Sudan University of Science and Technology
College of Graduate Studies

A Proposed Double Cluster Head Routing Protocol for Wireless Sensor Networks

بروتوكول توجيه مقترح ذو رأس مزدوج للعنقود لشبكات المحسسات اللاسلكية

A thesis Submitted in Partial Fulfillment of the Requirement for the Degree of M.Sc. in Electronics Engineering (Computer and Network Engineering)

Prepared By:
Hind Magdi Hamza Baldo

Supervisor:
Dr. Ebtihal Haider Gismalla Yousif

December 2018

الإستهلال

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

وَيَسْأَلُونَكَ عَنِ ٱلرُّوحِ ۖ قُلِ ٱلرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا أُوتِيتُمْ مِّنَ ٱلْعِلْمِ إِلَّا قَلِيلًا

سورة الإسراء، الآية ٨٥

Dedication

This Thesis is dedicated to my beloved parents, who have been a source of inspiration and gave me the strength and support needed.

To my family and friends who shared their words of advice and encouragement to finish this study.

Acknowledgments

I would like to express my thanks of gratitude to Dr. Ebtihal Haider as well as Dr. Sami Hassan who gave me the golden opportunity to do this thesis. I would also like to thank my family and friends who helped me during the Masters programme and in finalizing this project.

Abstract

A wireless sensor network (WSN) is a collection of hundreds to thousands of compact, battery-operated sensors. They are developed to gather useful information from the nearby environment. Depending on the type of application, the sensors have to work for months to years with finite energy resources. In some extreme environments, the replacement of energy resources is challenging and sometimes not possible. Therefore, it is vital for sensors to perform their duties in an energy efficient way to improve the durability of the network. This thesis proposes an energy-efficient centralized cluster-based routing method. This routing method uses a two-level hierarchy of cluster heads to use the energy of sensors efficiently and to cut back the frequency of the cluster formation. The performance of this method is compared with that of the Low-Energy Adaptive Clustering Hierarchy Protocol (LEACH). The simulation results show that the proposed protocol outperforms that of its comparative by 15 percent in terms of network lifetime, 12.5 percent in overall energy consumption,and 15 percent in throughput and efficiency.

المستخلص

شبكة المستشعر اللاسلكية هي عبارة عن مجموعة من مئات إلى آلاف من أجهزة الاستشعار المدمجة التي تعمل بالبطارية. تم تطويرها لجمع معلومات مفيدة من البيئة المجاورة. اعتمادا على نوع التطبيق ، يجب أن تعمل أجهزة الاستشعار لأشهر إلى سنوات بمصادر طاقة محدودة. في بعض البيئات القاسية ، يكون استبدال موارد الطاقة أمرا صعبا وأحيانا غير ممكن. لذلك ، من الضروري أن تقوم المستشعرات بواجباتها بطريقة فعالة من حيث الطاقة لتحسين متانة الشبكة. تقترح هذه الأطروحة طريقة توجيه مركزية قائمة على كفاءة الطاقة. يستخدم هذا الأسلوب التوجيه التسلسل الهرمي من مستويين للرؤوس الكتلة لاستخدام طاقة أجهزة الاستشعار بكفاءة ولخفض وتيرة تشكيل الكتلة. ويقارن أداء هذه الطريقة مع أداء بروتوكول التسلسل الهرمي للتكتل منخفض الطاقة تظهر نتائج المحاكاة أن البروتوكول المقترح يتفوق على نظيره بنسبة ١٥ بالمائة من حيث العمر التشغيلي ، ١٢٠٥ بالمائة من حيث استهلاك الطاقة الكلي ، والإنتاجية والكفاءة.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

BS	Base Station
BCDCP	Base Station Controlled Dynamic Clustering Protocol
CDMA	Code Division Multiple Access
CH	Cluster Head
CHIRON	Chain-Based Hierarchical Routing Protocol
HEED	Hybrid Energy-Efficient Distributed Clustering
ID	Identifier
LEACH	Low Energy Adaptive Clustering Hierarchy
LEACH-B	Low Energy Adaptive Clustering Hierarchy(Balanced)
LEACH-C	Low Energy Adaptive Clustering Hierarchy (Centralized)
LEACH-E	Low Energy Adaptive Clustering Hierarchy (Energy)
LEACH-F	Fixed number of cluster Low Energy Adaptive Clustering Hierarchy
LEACH-I	Low Energy Adaptive Clustering Hierarchy Improved)
LEACH-K	Low Energy Adaptive Clustering Hierarchy (Kmedoids)
LEACH-L	Energy Balanced Clustering Algorithm Based on LEACH Protocol
LEACH-M	Low Energy Adaptive Clustering Hierarchy (Mobile)
LEACH-ME	Low Energy Adaptive Clustering Hierarchy (Mobile Enhanced)
LEACH-P	Low Energy Adaptive Clustering Hierarchy (Performance)
LEACH-S	Solar aware Low Energy Adaptive Clustering Hierarchy
LEACH-T	Threshold-based Low Energy Adaptive Clustering Hierarchy
LEBEERA	Load Balanced and Energy Efficient Routing Algorithm
MAC	Media Access Control
MEMS	Micro Electro-Mechanical Systems
PAN	Personal Area Network

PEGASIS	Power-Efficient Gathering In Sensor Information Systems
PSO	Particle Swarm Optimization
TDMA	Time Division Multiple Access
TREEPSI	Tree Based Energy Efficient Protocol for Sensor Information
USB	Universal Serial Bus
WSN	Wireless Sensor Network

List of Symbols

$T(n)$	Threshold
P	Cluster Head Probability
G	The set of nodes that were not cluster heads in the previous rounds
d_s	Crossover Distance
d_BS	Distance of the nearest sensor node to the base station
$E_(T,R)$	Transmission and Receive Energy
E_avg	Average Residual Energy
k	Number of bits
N_CH	Number of Cluster Heads
M	Sides of the deployment area
n_alive	Number of Alive Nodes
$W_(c)$	Weight Vector
$D_c(j)$	Distance of node from the centroid of the cluster
$S(c)$	Set of member nodes

Chapter one
Introduction

1.1 Overview

A wireless sensor network is a network that consists of small nodes with sensing, computation and communication capabilities. Special class of ad hoc wireless sensor networks are used to provide wireless communication infrastructure that allows to instrument, observe and respond to phenomena in the natural environment and in the physical and cyber infrastructure. Over the past few years sensor networks are being built for specific applications and routing is important for sending data from sensor nodes to Base Station (BS). Routing in sensor networks is a very challenging issue. Routing protocols should incorporate multi-path design technique. Multi-path is referred to those protocols which set up multiple paths so that a path among them can be used when the primary path fails.

With the recent advances in Micro Electro-Mechanical Systems (MEMS) technology, wireless communications, and digital electronics, the design and development of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate untethered in short distances have become feasible. The ever-increasing capabilities of these tiny sensor nodes, which include sensing, data processing, and communicating, enable the realization of wireless sensor networks (WSNs) based on the collaborative effort of a large number of sensors. WSNs have a wide range of applications and are slowly becoming an integral part of everyday lives. There is actual implementation and deployment of sensor networks tailored to the unique requirements of certain sensing and monitoring applications.

1.2 Problem Statement

WSN are divided into clusters with a single cluster head and multiple cluster members. The cluster members send their data to the cluster head which in turns transmits it to the base station. If a cluster head dies for any reason, the whole cluster is useless because the data of the member nodes will not reach the base station. Therefore the scalability is limited to some extent.

1.3 Proposed Solution

To implement a routing scheme in wireless sensor networks by modifying the LEACH protocol to achieve a secondary routing path to overcome the deficiency and improve the scalability.

1.4 Objectives

The objectives of this research are

- To overcome the deficiency in wireless sensor networks routing.
- To propose a routing scheme to improve wireless sensor networks scalability by introducing a secondary path that acts as a failover.

1.5 Methodology

A wireless sensor network simulation with a single PAN (Personal Area Network) was created using MATLAB simulation, this network included a single gateway node, multiple clusters each containing a single cluster head and cluster members. Data was then collected by cluster members and transmitted back to gateway nodes through cluster head nodes using LEACH protocol. Next a simulated scenario where a cluster head node is out of reach by the cluster members, the proposed protocol was applied to the network to determine an alternative path for the data to be transmitted from the cluster members to the gateway node/base station via a secondary cluster head. The two simulation results were gathered, compared and discussed to evaluate the performance of the two protocols.

