Debre Berhan University

College of Computing

Department of Information Technology

Developing Energy Efficient Modified TDMA Schedule for Wireless Sensor Network

A Thesis Submitted to the Department of Information Technology in Partial Fulfillment for the Degree of Master of Science in Computer Network and Security

By Zewditu Guangulie

Debre Berhan, Ethiopia

August, 2021

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Approval page

This is to certify that the thesis prepared by Zewditu Guangulie, in titled: Developing *Energy Efficient Modified TDMA Schedule to Reduce the Energy Consumption of Wireless Sensor Network* and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Computer Network and Security complies with the regulations of the university and meets the accepted standards with respect to its originality.

Advisor: Samuel Asferaw (PhD) Sign -------------------- Date---------------------

Internal Examiner Sign -------------------- Date---------------------

External Examiner: Sign -------------------- Date---------------------

Chairperson: Sign -------------------- Date---------------------

Dedication

This thesis work

dedicated

to

my beloved family

Acknowledgements

First and foremost, I want to express my gratitude to God and his Holy Mother (Kindest Mariam) for providing me with the strength to complete this thesis. I am extremely grateful to my advisor Dr. Samuel Asferaw for his sincere support, encouragement, and meaningful guidance on doing this thesis work. I would also like to express my gratitude to my families, all of my friends, and other people who have supported me in my endeavors.

Declaration

I, the undersigned, hereby declare that this thesis is my original work performed under the supervision of Dr. Samuel Asferaw, has not been presented as a thesis for a degree program in any other university and all sources of materials used for the thesis are duly acknowledged.

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Date of submission: ____________________

This thesis has been submitted for examination with my approval as university advisor. Samuel Asferaw (PhD) __________________

Advisor Signature

Abstract

Wireless sensor network is a group of low-cost, low-power, lightweight, thin, and multi-functional sensor nodes. It has a wide range of applications in our everyday lives. Environmental monitoring, healthcare applications, and military applications are among the most popular. LEACH (Low-Energy Adaptive Clustering Hierarchy) was discovered after researchers examined a number of wireless routing protocols. LEACH is a cluster-based routing protocol with self-organizing sensor nodes grouped into clusters. Each cluster has a cluster head who is in charge of accepting data from all member nodes through a TDMA schedule. This protocol's method for assigning TDMA schedules has a flaw for unbalanced clustering. As a result, modified TDMA schedule has been proposed. It makes use of the cluster's largest capacity to allocate TDMA schedules. CHs communicate with one another to announce their capacity to other CHs, allowing the cluster's largest capacity to be determined. To know the capacity of the largest cluster, each CH receives message from other remaining CH to know their cluster capacity and broadcast message to announce its own number of member nodes for other CH. In this scenario, each CH consumes more energy due to CH communication. To overcome this problem, we proposed Energy Efficient Modified TDMA schedule for WSNs. To fill this gap Energy Efficient Time Division Multiple Access (EETDMA) algorithm was proposed. This algorithm reduced communication between cluster heads by determining the cluster's largest capacity using the base station. Castalia 3.3 simulator with OMNET++ framework was used to test the proposed work. The proposed work is more energy efficient than the existing work, according to simulation results. Average energy consumption was reduced by 7.9 % & 13.29% respectively in LEACH with MTDMA and LEACH with TDMA. Packet received per node to base station were improved 3.29% & 5.47 % respectively in LEACH with MTDMA and LEACH with TDMA.

Keywords: Energy Efficient TDMA, WSN, LEACH, TDMA schedule, Cluster head, Base station

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List of Abbreviations

AODV	Ad-hoc On-demand Distance Vector
BS	Base Station
CH	Cluster Head
CSP	Current State Probability
DSDV	Destination Sequenced Distance Vector
EEMTDMA	Energy Efficient Modified Time Division Multiple Access
GAF	Geographic Adaptive Fidelity
GEAR	Geographic and Energy Aware Routing
GP	General Probability
HEED	Hybrid Energy Efficient Distributed Clustering
LEACH	Low-Energy Adaptive Clustering Hierarchy
LEACH-A	Advanced Low-Energy Adaptive Clustering Hierarchy
LEACH-B	Balanced Low-Energy Adaptive Clustering Hierarchy
LEACH-C	Centralized Low-Energy Adaptive Clustering Hierarchy
MANET	Mobile ad hoc network
M-LEACH	Modified Low-Energy Adaptive Clustering Hierarchy
MTDMA	Modified Time Division Multiple Access
MTE	Minimum Transmission Energy
O-LEACH	Orphan Low-Energy Adaptive Clustering Hierarchy
OMNET++	Objective Modular Network simulator framework in C++

PEGASIS	Power-Efficient Gathering in Sensor Information Systems
Q-LEACH	Quadrant Low-Energy Adaptive Clustering Hierarchy
SPIN	Sensor Protocol for Information Via Negotiation
TDMA	Time Division Multiple Access
TEEN	Threshold sensitive Energy-Efficient Sensor-Network protocol
UHBA	Unified Heuristic Bat Algorithm
V-LEACH	Vice-CH Low-Energy Adaptive Clustering Hierarchy
WSN	Wireless Sensor Network

Chapter 1. Introduction

1.1 Background of the Study

Wireless sensor networks are becoming more popular as wireless communications and electronics become more advanced (WSNs). It is a group of low-cost, low-power, small-size, thin, multi-functional sensor nodes. Those sensor nodes are used to collect relevant information from in accessible or dangerous conditions and transmit it to the base station (BS)[1]. A base station is a type of node that is placed in a specific location to receive data from a group of sensor nodes [2]. Environmental monitoring, healthcare applications, civil applications, agriculture, and military applications are just a few of the many uses for wireless sensor networks in our daily live[3].

Wireless sensor networks use routing protocols to route data from the sensed area to the base station. Because of the complex nature of sensor nodes, their limited battery life, computational overhead, lack of a traditional addressing scheme, self-organization, and limited transmission range, developing routing protocols for WSN requires extra care. As a result, WSN routing protocol design techniques are complex WSN routing protocols must be designed to meet the network's performance requirements, such as energy efficiency, scalability, robustness, stability, and convergence[4].

Many researchers looked into a variety of routing protocols for WSN in order to provide users with an efficient data path. The hierarchical routing protocol uses the least amount of energy compared to the other protocols[5]. The network is divided into clusters in the hierarchical routing protocol, and each cluster has a cluster head (CH). Those protocols that can provide increased scalability, lower energy consumption, lower load, and greater robustness[6].

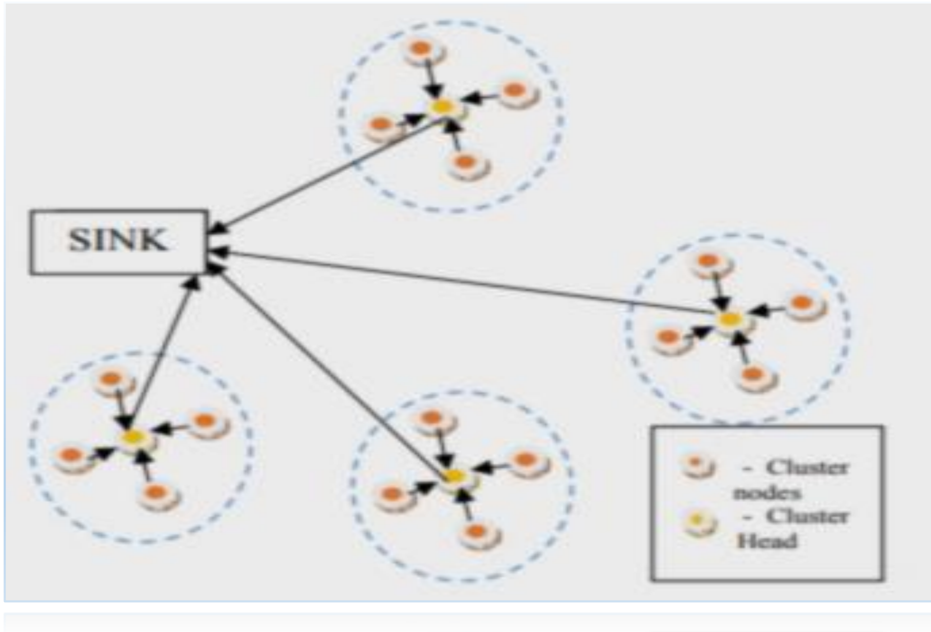

Figure 1. 1   Network Topology of WSNs[7]

Many hierarchical routing protocols have been proposed by researchers. According to the study, LEACH is the first and most widely used hierarchical routing protocol for WSN [4]. This micro sensor network routing protocol combines Power-saving cluster routing and application-specific data aggregation and media access **to provide** good WSN performance.[2].

To avoid inter-cluster and intra-cluster collisions, the LEACH protocol employs a TDMA/CDMA MAC. Time division multiple access (TDMA) has been widely adopted as a media access control (MAC) scheme in WSN due to its collision-free and energy-efficient properties[6][8]. However, the LEACH routing protocol's method of assigning TDMA schedules has a flaw. To address this shortcoming, this project aims to improve the method of assigning TDMA schedules for sensor nodes in the LEACH routing protocol.

1.2 Motivation of the Study

Wireless sensor networks are one of the newest areas of today's ad-hoc networks (WSN). Because of the proliferation of low-cost wireless devices and the network community's interest in mobile computing, this area has gotten a lot of attention in today's world. WSN has become increasingly relevant for our day-to-day activities as a way of collecting and disseminating critical information from potentially hazardous environments[9][10]. Due to their deployment in remote and hazardous areas, non-rechargeable and non-replaceable batteries, tiny, restricted battery life, and computational overhead, they have presented new challenges.

Because of node characteristics such as small size, restricted battery life, and computational overhead, WSN routing protocols must be energy-efficient in today's world. They can also be deployed in remote and dangerous environments. Restricted battery life is one of the open research areas among them. One of the techniques for reducing energy consumption is to use a routing protocol. Most of the existing WSN routing protocols are not designed considering the energy consumption of sensor nodes due to way of assigning TDMA schedule, such as, LEACH, LEACH-C, LEACH-A LEACH B[1], [11]–[13].

Authors in [2] proposed modified TDMA schedule to reduce excessive energy consumption for WSN. When unbalanced clusters are formed within the network, all cluster heads used the capacity of the largest cluster to allocate TDMA schedule for their member nodes rather than based on their own number of member nodes. But the way of knowing the capacity of the largest cluster consumes the energy of each CH and also reduces overall network energy. This idea motivates us to do this research work.

1.3 Statement of the Problem

WSNs (wireless sensor networks) have a wide range of uses in our daily lives. Security, memory capacity, processing capability, and energy consumption are the key challenges in such networks[12], [14], [15]. Energy efficiency is a major problem for sensor networks among the remaining challenges[16][17]. As a result, several researchers looked into the most common solutions, known as cluster-based routing methods. LEACH is one of the energy-efficient hierarchical clustering protocols that has been announced as a way to reduce power consumption and increase network lifetime. To minimize the energy consumption of member nodes, routing information is only transmitted through the cluster heads[1].

Even though the LEACH protocol conserves energy in sensor nodes, we still need to improve the way to assigned TDMA schedules for sensor nodes. Many researchers developed new routing protocols to improve the LEACH routing protocol, but the majority of them concentrated on the cluster head selection criterion. But here are problems related to preserving the energy consumption of sensor nodes due to the way of assigning TDMA schedule[2] .

