشبكة. المفهوم الأكثر أهمية في شبكة المتحسسات اللاسلكية هو طريقة تسليم البيانات المجمعة من اجهزة الشبكة الى المحطة الرئيسة (المستلم). وهذه تسمى تقنية التوجيه. بنية التوجيه الهرمية هي أكثر البنى استخداما من قبل العديد من الباحثين. ولكل من بنية السلسلة وبنية التجميع عدد من نقاط الضعف. ولبناء بروتوكول كفؤ، اتجه اهتمام الباحثين الى تقليل التأخير الحاصل في تسليم حزم البيانات بقدر الإمكان، لذا من المهم ابتكار بروتوكول كفؤ. في هذا البحث تم تقديم بروتوكول يستخدم تقنية دمج بين نوعين من البنى وهي التقسيم الى مجاميع والسلسلة. واستخدام طريقة نشر أجهزة الاستشعار بمسافات ثابتة عن بعضهم البعض. البروتوكول المقترح يدعى بروتوكول توجيه فعال وحساس للوقت في شبكة المتحسسات اللاسلكية (ETSRP). وله ثلاث آليات: الأولى تشكيل مجاميع من السلاسل، وآلية اختيار الجهاز الرئيسي، وآلية الاتصال مع المحطة الرئيسية (المستلم). المعاملات الأساسية المستخدمة لاختيار الجهاز الرئيسي المسؤول عن تسليم كل حزم البيانات الى المستلم هي المسافة والطاقة المتبقية وعدد الأجهزة المتصلة مع كل جهاز. تمت مقارنة أداء البروتوكول ETSRP مع ثلاث برتوكولات وهي Grid-PEGASIS وTSCP وDCBRP بالاعتماد على برنامج المحاكاة المستخدم هو NS-3 و مقارنة نتائج أداء ETSRP مع بقية البروتوكولات تمت باستخدام مقاييس وهي End-to-End Delay وPower consumption و CHs power Consumption وFirst Node Die وDelay×Energy. نتائج المحاكاة أظهرت بانه ETSRP أفضل من ناحية التأخير حيث كانت النتائج بدون ومع NoC مساوية الى (0.021), بينما نتائج المحاكاة للتأخير في ارسال حزم البيانات لكل من DCBRP وTSCP وGrid-PEGASIS هي بالترتيب (0.036) و (0.99) و (0.085). ETSRP يمكن استخدامه في العديد من التطبيقات لزيادة سرعة تسليم البيانات مثل المدن الذكية و الزراعة وتحسس البيئات.

جامعة كربلاء
كلية علوم الحاسوب وتكنولوجيا المعلومات
قسم علوم الحاسوب

بروتوكول توجيه فعال وحساس للوقت في شبكة المتحسسات اللاسلكية

رسالة ماجستير
مقدمة الى مجلس كلية علوم الحاسوب وتكنولوجيا المعلومات / جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في علوم الحاسوب

كتبت بواسطة

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1444 هـ **2023 م**