1.6 Thesis Outline

Chapter one presents an overview of wireless sensor networks and the problems that will be addressed and a proposed solution. Chapter two focuses on the history and literature review of wireless sensor networks, routing protocols and their integration. Chapter three describes the methodology of work that will be conducted in chapter four. Chapter four presents the proposed routing scheme and evaluates the scheme's performance parameters and report the results. Chapter five summarizes the conclusions and recommendations for further work.

Chapter Two
Background and Literature Review

2.1 Introduction

A wireless sensor network can be defined as a network of devices that can communicate the information it gathered from a monitored field through wireless links. The data is forwarded through multiple nodes, and with a gateway, the data is connected to other networks. WSNs are wireless networks that consist of a number of nodes and a base station, they are used to monitor physical or environmental conditions like pressure, temperature and pass that data to a central location for processing.

2.2 Sensor Mote Platforms

WSNs are composed of individual embedded systems that are capable of

- Interacting with their environment through various sensors
- Processing information locally
- Communicating this information wirelessly with their neighbors.

A sensor node typically consists of three components and can be either an individual board or embedded into a single system:

- Wireless modules or motes are the key components of the sensor network as they possess the communication capabilities and the programmable memory where the application code resides. A mote usually consists of a microcontroller, transceiver, power source, memory unit, and may contain a few sensors.
- A sensor board is mounted on the mote and is embedded with multiple types of sensors.

- A programming board, also known as the gateway board, provides multiple interfaces including Ethernet, WiFi, USB, or serial ports for connecting different motes to a network. These boards are used either to program the motes or gather data from them. [?]

The main tasks of WSNs are to sense and collect data from a given target, process that data and transmit it directly to the base station, but due to the required transmission energy which increases proportionally with the distance, this task is not feasible. Therefore another mechanism is introduced. Data is routed using multi-hop communication. This mechanism requires the introduction of an energy efficient routing protocol to define paths between the sensing nodes and the base station. This may result in several available routes, so a routing decision should achieve load balancing, end to end reliability and latency. It must also ensure that the lifetime of the network is maximized.

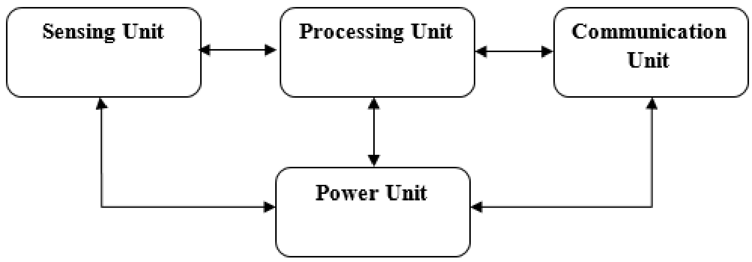

Figure 2.1: Block Diagram of a Sensor Node

2.3 Routing Protocols in WSN

The goal of routing protocols is to achieve end to end packet delivery; each protocol achieves this using a different approach. Routing paths can be achieved in one of three ways.

2.3.1 Proactive

In Proactive routing all the routes are computed in advance and maintain consistent up to date routing information from each node to every other node in the network. Every node in the network maintains one or more routing tables that store the routing information. This is also called table driven routing and is preferably used in applications where the sensor nodes are static.

Proactive routing protocols periodically monitor the changes in the topology to ensure the ready availability of any path amongst active nodes. When a topology changes due to the failure of nodes, the change has to be propagated throughout the network as updates so that the network view remains consistent. The protocols vary in the number of routing tables maintained and the method by which the routing updates are propagated. [?]

2.3.2 Reactive

In reactive routing, routes are discovered only when desired. This means that protocols don't make the nodes initiate a route discovery process until a route to a destination is required. Route discovery can be initiated either by source or destination. Source initiated routing means that it is the source node that begins the discovery process, while destination initiated is the opposite. Once a route has been established, the route discovery process ends and a maintenance procedure preserves it until the route breaks down or is no longer desired. The main disadvantage of reactive protocols is that significant amount of energy is expended in route discovery and startup.

2.3.3 Hybrid

Hybrid Routing combines characteristics of both reactive and proactive routing protocols to make routing more scalable and efficient. [?] Routing protocols in WNSs are classified based on network structure and protocol operation. Depending on the network structure, the routing protocols are divided into flat based routing (figure 2.2); hierarchical based routing and localization based routing. Generally, in flat-based routing, the same functionality is assigned to every node in the network. However, in hierarchical-based routing, the nodes play different roles in the network. In localization-based routing, the location information is used to adequately route the data. A routing protocol will be considered adaptive if it can adapt to the current network conditions and available energy levels. Depending on the protocol functioning, these can be classified as multi-path based routing, query based, negotiation based, quality of service based or coherent based. [?]

In this project we will consider hierarchical cluster based routing protocols.

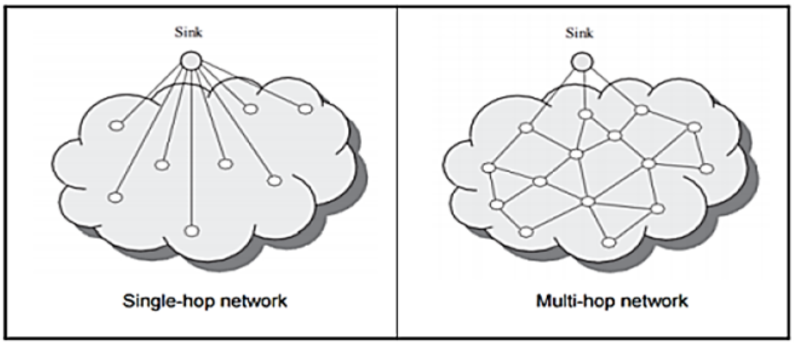

Figure 2.2: Flat Based Routing

2.4 Hierarchical Routing

Hierarchical or cluster based routing (figure 2.3), originally proposed in wireline networks, are well known techniques with special advantages related to scalability and efficient communication. As such the concept of hierarchical routing is also utilized to perform energy efficient routing in WSNs. In a hierarchical architecture, higher energy nodes can be used to process and send information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that the creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the base station. Hierarchical routing is mainly two layer routing where one layer is used to select cluster heads and the other layer is used for routing. [?]

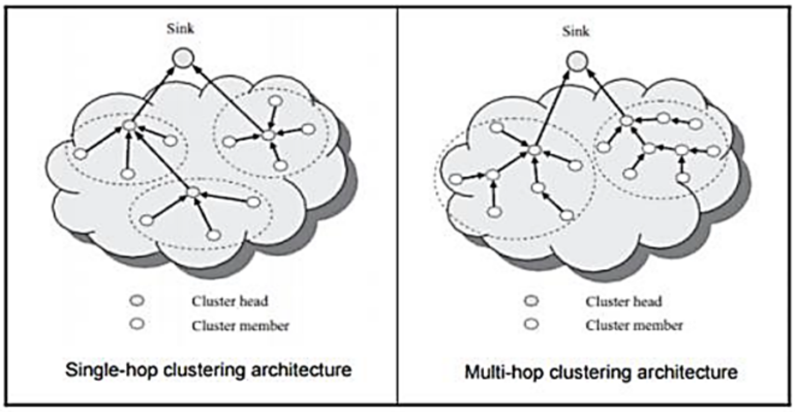

Figure 2.3: Hierarchical Cluster Based Routing

2.5 Cluster Based Routing Protocols Architecture

Energy aware routing and data transmission protocols which offer scalability and increase the lifetime of wireless sensor networks are required. This can be achieved by grouping sensor nodes into clusters. In a clustered network, sensor nodes are grouped together to form a cluster, each cluster consists of a number of nodes (member nodes) and a leader (cluster head). This results in a two tier hierarchy in which the cluster heads are the higher tier whereas the member nodes are the lower tier. In this scenario member nodes do not transmit their data directly to the base station, instead they have to transmit their data to the respective cluster head which in turn either sends the received data directly to the base station or through multi-hop transmission via other cluster heads. This results in the reduction of transmissions to the base station and in return minimizing the energy consumption. In this architecture the cluster heads consumes more energy in receiving, processing and transmitting data to the base station, so in order to balance the energy consumption, the network is re-clustered periodically. The base station is the collection center for the data and it provides the access to the end user. The base station is fixed and away from the sensor nodes. The cluster heads act as a gateway between the members of the cluster (sensor nodes) and the base station.