Authors in [2] proposed modified TDMA schedule to preserve the energy consumption of WSNs when unbalanced cluster is formed. In the previous work each cluster head assigned TDMA schedule based on their own numbers of member nodes, but it is not more energy efficient for unbalanced cluster because a smaller cluster consumes more energy than a larger cluster. Nodes in smaller clusters send information continuously, this may cause for dropping of information and more energy consumption because they collect similar data. To overcome this shortcoming, the work in [2] uses the capacity of the largest cluster for all clusters to assign TDMA schedule for member nodes. Each CH should know the capacity of all clusters to know the largest capacity. To do this, all CH broadcast their own number of member nodes for all CHs. This condition highly increases the energy consumption of WSNs based on the following scenario.

Scenario: Way of selecting the capacity of largest cluster

If "N" numbers of clusters are formed within the network, "N" numbers of CHs are also selected to manage each cluster. To know the capacity of the largest cluster, each CH receives N-1 message from other CH to know the number of its member nodes and broadcast message to announce their own number of member nodes for other CH. In this scenario, one CH consumes its energy N-1 times to receive a message and one time to announce their own cluster capacity for other cluster heads. And also "N*N" time’s energy consumption of the overall network occurred. To overcome this problem, we proposed Energy Efficient Modified TDMA schedule for WSNs.

Hence, this research work attempts to answer the following research questions:

1. How to enhance modified TDMA schedule for WSNs?
2. How energy efficient modified TDMA schedule reduces the energy consumption of WSNs?
3. What are the performance metrics that used to evaluate the efficiency of the proposed work?

4. What is the impacts of energy efficient modified TDMA schedule and modified TDMA schedule on the performance of WSNs?

1.4 Objectives of the Study`

1.4.1 General Objective

The general objective of this study is to develop Energy Efficient Modified TDMA Schedule to reducing the energy consumption of wireless sensor network.

1.4.2 Specific Objectives

The specific objectives of this study includes:

- To assess the existing literature, work for WSNs
- To propose energy-efficient modified TDMA schedule for WSNs
- To implement energy-efficient modified TDMA schedule for WSNs.
- To select the appropriate simulation tools for simulating the proposed work.
- To analysis the impact of energy efficient modified TDMA schedule on the performance of WSNs.
- To evaluate the efficiency of energy efficient modified TDMA schedule based on its energy consumption when compared to modified TDMA schedule.

1.5 Scope and Limitation

WSNs face numerous challenges, including limited energy, storage, and processing power, as well as insecure wireless communication due to a lack of infrastructure[1]–[3], [18].Due to a time constraint, this study only considers how to reduce energy consumption for homogeneous WSNs through Energy Efficient Modified TDMA schedule.

1.6 Significance of the Study

This study has the following significance:

We have done more significant energy efficient modified TDMA schedule, this helps to reduce energy consumption of WSNs.

- It reduces computational power for CH under wireless sensor networks.
- It reduces the memory consumption of CH by reducing message exchange.

- It reduces packet loss.
- It will be used as a reference for future research works.

1.7 Organization of the Thesis

The rest of the chapters are organized as follow: Chapter 2 discusses the literature review and related works. Chapter 3 introduces the proposed work, while Chapter 4 details the implementation of the improved algorithm, as well as the simulation results and discussion. Finally, Chapter 5 introduces the conclusion and future works.

Chapter 2: Literature Review

2.1 Survey of Related Literature

2.1.1 Fundamental Concept of WSNs

The advancement of WSN communications and electronics have facilitated the incidence of low cost, low-power, multifunctional sensor nodes that are small in size sensor nodes [1] [19].They watch environment through infrastructure less communication .for example, temperature, motion or pollutants and then send their data a specfide location or sink where the information are often observed and analyzed[20][21].

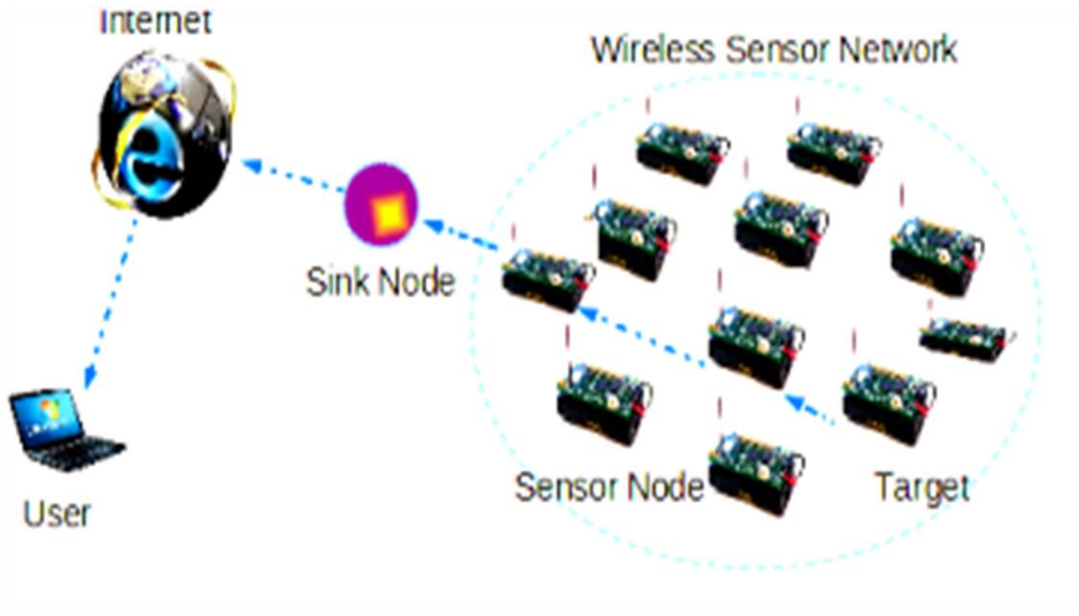

Figure2. 1 Organization of WSN [22]

A wireless sensor network could even be a bunch of nodes connected together during which each node consists of processing capability, memory, communication resources, sensors and actuators and power source. The functionalities of wireless sensor network include detecting activities, exchanging sensed information, aggregating data, raising alarms, initiating othersensors, etc. Sensing, processing and communication are three key elements whose combination in one tiny device gives rise to a vast number of remote sensing applications [23].

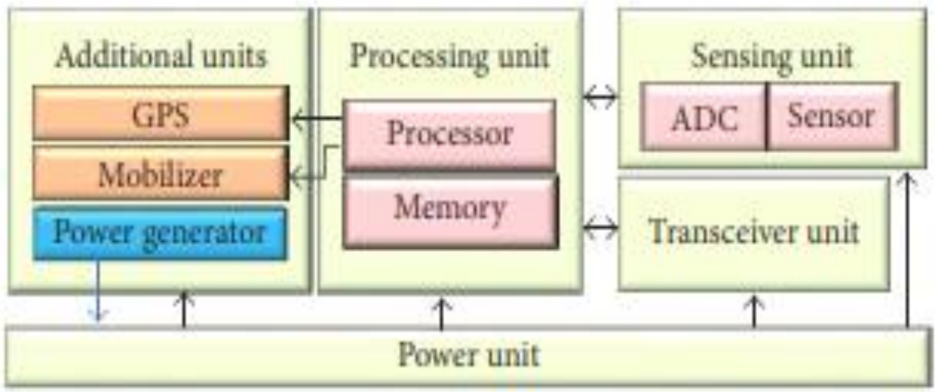

Figure 2. 2 Part of Sensor Nodes [24]

Wireless sensor networks run different topologies of wireless communication networks. The following is a brief description of the network topology that applies to wireless sensor networks [20].

Star network (single point-to-multipoint)

This type of communication, a number of remote nodes may send or receive data from a single base station. Remote nodes are not allowed to transmit information to one another. The main goal of this type of network for wireless sensor networks is simplicity, as well as Ability to keep remote node power consumption to a minimum. There is short latency communication between the remote node and the base station. Base stations must be within the radio transmission range of all individual nodes and are not as powerful as other networks. in case of dependency on one node to manage the networks this may be one drawback of such types of networks.

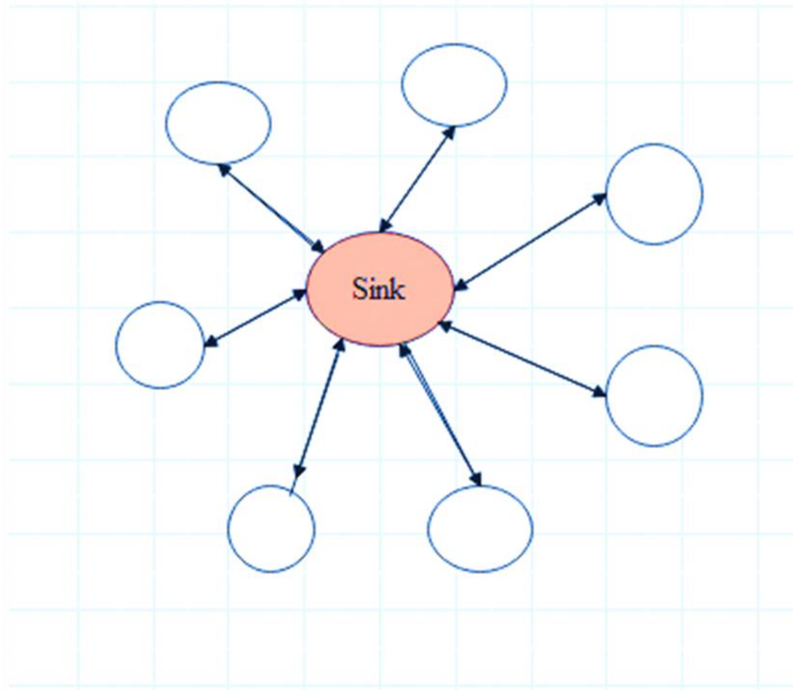

Figure 2. 3 Star Network Topology[25]

Mesh network

In mesh network nodes allow to communicate one another within its radio transmission range we call it as multi-hop communication. Each node ready to communicate other nodes that are out of its transmission range by using intermediate node. This topology important for redundancy and scalability. The scope of the network is not necessarily limited by one node. It can be easily scaled by adding nodes to the system. The disadvantage of such networks is power consumption, often limiting the battery life, and latency.

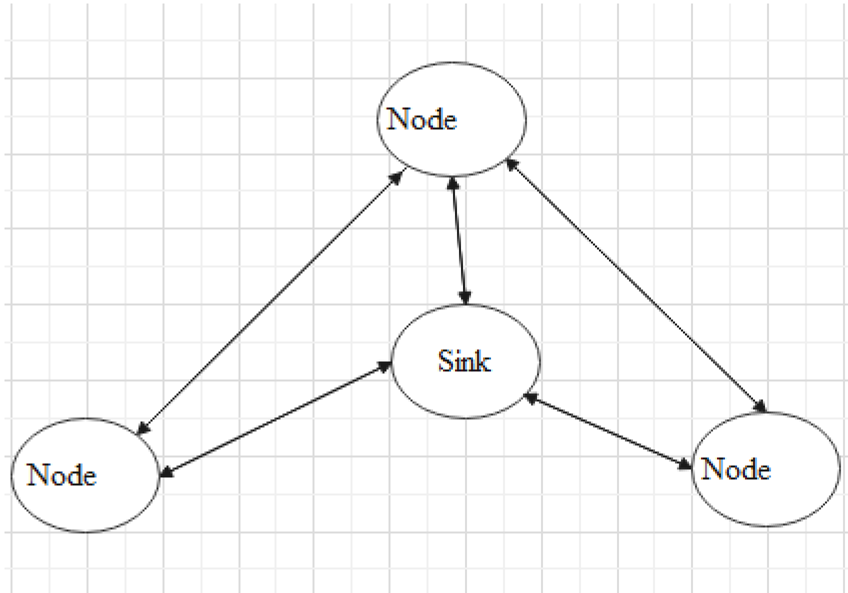

Figure 2. 4 Mesh Network Topology [25]

Hybrid star – Mesh network

Hybrid topology provides a forceful and stretchy communication network, while maintaining the capacity needed to minimize the power consumption of wireless sensor nodes. Nodes with minimal capacity cannot transmit information. This keeps energy consumption to a minimum. However, other nodes can forward messages from low-power nodes to other nodes in the network.