Ultimately, the clustering the network greatly minimizes number of communication to the base station, thereby increases the network lifetime. Figure 2.4 describes the architecture of a hierarchy cluster wireless sensor network.

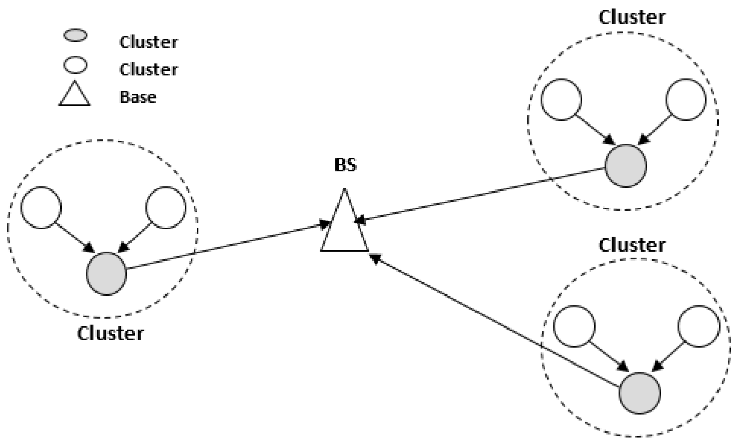

Figure 2.4: Hierarchy Cluster Wireless Sensor Network

2.6 LEACH Protocol

Heinzelman introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy. LEACH is a cluster based protocol, which includes distributed cluster formation. Leach protocol is a TDMA based MAC protocol to reduce inter-cluster and intra-cluster collision. It is the first protocol of hierarchical routing which proposed data fusion. The main aim of this protocol is to improve the life span of wireless sensor networks by lowering the energy. The Leach protocol consists of two phases, setup phase and steady phase. [**?**]. Leach protocol operation is made of several rounds, with two phases in each round; it is a self adaptive and self organized protocol.

2.6.1 Setup Phase

The main goal during this phase is to establish the cluster and select the cluster head of each cluster by electing the sensor node with the maximum energy. This phase has three primary steps.

1. Cluster head advertisement
2. Cluster set up
3. Creation of transmission schedule

During the first step, cluster heads send an advertisement packet to inform the cluster nodes that they have become a cluster on the basis of a given formula.

$$T(n) = \frac{P}{1 - P\left(rmodP^{-1}\right)}, \qquad \forall N \in G \qquad (2.1)$$

$$= 0 \qquad \forall N \notin G \qquad (2.2)$$

where n is a random number between 0 and 1, P is the cluster head probability, G is the set of nodes that were not cluster heads in the previous rounds and $T(n)$ is the threshold.

A sensor node becomes a cluster head for that round if the number is less than the threshold. Once a node is selected as a cluster head, it cannot become a cluster head until all the member nodes in the cluster have become cluster heads. This is to balance the energy consumption

In the second step, non cluster head nodes receive an advertisement from the cluster head and send a join request to the cluster head informing that they are members of the cluster under that cluster head. All non cluster head nodes save a lot of energy by switching off their transmitter all the time and turning it one only when have something to transmit to the cluster head. [**?**]

In the third step each of the cluster heads create a transmission schedule for the member nodes of their cluster. TDMA scheduling is created according to the number of nodes in the cluster. Each node then transmits its data to the respective cluster head.

2.6.2 Steady Phase

In this phase, cluster nodes send their data to the cluster head. The member sensors in each cluster can communicate only with the cluster head via a single hop transmission. Cluster heads combine all the collected data and forward it to the base station either directly or via other cluster heads. After a predefined time, the network goes back to the setup phase.

2.7 Advantages of LEACH Protocol

The various advantages of the LEACH protocol are:

1. The cluster heads aggregates all the data which leads to reduced traffic in the entire network.
2. Energy is saved as a result of single hop routing from member nodes to cluster heads.
3. Increased life time of the wireless sensor network
4. Location information of the cluster nodes is not required to form the clusters
5. Leach does not require control information from the base station nor does it require a global knowledge of the network.

2.8 Disadvantages of LEACH Protocol

Despite the many advantages of the LEACH protocol it has a number of disadvantages

1. The cluster heads are selected randomly, so the optimal number and distribution of cluster heads cannot be ensured.

2. Clusters are divided randomly, which results in uneven distribution of clusters.

3. One of the biggest challenges of the Leach protocol is that when due to any reason a cluster head dies, the whole cluster will become useless because the data gathered by the cluster nodes will not reach the base station.

This is the challenge we wish to overcome in this project.

2.9 Successors of LEACH Protocol

There are a number of successors to the LEACH protocol, three of which are detailed below

2.9.1 LEACH-B (Balanced)

This protocol is based on a decentralized algorithm of cluster formation in which each sensor node only knows its own position and the position of the final receiver, but the position of all the sensor nodes. It operates in three phases; cluster head selection, cluster formation and data transmission. Each sensor nodes selects its cluster head by evaluating the energy dissipated in the path between the node and the final receiver. Despite the cluster heads energy draining out quickly it still provides better energy efficiency to the network than the LEACH. [**?**]

2.9.2 LEACH-C (Centralized)

The first centralized routing protocol is the LEACH-C, it is basically the LEACH protocol using distributed cluster formation algorithm. Because the clusters are adaptive, the overall performance is not affected by the poor clustering setups during any given round. Opposite to LEACH, centralized LEACH can produce better performance by distributing the cluster heads throughout the network. During the setup phase, each sensor node sends its remaining energy and its location to the base station, the base station then executes a centralized cluster formation algorithm to determine the clusters for that round. This protocol requires less energy for data transmission because it can produce better clusters than the LEACH protocol because the base station has global knowledge of the location and energy of all the nodes in the network. [?]

2.9.3 LEACH-F (Fixed)

Fixed number of cluster Low Energy Adaptive Clustering Hierarchy. In this protocol, the cluster formation is done at the beginning of the network setup, and is fixed. It is like the LEACH protocol in that the cluster head position rotates within the cluster among the cluster nodes. It also uses a centralized cluster formation same as the LEACH-C. One advantage is that there is no setup overhead at the beginning of each round as in the LEACH, but in return it does not allow new nodes to be added to the network. [?]

2.10 Comparison of LEACH and its Successors for WSNs

LEACH protocol enhances the lifetime of a WSN and saves the energy by random rotation of cluster heads and assigns the TDMA schedule to each cluster member to avoid collision. Selection of cluster heads is random, even though LEACH improves energy efficiency but it does not work well in large coverage areas which need multihop transmission, does not support mobility, reliability, etc. To overcome these drawbacks, more efficient descendant of LEACH were developed. They are summarized in table 2.1. [?]

Table 2.1: Descendant of LEACH Protocols

LEACH	Clustering Method	Data Aggregation	Mobility Type	Scalability	Advantages	Disadvantages
LEACH	Distributed	Yes	Static	Limited	Load distribution in network	CHs are not uniform
LEACH-B	Distributed	Yes	Static	Good	Network lifetime increase	Overhead increase
LEACH-C	Centralized	Yes	Static	Good	Achieves more rounds in NW	Overhead on the BS
LEACH-E	Distributed	Yes	Static	Very Good	Improves CH selection	CH is always active
LEACH-F	Centralized	Yes	Static	Limited	Delay is small	Cover large region
LEACH-I	Distributed	Yes	Static	Very Good	Equally divide field	Periodically updates
LEACH-K	Distributed	Yes	Static	Good	Prolonged stability period	Needs load balancing
LEACH-L	Distributed	Yes	Static	Very Good	Balanced network load	Needs more storage capacity
LEACH-M	Distributed	Yes	Mobile	Good	Mobility of CH node	Overhead increase
LEACH-ME	Distributed	Yes	Mobile	Limited	Supports nodes mobility	Extra overhead
LEACH-P	Distributed	Yes	Static	Good	Increase network lifetime	Introduced extra overhead
LEACH-S	Centralized	Yes	Static	Very good	Power gain from solar	Centrally controlled
LEACH-T	Distributed	Yes	Static	Good	Reducing CH selection	CH based on threshold

All the above mentioned protocols do not solve the issue of a failing cluster head. The proposed solution will elect a secondary cluster head in an event where the primary cluster head fails, to ensure that the data gathered by the sensor nodes reach the base station and are processed.