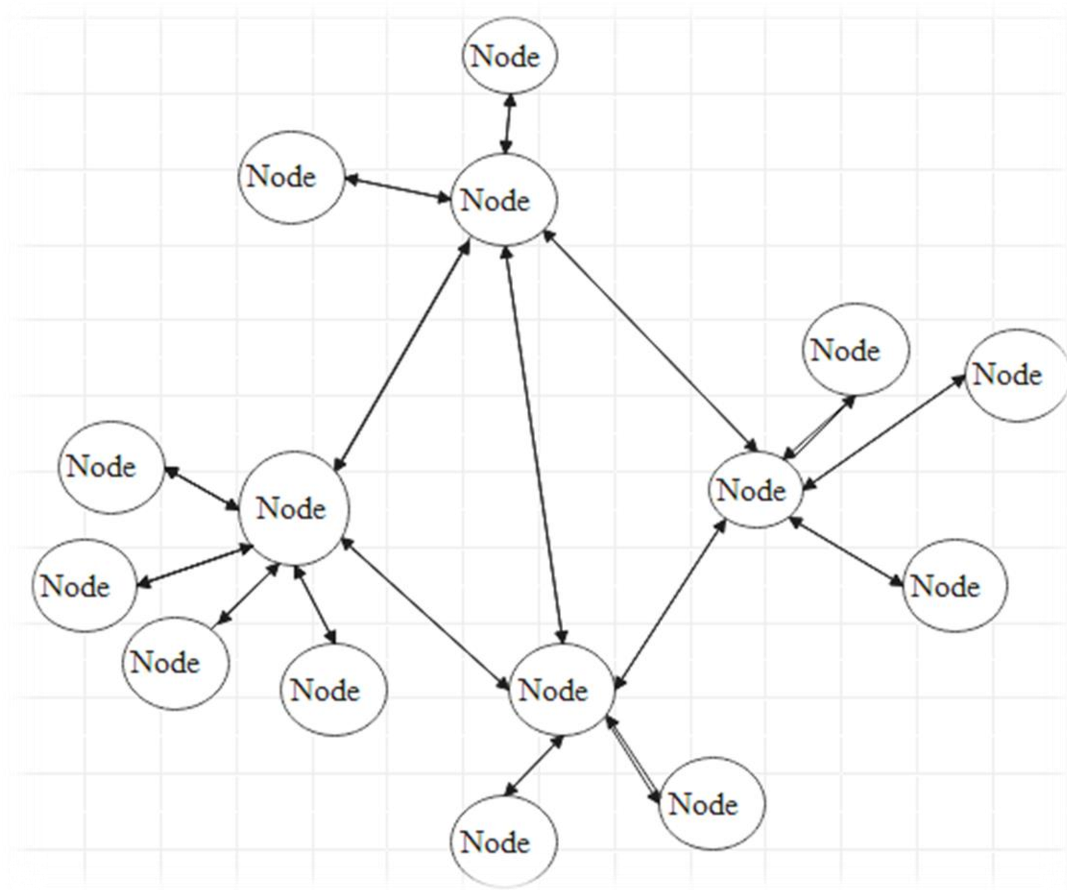

Figure 2. 5 Hybrid Star – Mesh Network Topology [25]

2.1.2 Characteristics of WSNs.

WSNs are different from other wireless networks due to the following features [26]–[29].

Dynamic Network Topology: Subsequently sensor nodes are often added or removed there may be the occurrence of node failure, energy depletion, or channel fading topology changes repeatedly.

Self-configurable: Nodes in WSN are deployed without careful planning. After deployment they need to configure autonomously themselves into a communication network.

Dense sensor node deployment: Number of sensor nodes deployed in WSN are denser than that of MANET and a number of other orders of magnitudes are larger.

Battery-constraint sensor nodes: Sensor nodes are usually positioned in hostile environment. After configuration of sensor node unable to change and recharge the battery of nodes, in explanation for this they safer from energy constraint.

Computation, and storage constraints: the computation and the storage of WSN are highly constrained than other wireless networks.

2.1.3 Application of WSN

Wireless sensor network plays major role in our live thanks to their flexibility in solving problems in several application domains. WSN are successfully applied in various application fields like[20], [25], [30].

Transportation: WSN helps to collect traffic information from world and alert drivers of congestion and traffic problems.

Agricultural sector: To provide modern and efficient agricultural activities wsn play great role throughout the world. Make farmers life easy from the maintenance of wiring in a difficult environment. Irrigation automation enables more effective water use and decreases waste.

Habitat Monitoring: in this area animal or plant grow or lives. WSN helps to watch species autonomies and stop any ecological disturbance for animals and plants. Pollution provide negative impact to health and ecological balance. Since, it's important to manage a system which will monitor pollution in order that it's under controlled

Greenhouse Monitoring: The radiation, is trapped by the gases within the earth's atmosphere and reflected back from the world it causes for the atmospheric phenomenon, it'll heat the surface of earth and results in heating. Therefore, greenhouse monitoring system is vital to make sure the stabilization of the environment.

Climate Monitoring: By using wireless sensor network we can observe global climate change, such as: breaking of sea ice, increasing in sea water level, heat waves, glazier melting, lake temperature warming, and lots of more.

2.1.4 Design Challenges of Routing Protocols in WSNs

In the time of deployment wireless sensor network is highly suffering from millions of challenges. To reduce those challenges protocols for sensor networks must address the range of challenges and obstacles. Other subsequent Features are listed below [20], [31]–[33].

Node distribution strategy: Nodes are deployed on the basis of application in WSNs It has two categories: ad-hoc and deterministic. In ad-hoc, the deployment of sensor nodes are randomly scattered, while in deterministic the sensor nodes are manually placed and transmit the data with the pre-planned route.

Data reporting method: According to different applications, data reporting method are often categorized in to four[34]. Those are: time-driven, event-driven, query-driven and mixed-mode.

Network dynamics: Most wireless network architecture the statues of sensor nodes are stationary but actually the sink node is dynamic and therefore the demands of various applications will produce an impact on research object whether dynamic or stationary.

Node localizations: Node localization management is one among the challenges on designing routing protocols[35]. In localization routing protocols, it's vital to make sure the nodes' location information in transmission of knowledge between sensor nodes.

Fault-tolerance: The sensor nodes are vulnerable, when the node is removed or there are newly nodes, the routing protocol should be identify the statuses of nodes then lets them add or remove [36].

Node nature: Sensor nodes are highly resource constraint like energy and memory. Therefore, the routing algorithm should be simple and lightweight.

Limited energy capacity: Sensor nodes are powered by battery and they have limited energy capacity unable to recharge and replace the battery of sensor nodes that are deployed in hostile environment. The only choice is designing energy efficient routing protocol for extending their life time.

Data Aggregation: By any means variety of sensor node may collect similar data this might cause for redundancy that affect energy and processing capacity of sensor node.

Scalability: When we scale the network size there could also be the occurrence of challenges because of the variation of sensor in terms of energy, processing, sensing, and particularly communication. So routing protocol designer shouted be taken take care of such like issue.

Limited bandwidth: Bandwidth limitation directly affects message exchanges among sensors, and synchronization is impossible without message exchanges.

Design Constraints: Designing sensor nodes must be smaller, cheaper, and more efficient devices. a spread of additional challenges can affect the design of sensor nodes and wireless sensor networks. WSN have difficulty on both software and hardware design models with due to its resource constraint.

Security: the one challenge in wsn is applying security mechanism due to its resource constraint. Many wireless sensor networks collect sensitive information. The distant and unattended operation of sensor nodes results in the exposure to malicious intrusions and attacks.

2.1.5 Types of WSN Routing Protocols

In case of the WSN, energy saving and increasing network lifetime are major issue. So, while designing the routing protocol for WSN resource management is vital[37]. Sensor nodes have limited battery and unable to replace and recharge battery due to its area of deployment. To solve such like problems and prolong the network life time researchers have been developing the subsequent routing protocols[15][38].

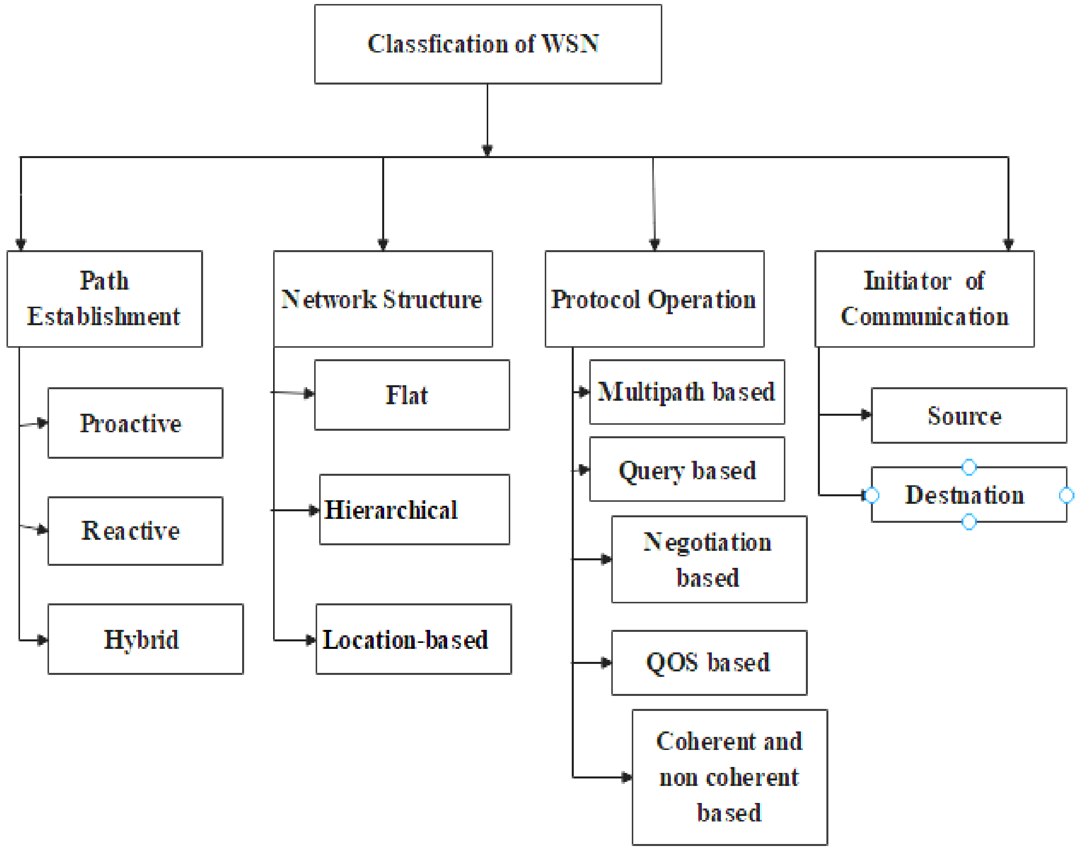

Figure 2. 6 Classification of WSN Routing Protocols [38]

1. Path Establishment

According to path establishment routing protocol can be classified in to the following type [15],[38].