2.11 Related Studies

Anastasi et al, [?], discussed the sensors under different communication aspects such as energy resources, localization, transmission cost and the communication capabilities. The network was formed to improve the network lifetime and life of the network nodes. It showed an improvement in the network life and the throughput by reducing the maintenance and the overheads. It also defined the synchronized protocol so that the overheads involved in establishing the communication will be reduced and the effective communication will be drawn over the network.

Shelby et al, [?], presents an agent based network architecture to control the communication under the mobility network. The work includes the network lifetime improvement so that the packet delivery ratio will be improved and the effective communication will be performed. The work includes the data delivery ratio and the delay analysis. The work also includes maintaining low infrastructure communication so that effective communication will be drawn over the network.

Camilo et al, [?], proposed a task management and analysis based network architecture so that the effective task oriented lightweight communication network will be established. Author also improved the network effectiveness in terms of management protocol.

Gandham et al, [?], presented a mobile network architecture so that the effective sink sensing will be performed and the energy effectiveness will be achieved under the cluster architecture. The important aspect of clustered network is to perform the routing scheduled queue so that effective path generation over the cluster will be performed.

Purohit et al, [?], presented an improved performance mechanism to achieve the synchronized communication under the realistic clustering architecture. Author defined some realistic and optimum schemes so that effective communication will be achieved over the network.

Slijepcevic et al, [?], has described uniform point process under a square or disk region so that the probability of the boundary effective communication is performed so that the network throughput will be improved.

In [**?**], Younis and Fahmy proposed that periodically select cluster heads according to a hybrid of their balance energy and a secondary guideline, such as node proximity to its neighbors or node degree. HEED does not make any supposition about the instance or quality of nodes. The clustering process complete in O(1) iterations, and does not trust on the network topology. The code of behaviors incurs low overhead in terms of processing cycles and messages interchange. It also achieves fairly different cluster head distribution. A caution selection of the secondary clustering guidelines can settle load among cluster heads.

Finally, the PSO approach is an evolutionary programming technique where a 'swarm' of test solutions, analogous to a natural swarm of bees, ants or termites, is allowed to interact and cooperate to find the best solution to the given problem [**?**]. It is a computational method that optimizes a problem by iteratively trying to improve a member of set. Function is used as a criterion for the optimization.

Chapter Three
Wireless Sensor Network Routing Scheme

3.1 Proposed Routing Scheme

This chapter will discuss the network model of the proposed protocol, the energy model and then a complete overview of how the model will work.

3.2 Background

Energy saving routing schemes for WSN can be well-classified using the logical topology used to organize nodes in the network. [?] An ideal efficient topology would minimize energy consumption, the possibility of the message loss and radio interference between nodes with enhancing the lifetime and scalability of the network. Furthermore, it should also deal with various aspects of managing cluster such as a cluster size and management of new and dead nodes. Based on the topology, WSN routing schemes can be classified as flat, chain-based, tree-based, and cluster-based routing. Flat routing schemes use message flooding to find the routes between nodes. Therefore, they cannot be considered as energy-saving schemes for WSNs. The following will discuss the major energy-saving routing schemes for WSNs.

3.2.1 Chain-Based Routing

The chain-based protocols set up chains to connect the sensor nodes with one another with the objective to minimize the energy consumption for the duration of data transmission. After the chain is formed, a random node is selected as the chain leader. The chain leader is responsible for transmitting the data to the BS. All other nodes forward their data to their successor node towards the BS. The successor node aggregates its data with the data received from the predecessor and then transmit it to its successor. This way data reaches the chain leader. At any time, the leader can receive data from two directions and therefore, it uses token passing arrangement to start the data transmission from the ends of the chain. [?] Examples for chain-based routing protocols are, Power-efficient gathering in sensor information systems (PEGASIS) [?], Load balanced and energy efficient routing algorithm (LBEERA) [?], and chain-based hierarchical routing protocol (CHIRON) [?]. LBEERA and CHIRON use multiple chains. LEBEERA uses a centralized protocol for chain formation.

3.2.2 Tree-Based Routing

Tree-based protocols set up a logical tree of sensor nodes. All the nodes send their data to their parent node. The parent node aggregates the data received from its children with its data and then transmit it to its parents. This way the data transmission proceeds from the end node to the root node (BS). TREEPSI [?] and Plus-tree [?] are tree-based routing protocols proposed for WSNs. The Plus-tree protocol stores alternative neighbor paths other than tree paths to transmit the data.

3.2.3 Cluster-Based Routing

Clustering techniques can be generally classified as distributed and centralized clustering based on who coordinates the cluster setup, the base station and the cluster heads.

In distributed clustering, the cluster head selection is done either at the individual node level or using neighbor coordination. The cluster head selection can be random or based on some predefined parameters such as residual energy, inter-cluster communication cost, distance from the base station, the number of neighbor nodes, and timer-based approach. The parameters can also be combined to get a trade-off between different parameters. Once the cluster heads get selected, they use a broadcasting message to send their status to the other nodes. The non-CH nodes join one of the cluster heads based on a cluster formation algorithm. The decision is based on minimum cluster distance to reduce inter-cluster communication cost, but in the case of a load-balanced cluster, the non-CH node may join a higher communication cost cluster head. The performance of clustering techniques highly depend on the CH selection and the way other nodes join a CH. The major drawbacks of distributed clustering are summarized

- Poor distribution of CHs; CHs may be placed in one area of the network.

- No control over the total number of CHs; Any node which passes the cluster head selection check becomes a cluster head.

In centralized clustering, the base station takes the responsibility of cluster formation. All the nodes send their location, energy, and ID information to the BS. The BS selects the optimum clusters after analyzing the information received from the nodes. It then broadcasts the information of all the clusters in the network. Upon receiving this information, each node finds its responsibility in the cluster by comparing its ID with the IDs of the selected cluster heads. If the node is a cluster head, it takes the responsibility of data aggregation and data transmission to the BS; otherwise, the node waits for its TDMA slot and goes to sleep until its transmission slot comes. LEACH-C [**?**] is a centralized cluster-based routing protocol. The BS runs simulated annealing optimization to determine the optimum clusters. After cluster formation, the BS broadcasts back the cluster information in the network, and then, data dissemination starts. BCDCP [**?**] is another centralized clustering protocol that uses cluster splitting for cluster formation and energy-aware minimum spanning tree of CHs for data dissemination. In BCDCP, CHs share the burden of sending data to the BS. In each communication round, a randomly chosen cluster head act as the leader for all other CHs. The other CHs communicate with the leader CH to reach the BS. In every setup phase of BCDCP, every node sends its energy information to the BS. BCDCP assumes that the BS keeps up-to-date information on location for all the nodes in the network. The major drawbacks of centralized clustering are summarized as

- High energy transmission over long distances in every communication round as each node sends it location, energy, and ID information to the base station.

- They are suitable for small networks because they assume that all the nodes can directly communicate with the base station which is not always true for larger networks.

One common problem with both centralized and distributed clustering is the frequency of the clustering formation. The setup cost increases as the clustering frequency increases. To overcome this problem, protocols use the concept of cluster head rotation. In the CH rotation technique, some of the communication rounds use clusters of their predecessor round with a new CH chosen among the cluster members.

Cluster head rotation may lead to new problems, for instance, if the new CH is rotated solely based on residual energy than it may increase transmission cost of some cluster members. It is possible that a new cluster head for the next round is located far away from a member node compared to other cluster heads. As a result, the node has to use the large communication energy CH, while the CH of another cluster is nearby.

3.3 Network Model

The following assumptions were used in the network model:

1. The sensors are randomly deployed. The BS is located in the middle of the field where sensors are deployed.
2. The physical location of sensors is known
3. All sensors are homogeneous: starting with the same initial energy, computational, and communication capabilities.
4. All sensors have a restricted energy source. Battery replacement and recharge are not possible after the deployment.
5. All sensors have a restricted sensing range but can adapt their transmission power depending on the transmission distance.
6. All sensors are sensing at a steady rate, and so they always have data to send.
7. Single-hop communication is used for inter-cluster and intra-cluster communication.

3.4 Energy Model

The following energy model was used to calculate the energy dissipation of a node while transmitting k bits for a d distance and receiving bits, respectively,

$$E_(T,R)(k,d) = K * E_elec + k * \varepsilon_f s * d^2 \quad \forall d < d_s \tag{3.1}$$

$$= K * E_elec + k * \varepsilon_m p * d^4 \quad \forall d \geq d_s \tag{3.2}$$

$$E_R(k,d) = K * E_elec \tag{3.3}$$

Whered_s is the crossover distance calculated as:

$$d_s = \sqrt{(}\frac{\varepsilon_f s}{\varepsilon_m p}) \tag{3.4}$$

3.5 Secondary ClusterHeadEnabled Centralized Clustering

Like all the clustering methods, the communication process is divided into a numerous number of rounds. Each round consist of a setup phase and data transmission phase. The main focus of this protocol is to reduce the overhead caused by the setup phase and establish a secondary routing path once the primary path has failed. This method helps to reduce the required energy to transmit necessary information for the setup phase to perform clustering operations. Each phase is described in detail below:

3.5.1 Setup Phase

The setup phase is not identical for all communication rounds. It differs based on whether the network has clusters or not.

3.5.2 Setup Phase with Zero Clusters

When the network has zero clusters, each alive node sends a control packet to the base station which includes its ID, location, and energy information. A dead node is a node with zero residual energy. The base station uses location and energy information for two different purpose—location information for cluster formation and energy information for cluster head selection. After receiving the status information from all the nodes, the base station divides the network into several numbers of clusters. The number of clusters is not fixed, and in every re-clustering, the clusters are changed. The total number of clusters is equal to the desired number of cluster heads which are calculated using the below formula

$$N_C H = \frac{M}{d_B S^2}\sqrt{(}\frac{\varepsilon_f s}{\varepsilon_m p})\sqrt{(}\frac{n_a live}{2\Pi}) \tag{3.5}$$

Where M is the sides of $M * M$ deployment area, is the distance of the nearest sensor node to the base station, and $n_a live$is the number of alive nodes. Initially, the value of $n_a live$ is equal to n. In each communication round, the protocol keeps track of alive nodes and updates the value of $n_a live$.

The base station uses k-means clustering with minimum distance criterion to minimize the within-cluster sum of squares for cluster formation. The base station divide the nodes of the network $N_CH$into clusters (k = N_CH) using (3.4). The base station calculates the Euclidean distance from each node to all centroids using the location information and assigns it to the centroid nearest to it. The performance of the k-means clustering depends heavily on the initial centroids. Poor initialization of centroids will produce poor clusters.

Initial centroids are selected using the k-means++ initial centroid selection method to avoid the poor distribution of centroids. k-means++ is an approximation algorithm for the NP-hard k-means problem. The algorithm starts by randomly choosing a centroid $C_0$from all nodes. For centroid C_i, the probability of a node n to be chosen as a centroid is proportional to its squared distance from its nearest centroid. k-means++ ensures the good distribution of cluster heads. After cluster formation, the base station does the following steps for each cluster C(c): c = 1,……., k

Step 1. Calculate the average node energy of each cluster using

$$E_avg(C(c)) = \frac{\sum j = 1^N E(i)_r}{N} \quad \forall j \in C(c) \tag{3.6}$$

Where $E_r(j)$ and $E_avg(C(c))$are the residual energy of the jthmember node and average cluster energy of $(C(c))$respectively.

Step 2. Select a set of member nodes,such that

$$E_r(j) > E_avg(C(c)) \tag{3.7}$$

Step 3. Calculate the average node distance from the centroid using

$$AND(C(c)) = \sum j = 1^N \frac{D_c(j)}{N} \tag{3.8}$$

Where $AND\ _(C(c))$ is the average node distance of cluster $(C(c))$from its centroid, $D_c(j)$ is the distance of jth node from the centroid of the cluster, and N is the total number of cluster members.

Step 4. Apply function F to each node of set $S(c)$ to obtain the weight vector $W(c)$.

$$W(c) = F(S(c)) = (\frac{E_r(j)}{E_max - E_r(j)})(\frac{2 *\ AND\ _C(c) - D_C(i))}{D_C(i)}) \tag{3.9}$$

Where $E_max$represents the maximum energy of a node at the time of deployment. The multiplicand part of (3.9) ensures that the energy-rich node is selected as the cluster head whereas the multiplier part ensures that the node which minimizes the intra-cluster communication cost is selected as the cluster head.

Step 5. Select three nodes from $S(c)$for which maximum weights are obtained in (c), to act as the primary cluster head and secondary cluster head, respectively. The remaining nodes become the normal member of cluster $(C(c))$.

Step 6. Create TDMA schedule of $(C(c))$ for data transmission.

Step 7. For the selected cluster heads of each cluster, construct a chain using a minimum spanning tree such that it minimizes energy consumption of each CH in transmitting data to the base station.

Step 8. Broadcast a control packet into the network which includes information of each cluster.

Step 9. Upon receiving this, each node compares its ID with the IDs of primary cluster head and the secondary cluster head to know its responsibility in the cluster.

(1)If primary cluster head, then the node takes the responsibility of data aggregation of received data from cluster members and transmits it to the base station. (2)If secondary cluster head, then the node goes into sleeping mode. (3)If the node is not any type of cluster head, then it fetches the ID of the corresponding cluster head along with the TDMA slot.

3.5.3 Setup Phase with Clusters

Each primary cluster head performs the following steps: Step 1. Each cluster head checks its residual energy after every communication round, and if it is less than or equal to ten percent of its initial energy (when handed the responsibility of the cluster head) it awakens the corresponding secondary cluster head. It then transfers its current state to the secondary cluster head such as IDs of all cluster members and neighbour(s) information along the cluster head chain.

Step 2. The cluster head becomes the common node of the cluster.

Step 3. The secondary cluster head becomes the new cluster head, creates the new TDMA schedule for the cluster, and broadcasts it to the cluster members.

Step 4. The secondary cluster head joins the chain of cluster heads by sending a message to neighbouring cluster heads.

Each secondary cluster head performs the following steps: Step 1. The secondary cluster head becomes the common node of the cluster.

Step 2. The secondary cluster head informs its members and neighbours along the chain of CHs about the need of re-clustering. Also, it asks its members, the neighbours, and their members to submit their current energy status.

Step 3. The neighbouring CHs also inform their members about re-clustering and ask them to submit their current energy status. After getting the re-clustering message, the member nodes submit their current energy status to the associated cluster head. After this, the member nodes forget the associated cluster and its head and become the un-clustered nodes. All the cluster head submit the current energy status of themselves and their associated members to the secondary cluster head who called for re-clustering and then become un-clustered nodes.

Step 4. The secondary cluster head then sends energy status of all the member nodes to the base station and becomes un-clustered node. Now the network is in zero cluster mode, new clusters will be formed; in addition to this, the number of clusters can also change because the value of n alive can change if some nodes are dead in the previous communication rounds. In intermediate communication rounds, any node does not directly transmit its energy information, if needed, to the base station. It sends it through cluster head or the secondary cluster head. Therefore, if any of them fails due to the lack of energy, then all its members will get isolated from the network.

3.5.4 Data Transmission Phase

The data transmission phase involves three sub phases, data collection, data aggregation, and data routing. During the data collection phase, each node sends its gathered data to the corresponding primary cluster head or secondary cluster head. Once data from all the cluster members is received, the cluster head aggregates the received data. The data is then transmitted to the base station. The protocol uses Code Division Multiple Access (CDMA) to reduce the radio interference caused by neighbouring clusters. A unique spreading code is assigned to each cluster to differentiate their cluster member's data from the neighbouring cluster member's data. The need of a random cluster that sends data to the base station is justified since the data transmission to the base station is an energy-intensive job. If we use the same node to carry out this task regularly, then it results in heavy and quick depletion of energy resources. Therefore, by randomizing the cluster head transmissions to the base station, distribution of the load of routing is even among all the cluster nodes. [**?**]

Chapter Four
Design, Implementation and Discussion

4.1 Introduction

This chapter will discuss the functional flow of the LEACH protocol and that of the proposed solution. It will also present the proposed design and the simulation of the two protocols, and finally it will compare the results of the two simulated designs on the basis of scalability and efficiency.