Reactive routing protocol: In reactive protocols, the routes are computed based on demand. That means Protocols find out routes to destination only when they are wanted by broadcasting route query or request messages into the network.

Proactive routing protocol: while in proactive protocols, a WSN consist of thousands of nodes and needs a higher rate of routing table updates, the routing table that each node would have to keep could be vast due to large number of nodes. In cause of this proactive protocols are not suited to WSNs due to its resource constraints.

2. **Hybrid routing protocols:** when we use the idea of the above two routing protocol it called as hybrid routing protocol.

3. Network Structure

Based on network structure routing protocol can be classified in to three broad category[15],[38],[39].

Flat-based Routing Protocols: a number of sensor nodes are deployed in specified area and each of them performs equal function. This implies that all of them gather the data and send to base station, and there is no aggregation of data. In this types of routing protocol unable to give a particular identification for each sensor node in case of large number of node deployment[40].Example AODV, DSDV, MTE, SPIN

Location-based Routing Protocol: In location based routing protocol position determination is important for forwarding data for desired place. In this type of routing protocols, sensor nodes communicate on the basis of location of each node with other node. Example GAF, GEAR

Hierarchical-based Routing Protocols: In this type of routing protocol network divided in to groups which is called clusters each cluster has cluster head and member node. Unlike flat routing protocol all nodes not play equal role. Member node gather information and send it to its cluster head and the cluster head receive the data aggregate it then Transmit the data to base station. This process helps to prolog network life time. Examples of hierarchical routing protocols are: PEGASIS, TEEN, HEED, LEACH.

2.1.6 Communication Protocols Used in WSN

WSNS are used the following protocol stacks [6]

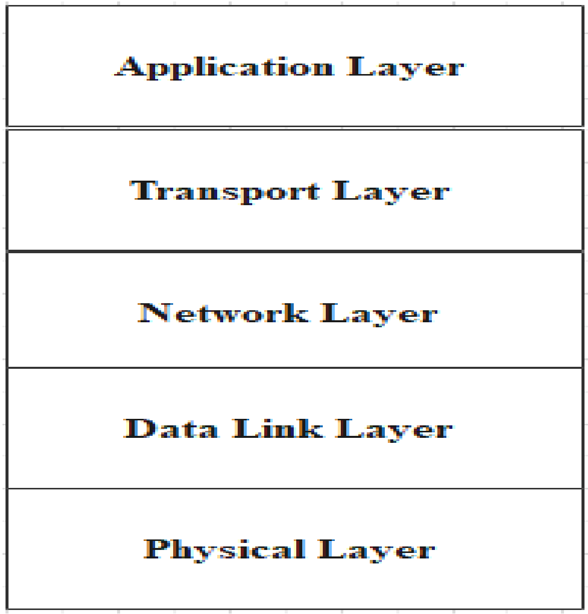

Figure 2. 7 Layered Architecture of WSN [6].

Physical Layer

The purpose of physical layer is to increase the reliability by reducing path loss effect and shadowing. The objective of this layer is establishing connection, data 7 rate, modulation, data encryption, signal detection, frequency generation and signal detection.

Data Link Layer

The purpose of Data link layer is to guaranty interoperability amongst communication between nodes to nodes. The objectives of this layer are: error detection, multiplexing, forbidding of collision of packets, and iterative transmission.

Network Layer

The objective of a Network layer is to discover best track for efficient routing mechanism. This layer is responsible for transferring the data from node to node, node to base station, node to cluster head and vice versa. The LEACH and Power-Efficient Gathering in Sensor (PEGASIS) Information Systems are the protocols which describe the mechanism to avoid the energy consumption so as to upgrade the life of sensors. LEACH gives cluster based transmission while PEGASIS is a chain protocol. WSN use ID based protocols and data centric protocols for transferring mechanism. In WSN, every node in the network acts as a router because they use propagation mechanism, so as to secure routing protocol. Encryption and decryption mechanism are applied for secure routing.

Transport Layer

The purpose of Transport Layer is to establish communication for external networks i.e. sensor network coupled to the internet. This is the most challenging problem in wireless sensor networks.

Application Layer

The purpose of Application Layer is to present final output by ensuring smooth information flow to lower layers. The objective of this layer is data collection, management and processing of the data through the application software for obtaining reliable results. Security Protocols in sensor Networks (SPINS) supply data authentication, replay protection, semantic protection and low overhead.

2.2 Related Work

In this chapter some of related research work is presented with regarding to the minimization of energy consumption and extending network life time in WSN. To achieve minimum energy consumption and extended network life time, cluster-based routing protocol is the best choice for WSN[5]. Most researchers investigated a remarkable cluster-based routing protocol. [18].

2.2.1 LEACH Routing Protocol

Author in paper [13] proposed LEACH routing protocol which is one of cluster based routing protocol and contains self-organized sensor nodes grouped in to clusters. Each cluster includes member nodes and one cluster head, a cluster head is responsible for accepting data from all member nodes and aggregate those data to minimize the amount of data sent to BS. Lastly, each cluster head sends the aggregated data to central node or BS. The operation of the LEACH routing protocol has rounds. Each round has two phases the first phase is setup phase and the second one is steady state phase.

Advertisement Phase

After deploying the sensor nodes to the desired location, the advertisement phase will start. In this phase, the node decides whether it is a cluster head or not by using a probabilistic method. Nodes choose a random number between 0 and 1 and compare it to the threshold value T (n). If the number is a smaller amount than the threshold, it come to be a cluster head for the current round otherwise it becomes a member node.

$$\boldsymbol{T(n) = \frac{p}{1-p\left[r*mod\left(\frac{1}{p}\right)\right]} \quad n \in G}$$ Equation………… (3.1) [13].

Where,

p = percentage of the CH nodes among all the nodes

r = number of round

G = the collections of the nodes that have not yet been CH during the first rounds.

n = node

Nodes who elect themselves as a cluster head, broadcast an advertisement to all nodes within its transmission range. During this setup phase all the member nodes hear the advertisement. After the completion of the current round, all the member nodes decided to which cluster head they will belong based on the received signal strength of the advertisement.

Join Request

A member node after deciding which cluster they will belong, they must inform the cluster head they will join the cluster for the current round.

Schedule Creation

After receiving the join message from all the member nodes, the cluster head assigns TDMA schedule for each member node to inform when they send their data to the cluster head.

Data Transmission

This is the steady state phase of LEACH routing protocol, in this phase a node gathers data from an environment and sends it to cluster head based on the given time slot and cluster head receives the data from all nodes and aggregate this data to reduce the amount of the information that is sent to BS.

Even though LEACH protocol preserves energy in sensor nodes, and minimizes the size of the routing table. It still has some limitations [2].

- ✓ This protocol is considered to work well if the area is small.
- ✓ The way of assigning TDMA schedule has a short coming.
- ✓ The cluster may be unbalanced, which affects the frequency of sending data to the CH.

To overcome the above limitation, a number of routing protocols have been proposed. Some of variants of LEACH are discussed below.

2.2.2 Variants of LEACH Routing Protocol

Advanced LEACH routing protocol (AL EACH) is one of the improved versions of the LEACH routing protocol. Like that of LEACH routing protocol, it's operation divided in to round where each round applying both set-up phase and steady state phase. This protocol is a distributed algorithm without central control. There is no need for knowing the location of each node and global communication. This proposed work improves the way of cluster head selection to select a particular node for CH by improving the threshold equation by introducing two terms: General probability (Gp) and Current State probability (CSp). It assigns TDMA based on LEACH routing protocol[20][40].

The new version of LEACH routing protocol VLEACH was proposed to extend the overall network life time by using two cluster heads. [41].

LEACH-C is a cluster based algorithm in which the node is selected as a cluster head if its energy is greater than the average energy. First, all nodes on the network send their energy and location to the base station. The base station calculates the average energy of nodes. Nodes which have greater energy than average are considered as candidates, then after the base station selects group of the cluster head from the candidate. Each node receives these cluster head group if its ID is included in the group. The node becomes a cluster head otherwise the node becomes a member node. Member node gathers data and sends it to the CH based on the TDMA slot. It assigns TDMA based on LEACH routing protocol[42].

Authors in [43] proposed quadrant leach (Q-LEACH) in this research work. As the name indicates, networks are divided in to four partitions to provide better performance and extended network life time. The other variant of leach is orphan leach (0-LEACH). It tries to solve the problem related to random selection of CH since when we select CH randomly it focuses on some part of the network field. The node will not be covered because of this the remaining part of the filed will be out of the network. The data received by the orphan node will not be transmitted to the base station. To overcome this problem, the authors proposed the O LEACH protocol. It assigns TDMA based on LEACH routing protocol [44].

In addition to the above variants of LEACH routing protocol, balanced leach (B LEACH) was proposed to try to reduce the wastage of energy by decreasing control packets it sends in each round. In these proposed work, sensor nodes consider the following state to send or receive the control packet, it assigns TDMA based on LEACH routing protocol[11].

- Sensor node to cluster head (CH) node: An advertisement packet use to broadcast the information to the neighbor nodes about the CH for formation of cluster.
- Cluster Head (CH) removal: when CH energy becomes lower limit then threshold value this advertisement packet will inform the cluster node that CH will no more a cluster head.
- Sensor node joining the CH: Sensor node joins the cluster head through hand shaking method and this will initiate the handshaking process.
- Sensor node leaving the CH: Sensor node will generate the control packet before leaving the cluster due to many reasons like sensor node become unable to sense data due to low battery or joining the another cluster closer to the sensor node etc.

Other authors proposed that enhanced LEACH in which the sensor node wants to join the cluster first calculate the distance from the sensor node to CH to the base station [6]. The Enhanced Effective Leach Protocol with Novel Cross-Layer Technique (EELP-NCLT) was proposed by researchers in paper [45] [46]as a novel protocol for efficient data forwarding in the WSN. The function of CH is shared by the nodes in the network in the proposed framework, ensuring that energy harvesting is balanced among them

Researchers suggested a solution that reduces the amount of energy used to elect cluster heads in each round. This can be accomplished by cluster forming based on threshold values. The proposed approach decreases the overhead of cluster formation in each round, resulting in lower energy consumption[47].

Researchers introduced a protocol called stable energy efficient clustering protocol to address the limitations of current clustering protocols. It uses energy-aware heuristics to balance the load among nodes[48].

Researcher in paper [49] proposed MG LEACH it makes use of a middle cluster header to send data, extend network lifespan, and send more data than ever.

Researchers suggested a idea to the solve problem in clustered wireless sensor networks [50]. The aim is to provide network-wide optimized time division multiple access (TDMA) schedules with high power reliability, no conflict, and low end-to-end latency.

Researchers proposed a solution to the scheduling issue in clustered wireless sensor networks (WSNs)[51].

Research on paper [52] focuses to improve elections in cluster heads, a unified heuristic bat algorithm (UHBA) was proposed. The cluster head election algorithm ensures that both global and local search can be freely transformed.

The design, analysis, and implementation of a novel energy-optimization routing protocol based on LEACH for WSN was presented in paper .This proposed routing protocol, which is a combination of the Micro Genetic algorithm and the LEACH protocol, was designed to address this problem[54].

The authors in paper [55] suggested the MW-LEACH protocol for multiple weight low energy adaptive clustering hierarchy. Sensor networks that are cellular The cluster heads (CHs) in MW-LEACH are chosen based on residual energy and distances. between the CHs, and the number of member nodes that is optimal. The nodes are chosen from the starting set based on their high quality.

Author in [2] proposed modified TDMA schedule to reduce energy consumption of WSN when unbalanced cluster formed. In this work to assign TDMA schedule CHs follow the following steps.

Step 1. Each cluster head computes the number of its member nodes to assign TDMA

Step 2. Each cluster head will broadcast a message including the number of its own nodes attached to the entire cluster heads in the WSN to announce their capacity for another cluster head.

Step 3. Each cluster head assigns TDMA for their member based on the largest capacity of the cluster in the network.

Step 4. Each sensor node within the cluster uses a similar time slot to transmit data according to modified TDMA in a steady state phase.

Figure 2.8 illustrates Modified TDMA Schedule algorithm uses the capacity of largest cluster to assign TDMA schedule for both largest and smaller clusters. This provide more sleeping time for smaller clusters to reduce continuous data gathering and unnecessary energy consumption for member nodes.

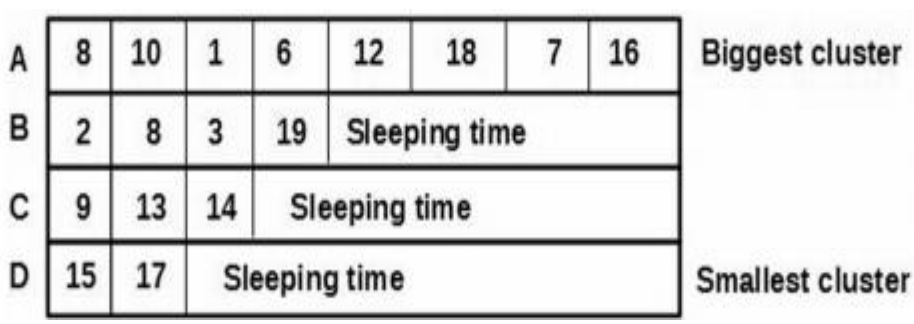

Figure 2. 8 Modified TDMA Schedule [2]

However, in this work there is a limitation in step 2. To overcome this limitation; we have proposed our Energy Efficient Modified TDMA schedule.

2.2.3 Summary of Related Works

Table 2. 1 Summary of Related Works

Year	Title	Aim	Method	Conclusion	Drawback
2000	LEACH (Low-Energy Adaptive Clustering Hierarchy	able to distribute energy dissipation evenly throughout the sensors, and increase network life time	MATLAB	The proposed work efficiently decrease the energy consumption of sensor network by using distributed algorithm	-Unequitable sensor node distribution within the cluster --Member node use RSS to select appropriate CH. -use TDMA schedule
2007	M-LEACH	Create multi-hop communication between CH and BS to reduce the energy consumption of CH when it far from the BS.	-	Multihop-LEACH protocols provide better performance than LEACH protocol.	-Not appropriate for small network -Use TDMA schedule
2008	A-LEACH	Select best node for CH by using General probability (Gp) and	NS-2	This algorithm select the best CH in terms of its	

		Current State probability		current state and general probability, so the nodes' die rate is less than LEACH	
2009	V-LEACH	Select two cluster head to reduce the burden and energy consumption of CH	OMNeT++	V-LEACH is more energy efficient than LEACH	- There is unbalanced distribution of node and member node. - Use TDMA schedule - Select CH based RSS from node to CH.
2012	LEACH-C	Select the CH if its energy is greater than the average.	MATLAB	LEACH-C reduce the total energy consumption of the whole network than LEACH	-Only focus on the CH selection criteria. -Member node use RSS to select CH for member node. - Use TDMA schedule
2019	Enhanced LEACH protocol	Try to solve the energy consumption of member node due to distance	-	consider the energy consumption of member node when they select the CH.	Does not consider Unequitable sensor node distribution within the cluster. - Use TDMA schedule
2018	Modified TDMA	Try to solve the problem related	MATLAB	Reduce the energy	-Member node use RSS to select CH

	schedule was proposed	to TDMA schedule for Unequitable sensor node distribution within the cluster.		consumption of WSN.	- More over head . More CH communication

Chapter Three: Proposed System

3.1 Overview of the Proposed Work

In this thesis, we have proposed Energy Efficient Modified TDMA schedule algorithm. The critical goal of this proposed work is to minimize unnecessary energy consumption of WSN during assigning TDMA schedule. We apply our algorithm by using LEACH routing protocol. Like that of LEACH routing protocol, the operations of the proposed work divide in to round each round takes account of two main phases which are set-up phase and steady state phase.

Set-up Stage

Our proposed work performs this stage for the purpose of cluster formation and scheduling. To complete this stage, our proposed work achieves seven sequential activities. Those activities are cluster head selection, cluster head announcement, member nodes send join request to their CH, each CH compute their number of member nodes and send it to BS, BS determines the Largest capacity of the cluster then announces it to all CH and, each CH assigns TDMA schedules for their member nodes based on the largest capacity.

Steady-state Phase:

In this phase data transmission should be started.

3.2 Topology of Proposed Work

Three types of nodes establish the topology of our proposed work. Those are member nodes, cluster head nodes and sink or base station node. All mentioned nodes play their own role for the proposed work. Member nodes sense and gather information from the particular environment and send it to its cluster-head based on its schedule. The other type of nodes is Cluster-head nodes. The main responsibility of cluster-head nodes is to assign TDMA schedule, receive the data from member nodes, aggregate the data and, finally, send to the base station. The base station node is also one part of topology. It is responsible to compute the largest capacity of the cluster, announce this largest capacity to all CHs, receive data from CHs and send it to the end-user.

3.3 Modular Architecture of the Proposed Work

The proposed architecture has five modules namely, resource management module, clustering module, scheduling module, steady-state module and data aggregation module. The Resource management module manages device resources. Regarding the clustering module, sequential activities are achieved, namely, deciding how cluster heads are selected based on a specific algorithm, and how member nodes select their cluster head. Under the scheduling module, cluster-head schedules cluster members when to send the data using TDMA based on a systematical way. After the cluster is fully formed and the schedules are setup well, actual data transmission will be started on the steady state module. The last module is a data aggregation module in which cluster-head nodes aggregate the data that comes from its members and send the aggregated data to sink.

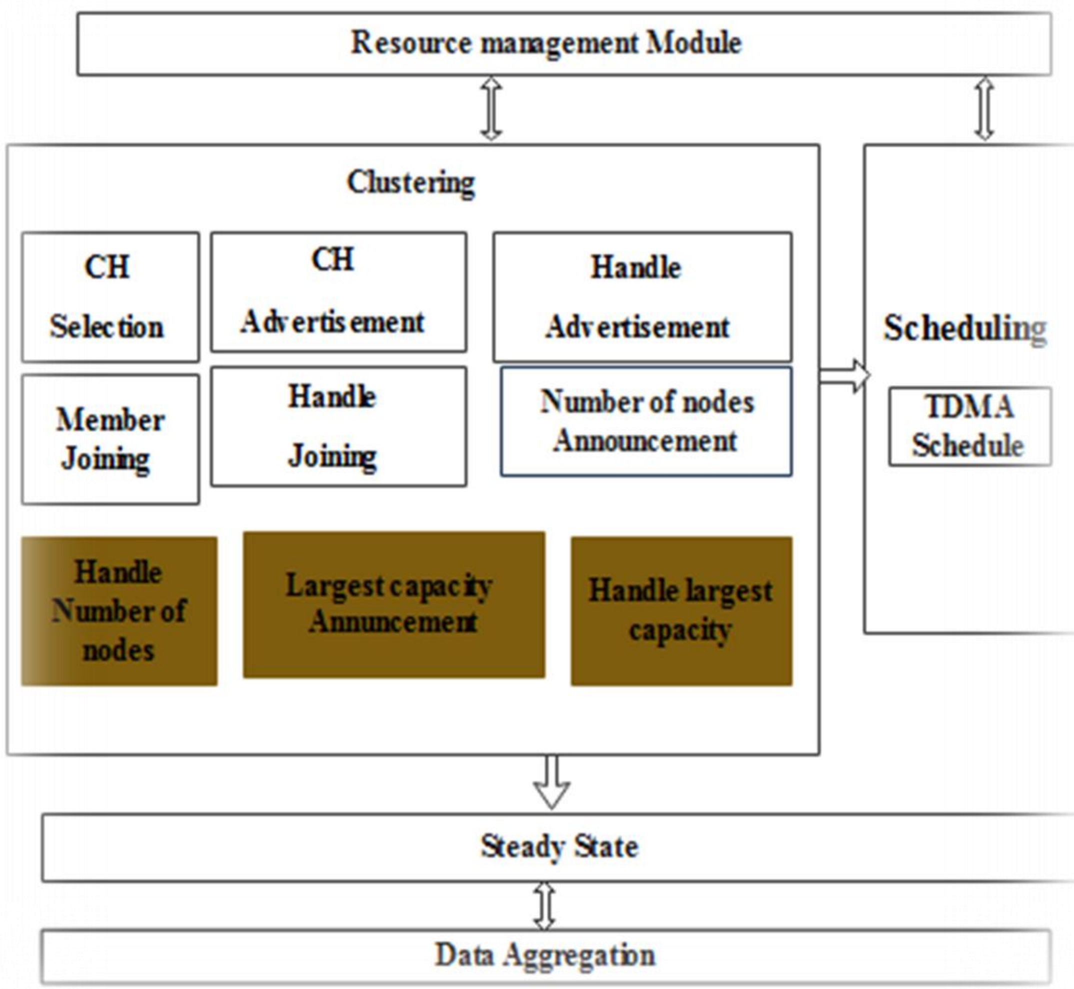

Figure 3. 1 Modular Architecture of Proposed Work

3.3.1 Clustering Module

Figure 3.1 shows modular architecture of the proposed work diagrammatically. Ways of achieving an activities of The shaded rectangle sub-modules in figure 3.1 are different from the related work modules. In this proposed work, nodes form clusters by using a distributed algorithm. This clustering module contains five sub-modules. Those modules are, cluster-head selection, send advertisement, member joining, number of member nodes announcement, and largest capacity announcement.