4.2 Design of the New Proposed Protocol

In the new proposed solution the cluster will consist of a primary cluster head, a secondary cluster head that will become active in the case of the primary cluster head failure and the member nodes. Each node will check its residual energy and determine whether it is a cluster head or member head, then transmission from cluster member to cluster heads will start according to the TDMA schedule broadcasted by the cluster head. A second transmission phase will now start from the cluster heads to the base station. If the cluster head fails the secondary cluster head will take the role and presume the data aggregation and transmission to the base station. The benefits of this arrangement are that the data collected by member nodes will have a higher percentage of reaching the base station, plus the increase in the overall lifetime of the network.

4.3 Flow Chart of the Protocols

The flow chart (figure 4.1) explains the steps each wireless sensor network takes in order to establish the network. The sensor node determines if it is a cluster head or a cluster member, if it is a cluster member then it awaits for the advertisement from the cluster head, if it is the same cluster head as before then it waits for the TDMA schedule, if not then it send a release message to the old cluster head and a join message to the new cluster head. The cluster head nodes send an advertisement message to the sensor nodes to form a cluster and awaits for the join message, it then creates a TDMA schedule for the cluster members. At this point the cluster has been established and the transmission of data can begin. Each cluster member sends it data to the cluster head according to the TDMA schedule, that data is aggregated at the cluster head and send either directly or via multi hop transmission to the base station. In the case that the cluster head is dead, a secondary cluster head takes the role of the cluster head and all data is transmitted to it from the cluster member and it in turn transmits the aggregated data to the base station.

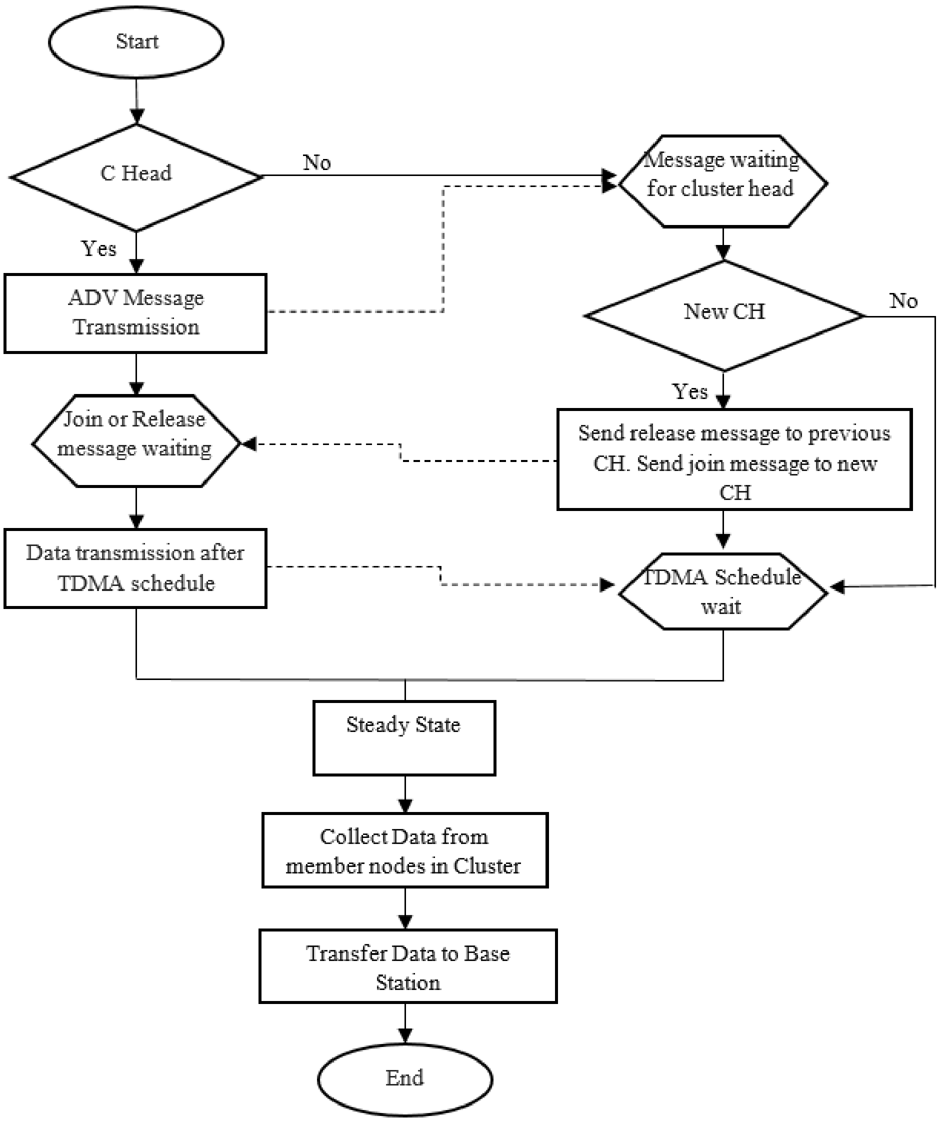

Figure 4.1: Flow Chart of the Proposed Protocol

4.4 Software Simulation

The simulation tool used is MATLAB which provides an efficient way for comparing the performance of the proposed protocol against that of the original LEACH protocol. The random, 100-node network is shown in Fig.4.2, the base station was placed at location (50, 50).

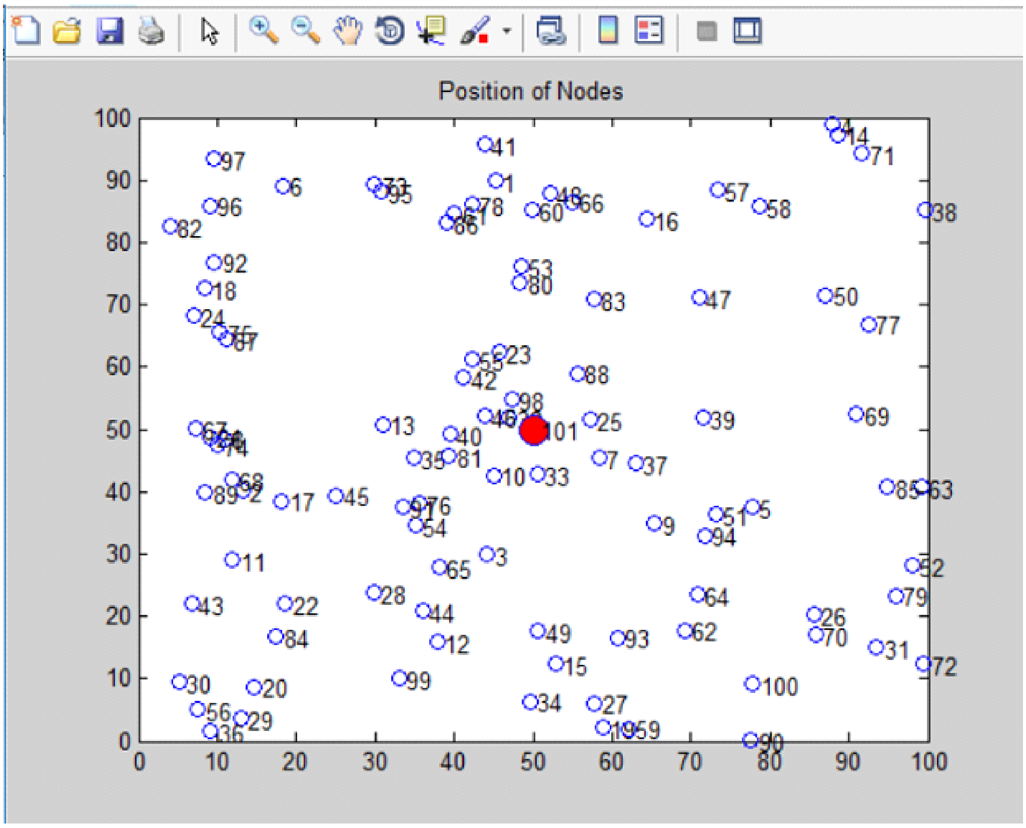

Figure 4.2: Position of Sensor Nodes and Base Station

The following performance metrics were used to evaluate the performance of the proposed protocol (1) Average energy consumption (2) Lifetime of the network (3) Throughput The average energy consumption is the proportion of the total amount of energy used per node to send data to the base station. The lifetime of the network is the time until the first or last node dies and the time until all the nodes are dead. Throughput is calculated as the total number of data packets received at the base station per communication round. The simulation parameters are shown in table 4.1.

Table 4.1: Simulation Parameters

Parameter	Variable
Node	100
Network Size	100×100
BS Location	(50,50)
Node Energy	0.5 j
Number of Rounds	2000
Energy dissipation for transmission	50×0.000000001 j/bit
Energy dissipation for reception	50×0.000000001 j/bit
The probability that a cluster can be a cluster head	0.2
Data aggregation energy	5×0.000000001 j/bit

4.5 Simulation Results and Discussion

The following is a comparison of the performance of the new proposed protocol against that of the original LEACH protocol. Table 4.2 shows the number of alive nodes for each protocol after a given number of rounds is executed.

Table 4.2: No. of Alive Nodes for each Protocol

Rounds	No. of alive nodes (LEACH)	No. of alive nodes (Proposed Solution)
1000	95	100
1500	0	35
2000	0	0

Table 4.2 clearly shows that the number of alive nodes at round 1500 is only 20, while it is increased to 350 in the second proposed protocol. That is because a second cluster head resumes the role of the first after it dies, providing more scalability for the wireless sensor network.

Table 4.3 shows at which round the nodes start dying for each protocol and at which round all the nodes are dead.

Table 4.3: No. of Dead Nodes for each Protocol

Protocol	Rounds when nodes start dying	Rounds when all nodes are dead
LEACH	997	1452
Proposed Solution	1056	1747

The below figures explain in detail the results achieved from the proposed protocol vs the results from the original LEACH protocol.

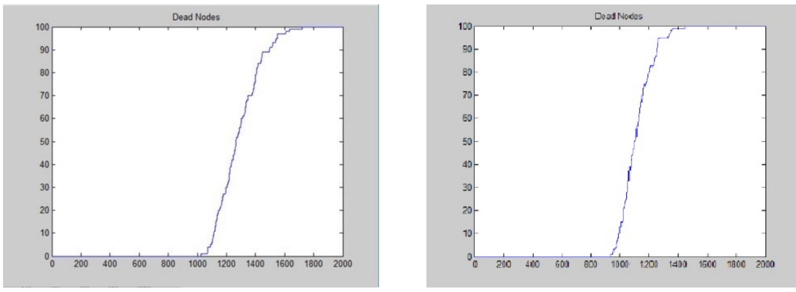

Figure 4.3: Number of Dead Nodes Per Round - Proposed Protocol vs LEACH Protocol

Figure 4.3 shows the dead nodes over the communication rounds. Nodes remain alive until round 1056 in the proposed protocol whereas they start dying at round 997 for the LEACH protocol

Figure 4.4 shows the alive nodes over the communication rounds, all nodes are dead at round 1747, whereas in the original LEACH all the nodes are dead at round 1452, which means the proposed protocol outperforms the original LEACH by 295 rounds out of the 2000, which is 15 percent.

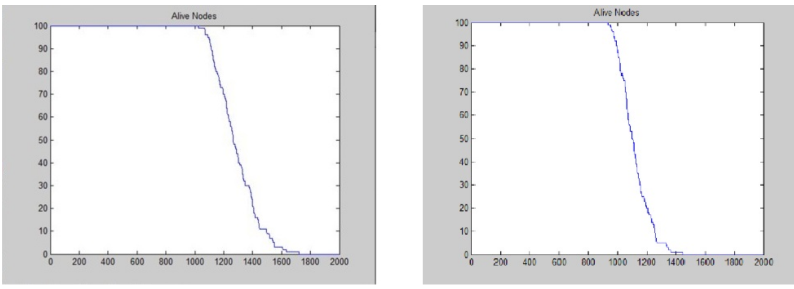

Figure 4.4: Number of Alive Nodes Per Round - Proposed Protocol vs LEACH Protocol

Figure 4.5 shows the average residual energy at each round for the two protocols, which shows an overall improvement of 12.5 percent.

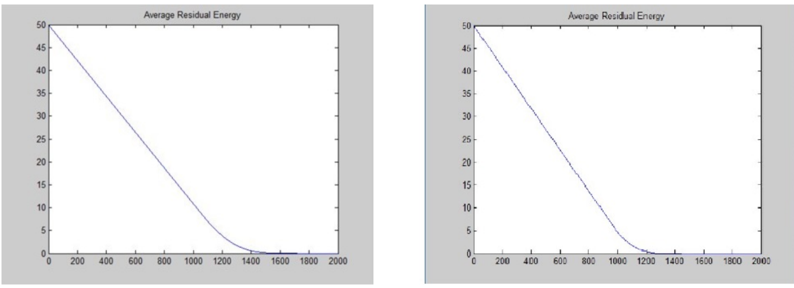

Figure 4.5: Average Residual Energy - Proposed Protocol vs LEACH Protocol

Figure 4.6 displays the number of alive cluster heads at each round for the two protocols. In the proposed protocol cluster heads remain alive until round 1747 whereas in the original LEACH Protocol all cluster heads are dead by round 1452, also the number of cluster heads at each round is increase by almost a third. that is because if a cluster head dies during a round a secondary cluster head takes the role, which means that at a single round there might be 2 cluster heads instead of one.

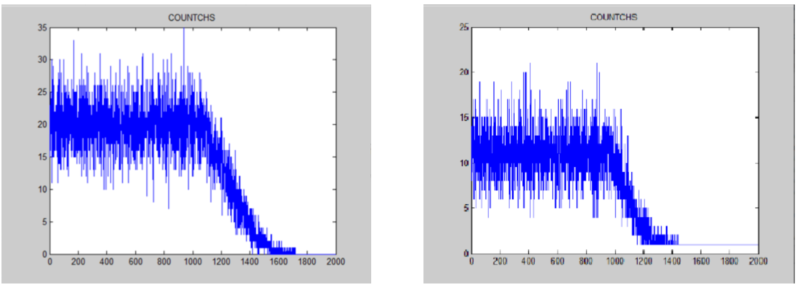

Figure 4.6: Count of Cluster Heads Per Round - Proposed Protocol vs LEACH Protocol

Chapter Five
Conclusion and Recommendations

5.1 Conclusion

WSNs play a vital role in minimizing various constraints such as limited energy, latency, computational resource crisis and quality of communication. That is why routing in WSNs is a major issue. This thesis proposed a centralized cluster-based communication protocol for WSNs which reduces the overall average energy consumption of the network. All communications to the base station are allowed solely through either the primary cluster head or secondary cluster head which leads to a reduction in energy consumption of individual nodes. Moreover, the provision of a secondary cluster head reduces the frequency of clustering thereby reducing the energy consumption. Simulation results demonstrate that the proposed solution outperforms its comparative LEACH protocol by increasing the network lifetime by 15 percent, reducing the average energy consumption by 12.5 percent and increasing the throughput by 15 percent.

5.2 Recommendations

In this thesis we assumed that the nodes are fault-tolerant, but if the nodes are not fault-tolerant and either of the two cluster heads die for any other reasons (other than battery depletion) then it leads to the complete isolation of all the cluster members from the network. Another addition could be the introduction of a third cluster head to take the role of the secondary cluster head to reduce re-clustering and the additional overhead. We also assumed that the inter-cluster and intra-cluster communications are one-hop communications which limits the scalability of the WSN. It is advised to allow multi-hop communication by the cluster heads to overcome this problem.

.