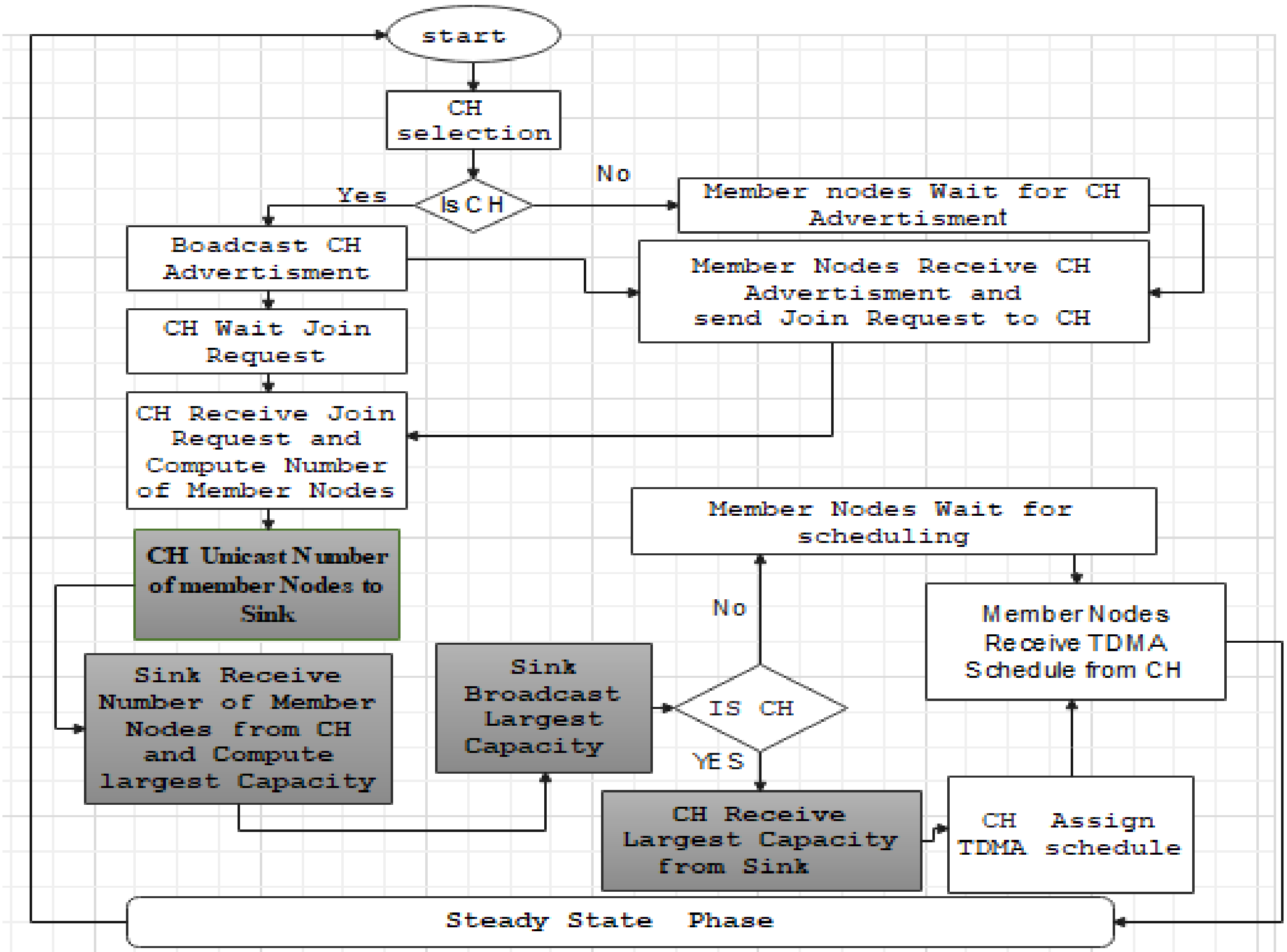

Figure 3. 2 Flow Chart for the Whole Process in LEACH with Energy Efficient Modified TDMA schedule

The subsequent paragraphs describe listed clustering sub-modules of the proposed work.

Cluster-head Selection

In our proposed work like that of LEACH routing protocol, sensor nodes organize themselves and form a cluster by a distributed algorithm. To form the cluster, the sensor nodes decided whether they are cluster head or not based on a probabilistic method see from equation 2.1. All nodes generate random numbers between o and 1 if the generated number is less than the threshold T (n) they decided they were cluster-head unless they became member nodes.

***Cluster-head* Advertisement**

After cluster head selection, each cluster head (CH) broadcast an advertisement message to member nodes for the purpose of announcing it became a cluster head (CH) for the current round, and wait to receive join message from member nodes. All nodes under the transmission range of CHs receive this announcement message.

Handle Advertisement

Nodes that receive those announcement messages non cluster-head node determines to which cluster it belongs and to choose the cluster.

Handle Joining

Nodes listens for a join packet from non-cluster heads that belongs to it. As soon as it receives these joining request packets, it adds to its cluster member by registering the source address.

Number of Member Nodes Announcement

After receiving the join request, all cluster-head compute the number of their member nodes based on the number of join requests message. After computing their capacity, announce it to sink to which compute the largest capacity.

Handle Number of Member Nodes Announcement

Sink waits to receive the number of member nodes from each cluster head. After receiving the message, it adds to the cluster length by registering the number of member nodes.

Largest Capacity of Cluster Announcement: After registering the capacity of each cluster, sink determines the largest capacity and announces it to CHs.

Handle Largest Capacity: Each cluster head waits to receive the capacity of the largest cluster to assign TDMA schedule for their member nodes based on the largest capacity. After receiving the largest capacity, each Cluster head begins to assign TDMA schedule for their member nodes.

3.3.2 Scheduling

The scheduling module includes TDMA schedule, which is used to assign schedule for nodes to transmit their data without collision.

TDMA Schedule

In this proposed work the way of assigning TDMA schedule is to some extent different from the way of assigning modified TDMA schedule. In the Modified TDMA schedule, all CH broadcast their own number of member node to all other CH. Each CH selects the capacity of the largest cluster to assign TDMA schedule. This may lead to more energy consumption of WSNs as a result, reduce the life time of the network. To overcome this problem, we used Energy Efficient Modified TDMA schedule.

In this Energy Efficient Modified TDMA scheduling, each cluster head (CH) knows the number of its member nodes based on the number of join request messages and sends the number of its members to BS. Then, it follows the following four steps to assign TDMA schedule.

Step 1: Each CH computes the number of sensor nodes assigned to its cluster based on the number of join requests.

Step 2: Each CH sends the number of its member nodes to BS.

Step 3: Based on the received message from all CH, the sink identify the capacity of the largest cluster.

Step 4: Then, the sink broadcasts the capacity of the largest cluster for all CHs, and then each cluster head knows the capacity of the largest cluster.

Step 5: The capacity of the largest cluster is used by all CHs for TDMA schedule for the steady state phase.

Each sensor node in each cluster has an equal chance to transmit data according to energy efficient modified TDMA schedule. Figure 3.4 and 3.5 clearly describe how energy efficient modified TDMA schedule different from the existing modified TDMA schedule.

Figure 3.3 shows how CHs communicate with each other to identify the capacity of the largest cluster. In this case, each CH consumes more energy and also increases the overall energy consumption of the network. But, the proposed work reduces the communication of CHs shown in Figure 3.3 to Figure 3.4. This reduces significantly the energy consumption of CHs in identifying largest capacity. As a result, it also reduces time and memory lost in CH communication for identifying the largest capacity. Reducing energy consumption of cluster head also increases the life time of the whole WSN. This process is shown in Figure 3.4

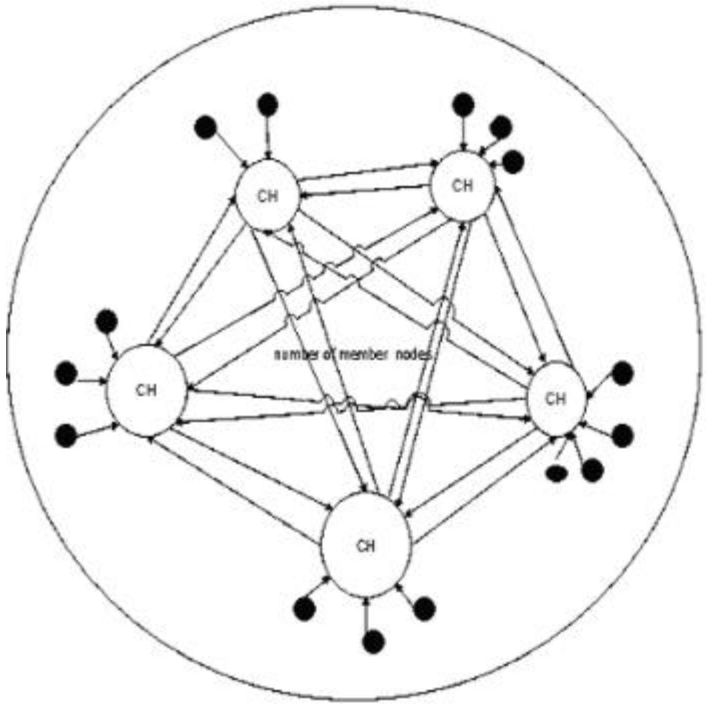

Figure 3. 3 Message Exchange between CHs in Modified TDMA schedule

Figure 3.4 shows that all CHs send their own number of member nodes to sink, and the sink identify the capacity of the largest cluster and announce it to all CHs. This step in our work avoids the energy consuming phase of CHs communication for identifying the largest capacity in Modified TDMA algorithm. This reduction of communication between CHs highly reduces energy consumption of WSNs. Figure 3.3 and Figure 3.4 the energy consumption difference of CHs between our proposed work and Modified TDMA during assigning TDMA schedule for their member nodes and overall energy consumption of WSNs.The reduction of communication between CHs highly reduces energy consumption of WSNs.

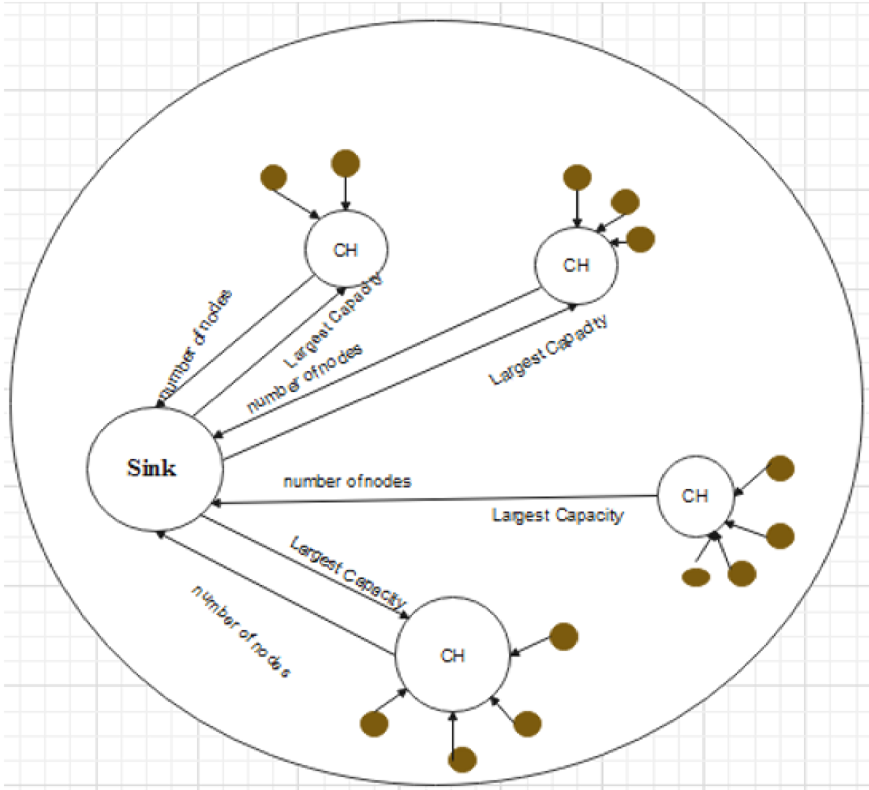

Figure 3. 4 Message Exchange between CH and Sink in Energy Efficient Modified TDMA Schedule

From the above two graphs we can predict the energy consumption of CH when they assign TDMA schedule for their member nodes and overall energy consumption of WSNs. The energy consumption difference between Modified TDMA and our proposed work, Energy Efficient Modified TDMA is compared in Table 3.1 and Table 3.2.

Table 3. 1 Scenario: Energy Consumption of Modified TDMA Scheduling [2]

CH energy consumption	If there is N numbers of cluster within network. Each CH receive n-1 message receive from other neighbors.
Over all network energy consumption	If there is N number of cluster, N number of CH exist and Each cluster head receive n-1 message and N*n-1 message received within the deployed network

Table 3. 2 Scenario: of Energy Consumption of our Energy Efficient Modified TDMA Schedule

CH energy consumption	Each CH receive only one message from base station. .
Over all network energy consumption	If there is N number of clusters, N number of CH exist and Each cluster head receive 1 message from base station and only N messages received within the deployed network

3.4 Resource Management Modules

The resource manager module keeps track of the node's energy usage as well as node-specific information including clock drift and baseline power consumption. Modules that model hardware devices (such as the radio and the sensor manager) send messages to the resource manager to tell it how much power they are using right now. The resource manager now has a complete picture of the overall power drawn and can measure energy consumption any time there is a power shift or on a regular basis (if a power change has not happened for some time)[56]. To evaluate the current level of nodes energy, we used an existing resource management module. Scheduled nodes will decide to quit the operation if their power is less than the provided value.

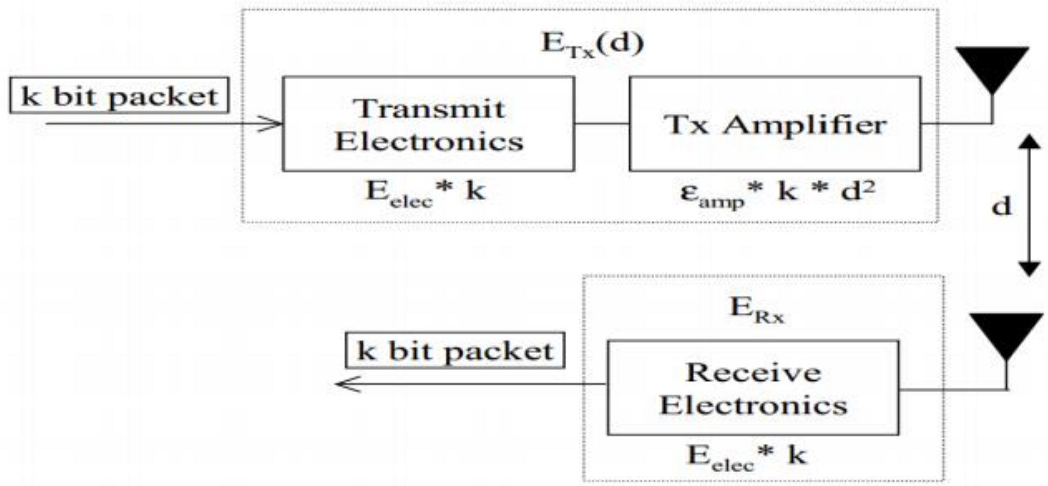

Figure 3. 5 Radio Energy Dissipation Model[1]

The researchers assume a simple model in which the transmitter uses energy to power the radio electronics and the power amplifier, and the receiver uses energy to power the radio electronics. power attenuation is affected by the number of data bits sent or received and distance. They believe that the transmitter and receiver electronics spent the same energy as described in the following equations [1].

Thus, to transmit a k-bit message to a distance d using this radio model, the radio expends.

ETx(k,d)= ETx-elec(k)+ ETx-amp(k,d)……………….. .(3.2) [1].

ETx(k,d)= Eelec*k+ Єamp *k*d2 …………………..equation (3.3) [1].

and to receive this message, the radio expends:

ERx(k)= ERx-elec(k)

ERx-elec= ERx-elec*k

Where ETx-elec = Energy consumed for transmit electronics

ERx-elec = Energy consumed for receive electronics

ETx-amp = Energy consumed for transmission amplifier electronics

Eelec = Energy consumed for transmit and receive electronics

Єamp = Amplification coefficient of free-space signal

d = distance between transmitter and receiver

k = number of message bits

3.5 Steady State Module

In this phase data transmission is started. To reduce the power consumption of the WSNs, the member node uses power control to set the amount of transmit power based on the strength received from the cluster head advertisement. Finally, the cluster head nodes use the CSMA approach to send data to the base station.

3.6 Data Aggregation

We can select different data aggregation methods depending on the application requirements as well as the relative energy savings [57]. In our proposed work, cluster-based techniques are used as we are using cluster-based routing protocol and its advantages in terms of scalability, conserve communication bandwidth and avoid redundant messages among nodes[57].

Pseudo code of our Energy Efficient Modified TDMA Schedule Algorithm is shown Figure 3.6 below. The improvements done by the proposed approach is shown in bold font:

Notation

CH = Cluster head

n = node

R = random number

r = round number

T(n) = threshold

$$\boldsymbol{T(n) = \frac{p}{1-p\left[r*mod\left(\frac{1}{p}\right)\right]} \quad n \in G}$$

P = percentage of CH among given Number of nodes

<u>Setup phase:</u>

In this phase clusters are created

1. Add n, percentage

2. n generate random number between 0 and 1 and Calculate (T(n) IF (T(n) < R) n become a CH

3. IF n become CH broadcasts a message advertising its CH status Else n become a regular node

4. IF n is CH wait join request message from non-cluster-head nodes

5. Non-cluster-head nodes broadcast join request for CH based on RSS

6. IF (join request! =0)

7. CHs computes their member nodes

8. CHs unicast number of member nodes to sink

9. IF (number of received member nodes! =0) sink compute capacity of largest cluster and broadcasts to all CHs

9. All CHs receive capacity of largest cluster from the sink

10. Each CHs assign TDMA schedule for its member nodes based on capacity of largest cluster.

Steady State phase

11. None CH nodes collect data from particular environment

12. None CH nodes send data based on TDMA scheduled

13. CHs receive data from member nodes

14. CHs aggregate the data and send it to the sink

Figure 3. 6 LEACH with Energy Efficient Modified TDMA Schedule Algorithm

Chapter Four: Implementation and Performance Evaluation

This chapter discusses about the result of the simulation process to evaluate the performance of our proposed work, simulation software, evaluation metrics, simulation parameter and analysis of the results.

4.1 Simulation Tool

The performance of the proposed work has been evaluated by conducting simulation experiment using a simulation tool. Simulation is the most popular, effective and feasible approach to design, develop and test routing protocols for WSNs. Simulators strive to accurately model and predict the behavior of real environment in different scenarios. Simulation-based approaches provide certain advantages like lower cost, scalability, time and ease of implementation [58]. There are a lot of simulation tools those used for simulating WSN [59][60][61]. some of them are described below

NS-2 is important testing tool for network research and that the new conventional protocols will be added to future releases. However, new proposals for WSN are increasingly being tested in specific tools, due to benefit of native sensor code simulation and the specific design of these tools for WSN. Since, it is unclear the availability of new WSN proposals for future releases of NS-2. In addition, NS2 does not allow hierarchical model, it seriously limits NS2 use in WSN.

OPNET is similar to OMNET++ with its hierarchical model but a significant difference between OMNET++ and OPNET is OPNET models always use permanent topology, while OMNET++' is customizable and more parametrized topology.

J-Sim is component-based simulation environment it uses Java. It delivers real-time process based simulation. The main purpose of J-sim is its considerable list of supported protocols. Its drawback is worse execution time.

OMNET++ is implemented in C++. OMNET++ also provides a great GUI library for animation and tracing and debugging support. It has the lack of available protocols in its library, compared to other simulators. It also popular and its modeling problem recently solved.

Castalia is also more advantageous simulator for WSN. It is constructed on top of OMNeT++ from which it gets hierarchical architecture, strong GUI and IDE support, has clear parting of simulation kernel, models, topology and scenarios. Castalia also provides realistic models of wireless channel.

To evaluate our proposed work, we used latest version of Castalia 3.3 simulator with OMNeT++ 4.6 framework because of the following reason [58].

- It is used for WSN Body Area Networks (BAN) and low power device.
- It tests protocols in realistic wireless channel and radio models with a realistic node behavior.
- Provide real radios for low-power communication.
- Extended sensing modeling provisions.
- MAC and routing protocols available.
- Designed for adaptation and expansion.

Description of OMNeT++ and Castalia are described below.

4.1.1 OMNeT++

OMNeT++ is an object-oriented modular discrete event simulator. The name itself stands for Objective Modular Network simulator framework in C++[62][63].

OMNeT++ Model Structure

The OMNeT++ model is composed of two types of modules that communicate with message passing. Those modules are simple modules and compound modules. Those simple modules written by C++, use the simulation class library. Those simple modules grouped together and form the compound module [62].

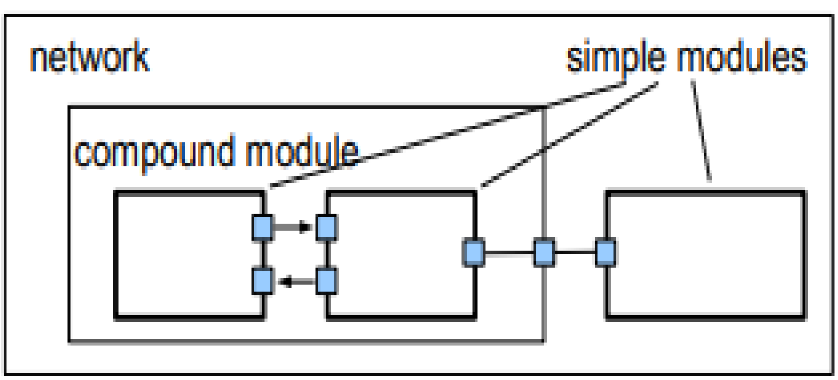

Figure 4. 1 Module Structure of OMNeT++[62]

4.1.2 Castalia

Castalia use OMNeT++ as its base. OMNeT basic thoughts are modules and messages. A simple module is the basic unit of execution. It receives messages from other modules or itself, and based on the message, it executes a piece of code[64] [63].

Structure of Castalia

Castalia simulator uses the OMNeT++ NED language. With this language we can easily define modules, like module name, module parameters, and module interface (gates in and gates out) and possible sub module structure. The structure of Castalia has shown in the hierarchy of directories in the source code. If the module is composite, then there are sub directories to define its behavior. If it is a simple module then there is C++ code (.cc, .h files) to define its behavior[56].

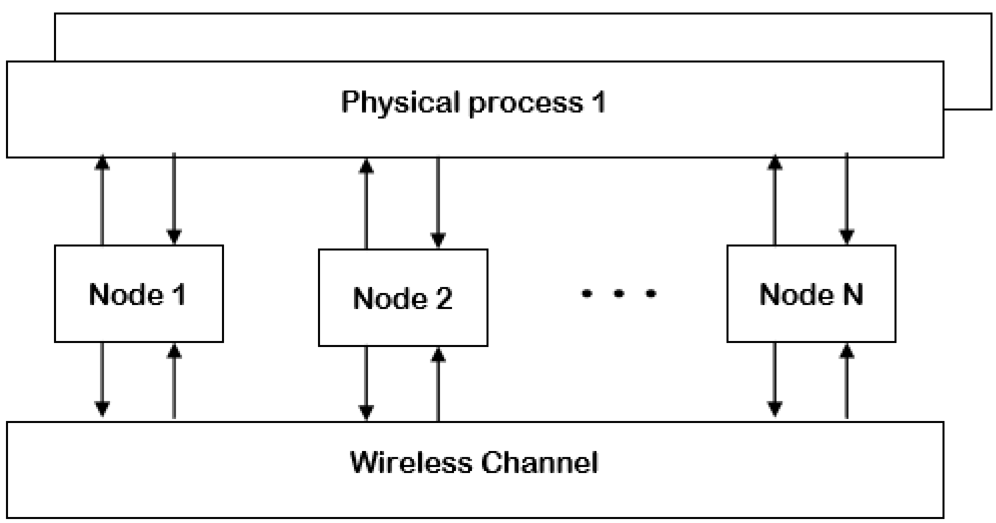

Figure 4. 2 The modules and their connections in Castalia[56]

4.2 Assumption of Proposed Work Simulation

This section explains the system environment assumptions for the proposed work. Our proposed work is appropriate for the WSNs under the following assumptions.