Appendix A
Matlab Code

```
% LEACH
clc
clear all;
close all;
xm=100;
ym=100;
sink.x=0.5*xm;
sink.y=0.5*ym;
n=100;
p=0.2;
Eo=0.5;
ETX=50*0.000000001;
ERX=50*0.000000001;
Efs=10e-12;
Emp=0.0013e-12;
EDA=5*0.000000001;
rmax=2000;
do=sqrt(Efs/Emp);
Et=0;
%%%%%%%%%%% LEACH %%%%%%%%%%%%%%%%%%%%%%%%%%%%
for h=1:1
      S(n+1).xd=sink.x;
      S(n+1).yd=sink.y;
      Et=0;
for i=1:1:n
      S(i).xd=rand(1,1)*xm;
      XR(i)=S(i).xd;
      S(i).yd=rand(1,1)*ym;
      YR(i)=S(i).yd;
      distance=sqrt( (S(i).xd-(S(n+1).xd) )^2 + ...
          (S(i).yd-(S(n+1).yd) )^2 );
      S(i).distance=distance;
      S(i).G=0;
```

```
    %initially there are no cluster heads only nodes
    S(i).type='N';
    S(i).E=Eo;
    Et=Et+S(i).E;
    figure(h*10)
      plot(S(i).xd,S(i).yd,'bo');
      title('Position of Nodes')
      text(S(i).xd+1,S(i).yd-0.5,num2str(i));
      hold on;
end

plot(S(n+1).xd,S(n+1).yd,'o', 'MarkerSize', 12, ...
    'MarkerFaceColor', 'r');
text(S(n+1).xd+1,S(n+1).yd-0.5,num2str(n+1));
hold off ;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
countCHs=0; %variable, counts the cluster head
cluster=1; %cluster is initialized as 1
flag_first_dead=0; %flag tells the first node dead
flag_half_dead=0; %flag tells the 10th node dead
flag_all_dead=0; %flag tells all nodes dead
first_dead=0;
half_dead=0;
all_dead=0;
alive=n;
%counter for bit transmitted to Bases Station and to ...
    Cluster Heads
packets_TO_BS=0;
packets_TO_CH=0;
packets_TO_BS_per_round=0;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for r=0:1:rmax
    r
    packets_TO_BS_per_round=0;
    %Operations for epochs
    if(mod(r, round(1/p) )==0)
        for i=1:1:n
            S(i).G=0;
            S(i).cl=0;
        end
    end

    %hold off;
```

```

    %Number of dead nodes
    dead=0;

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
     for i=1:1:n
        %checking if there is a dead node
        if (S(i).E<=0)
            %plot(S(i).xd,S(i).yd,'red .');

            dead=dead+1;
            if (dead==1)
              if(flag_first_dead==0)
                 first_dead=r;
                 flag_first_dead=1;
              end
            end
            if(dead==0.5*n)
              if(flag_half_dead==0)
                  half_dead=r;
                  flag_half_dead=1;
              end
            end
            if(dead==n)
              if(flag_all_dead==0)
                  all_dead=r;
                  flag_all_dead=1;
              end
            end

            %hold on;
        end
        if S(i).E>0
            S(i).type='N';
        end
    end

        %plot(S(n+1).xd,S(n+1).yd,'x');
        STATISTICS.DEAD(h,r+1)=dead;
        STATISTICS.alive(h,r+1)=alive-dead;
  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   countCHs=0;
    cluster=1;
```

```
    for i=1:1:n
        if(S(i).E>0)
            temp_rand=rand;
            if ( (S(i).G)≤0)

                %Election of Cluster Heads for normal nodes
                if ( temp_rand ≤ ( p/ ( 1 - p * ...
                    mod(r,round(1/p)) )) )

                    countCHs=countCHs+1;
                    packets_TO_BS=packets_TO_BS+1;
                    packets_TO_BS_per_round=packets_TO_BS_per_round+1;
                    PACKETS_TO_BS(r+1)=packets_TO_BS;


                    S(i).type='C';
                    S(i).G=round(1/p)-1;
                    C(cluster).xd=S(i).xd;
                    C(cluster).yd=S(i).yd;
                    %plot(S(i).xd,S(i).yd,'k*');

                    distance=sqrt( (S(i).xd-(S(n+1).xd) )^2 ...
                        + (S(i).yd-(S(n+1).yd) )^2 );
                    C(cluster).distance=distance;
                    C(cluster).id=i;
                    X(cluster)=S(i).xd;
                    Y(cluster)=S(i).yd;
                    cluster=cluster+1;

                    %Calculation of Energy dissipated
                    distance;
                    if (distance>do)
                        S(i).E=S(i).E- ( (ETX+EDA)*(4000) + ...
                            Emp*4000*( ...
                            distance*distance*distance*distance ...
                            ));
                    end
                    if (distance≤do)
                        S(i).E=S(i).E- ( (ETX+EDA)*(4000)  ...
                            + Efs*4000*( distance * ...
                            distance ));
                    end
                end
```

```
                end
            end
        end

            STATISTICS.COUNTCHS(h,r+1)=countCHs+1;
        % or STATISTICS.COUNTCHS(h,r+1)=clster-1;
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    %Election of Associated Cluster Head for Normal Nodes
        for i=1:1:n
          if ( S(i).type=='N' && S(i).E>0 )
           if(cluster-1≥1)
          min_dis=sqrt( (S(i).xd-S(n+1).xd)^2 + ...
              (S(i).yd-S(n+1).yd)^2 );
          min_dis_cluster=0;
            for c=1:1:cluster-1
              temp=min(min_dis,sqrt( (S(i).xd-C(c).xd)^2 + ...
                  (S(i).yd-C(c).yd)^2 ) );
               if ( temp<min_dis )
                   min_dis=temp;
                   min_dis_cluster=c;
              end
          end
          %        ´ · ¢4000bit¾© - º
          if(min_dis_cluster≠0)
               min_dis;
               if (min_dis>do)
                   S(i).E=S(i).E- ( ETX*(4000) + Emp*4000*( ...
                       min_dis * min_dis * min_dis * min_dis));
               end
               if (min_dis≤do)
                   S(i).E=S(i).E- ( ETX*(4000) + Efs*4000*( ...
                       min_dis * min_dis));
               end

               S(C(min_dis_cluster).id).E = ...
                   S(C(min_dis_cluster).id).E- ( (ERX + ...
                   EDA)*4000 );
               packets_TO_CH=packets_TO_CH+1;
          else
               min_dis;
               if (min_dis>do)
```

```
                    S(i).E=S(i).E- ( ETX*(4000) + Emp*4000*( ...
                        min_dis * min_dis * min_dis * min_dis));
                end
                if (min_dis<=do)
                    S(i).E=S(i).E- ( ETX*(4000) + Efs*4000*( ...
                        min_dis * min_dis));
                end
                packets_TO_BS=packets_TO_BS+1;
                packets_TO_BS_per_round=packets_TO_BS_per_round+1;
                PACKETS_TO_BS(r+1)=packets_TO_BS;
            end
             S(i).min_dis=min_dis;
            S(i).min_dis_cluster=min_dis_cluster;
    else
                min_dis=sqrt( (S(i).xd-S(n+1).xd)^2 + ...
                    (S(i).yd-S(n+1).yd)^2 );
                if (min_dis>do)
                    S(i).E=S(i).E- ( ETX*(4000) + Emp*4000*( ...
                        min_dis * min_dis * min_dis * min_dis));
                end
                if (min_dis<=do)
                    S(i).E=S(i).E- ( ETX*(4000) + Efs*4000*( ...
                        min_dis * min_dis));
                end
                packets_TO_BS=packets_TO_BS+1;
                packets_TO_BS_per_round=packets_TO_BS_per_round+1;

      end
    end
end

 En=0;
for i=1:n
     if S(i).E<=0
          continue;
     end
     En=En+S(i).E;
end
ENERGY(r+1)=En;
STATISTICS.ENERGY(h,r+1)=En;

end
first_dead_LEACH(h)=first_dead
```

```
half_dead_LEACH(h)=half_dead
all_dead_LEACH(h)=all_dead
end
for r=0:rmax
      STATISTICS.DEAD(h+1,r+1)=sum(STATISTICS.DEAD(:,r+1))/h;
      STATISTICS.alive(h+1,r+1)=sum(STATISTICS.alive(:,r+1))/h;
      STATISTICS.COUNTCHS(h+1,r+1)=sum(STATISTICS.COUNTCHS(:,r+1))/h;
      STATISTICS.ENERGY(h+1,r+1)=sum(STATISTICS.ENERGY(:,r+1))/h;
end

first_dead=sum(first_dead_LEACH)/h;
half_dead=sum(half_dead_LEACH)/h;
all_dead=sum(all_dead_LEACH)/h;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
r=0:rmax;
figure(1)
plot(r,STATISTICS.DEAD(h+1,r+1));
title('Dead Nodes')
figure(2)
plot(r,STATISTICS.alive(h+1,r+1));
title('Alive Nodes')
figure(3)
plot(r,STATISTICS.COUNTCHS(h+1,r+1));
title('COUNTCHS')
figure(4)
plot(r,STATISTICS.ENERGY(h+1,r+1));
title('Average Residual Energy')
```