- Nodes are immobile and not-heterogeneous.
- All nodes expend energy at the same rate and are able to know their residual energy and control transportation power.
- The sink node is fixed.

- Every node has data to transmit in every time frame. The data transmitted by member nodes are related and can be merged.
- Clusters can have unequal capacity or unequal member nodes.
- Used for small area network.

4. 3 Evaluation Metrics and Simulation Parameters

4.3.1 Evaluation Metrics

The output of our proposed work was evaluated using Average energy consumption and packet received per node by base station metrics.

Average energy consumption: The sum of consumed energy of deployed nodes in network per number of deployed nodes.

packet received per node by base station: Total amount of data received by base station from each cluster-head.

4.3.2 Simulation Parameters

The input data or simulation parameter list for this work is presented in Table 4.1 below

Table 4. 1 Parameter List

No	Parameter list	Specified
1	Simulation time	1000s
2	Simulation area	100m×100m
3	Number of nodes	100
4	Initial energy	100J
5	Cluster head probability	0.05
6	Base station coordinates	(0,0)
7	Number of configuration	1
8	Round length	20s
9	Slot length	0.2 second
10	Number of trail	10

Simulation Time: It shows how long the simulation should run We used 100s to 1000s to simulate our proposed work and to determine its energy consumption by varying simulation time.

Simulation Area: It determines the size of the sensor field where sensor nodes will be positioned. We deployed our proposed work in the 100m×100m area.

Number of Nodes: The number of nodes determines the density of the network. We used 50 to 100 node to validate the energy consumption of our proposed work.

CH Probability: Determines the probability of sensor nodes to be a cluster head. Using a probabilistic process, select CH from the deployed sensor node.

Base Station Coordinates: The coordinate that the base station places.

Slot Length: describe the length of the basic allocation slot for cluster members.

Round Length: It shows how long the setup phase and steady state phase completed in one round.

Figure 4.3 shows that arrangement of nodes and their joining to the wireless channel modules and physical process. Nodes do not communicate to each other without any wireless channel module(s). The arrows show a message passing from one module to another.

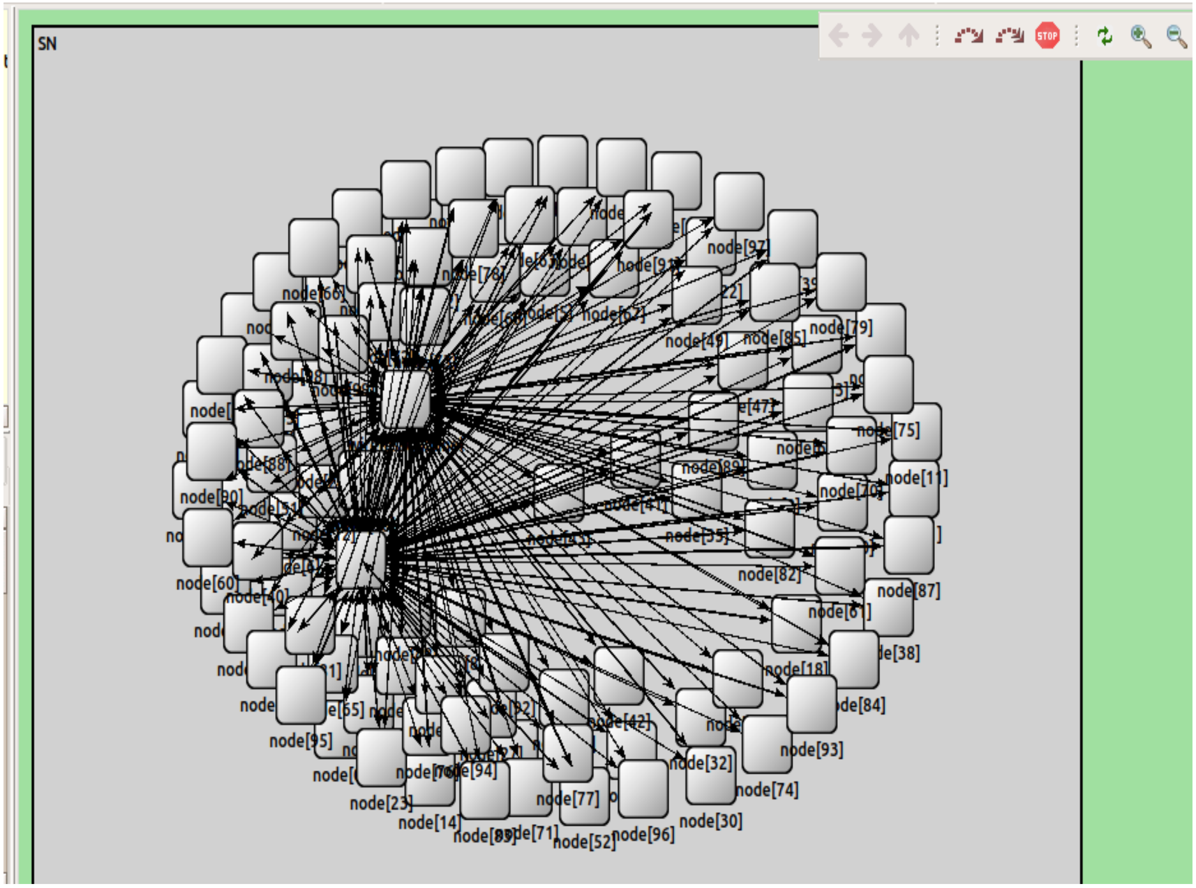

Figure 4. 3 Simulation Topology

4.4 Simulation Result

This subsection depicts the overall power consumption and packet received per node by the base station in our proposed and existing work. Each scenario has a different number of nodes and a different simulation time.

4.4.1 Simulation Result by Varying Simulation Time

Within a given Simulation time number of operational round performed, each round has two phase each phase has set-up phase and steady state phase. In both phase there is energy consumption based on its complexity. The complexity of our proposed work is less than that of the existing work

In Figure 4.4, we have simulated LEACH with MTDMA, LEACH with EEMTDMA and LEACH with TDMA by varying simulation time from 100s to 1000s, and we have evaluated the energy consumption of the proposed work with the related works. As illustrated in the, LEACH with EEMTDMA algorithm consumes minimum energy than the MTDMA and

TDMA. As the simulation time increase, the average consumed energy of the MTDMA and our proposed work is less significant until simulation time 300s but after 400s, the proposed work's energy consumption is proportionally lower than the MTDMA and TDMA.

This is because the computational power needed to determine the largest capacity of clusters in MTDMA work is higher than our proposed work. Since The number of cluster formation is proportional to the number of rounds and the number of rounds increases as the simulation time increases. Sensor nodes in MTDMA consume more energy than sensor nodes in EEMTDMA for each cluster formation. This is because there is no communication between CH for each round in the EEMTDMA unlike in MTDMA algorithm.

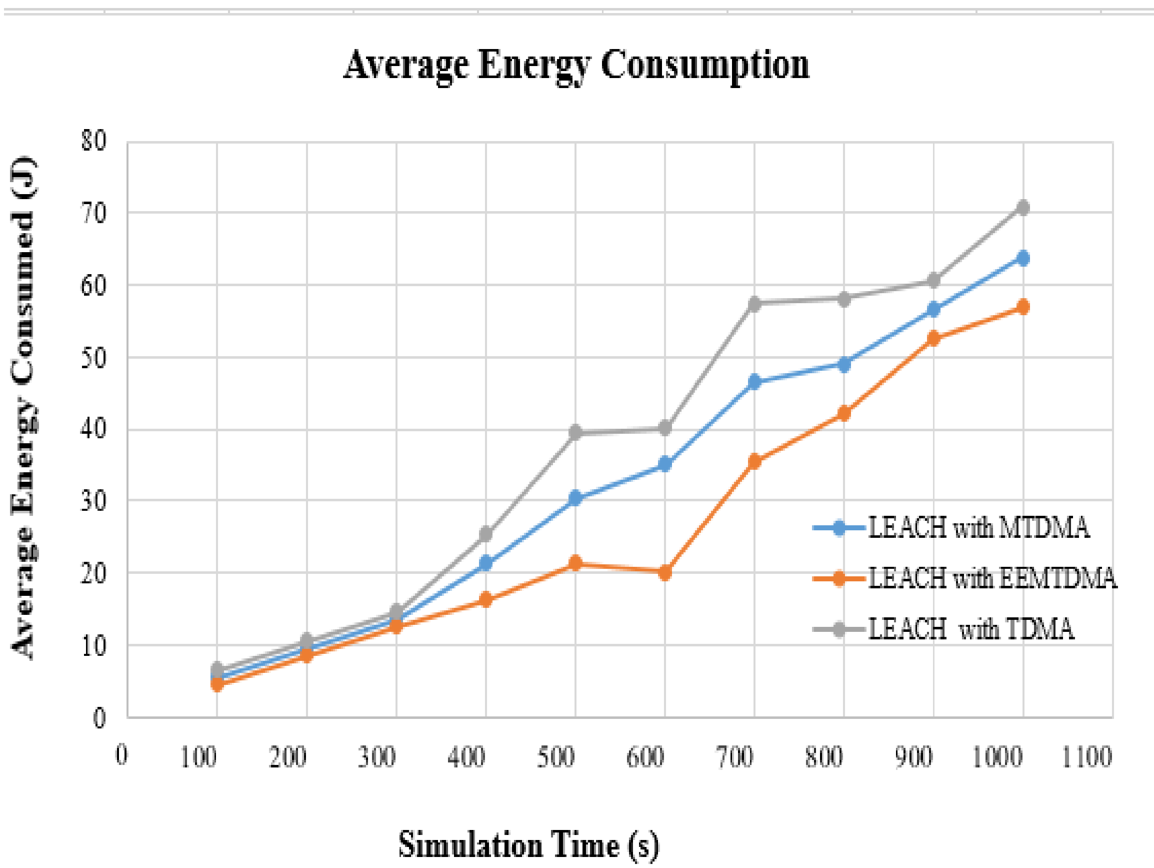

Figure 4. 4 Average Energy Consumption by Varying Simulation Time

As shown in Figure 4.5, the proposed work has a higher packet received per node to base station than LEACH with MTDMA and LEACH with TDMA. Because, as the number of node increase the computational power consumption of nodes in LEACH with MTDMA increases. As power consumption raises, node death rises as well, it causes to fewer packets being sent to the base station. As seen in the graph, packet received to base station increases in our proposed work because its computational power consumption is lower than that of LEACH with MTDMA, and LEACH with TDMA, it resulting in less dead nodes. As a result, more packets are sent to the base station.

4.4.2 Simulation Result by Varying Number of Nodes

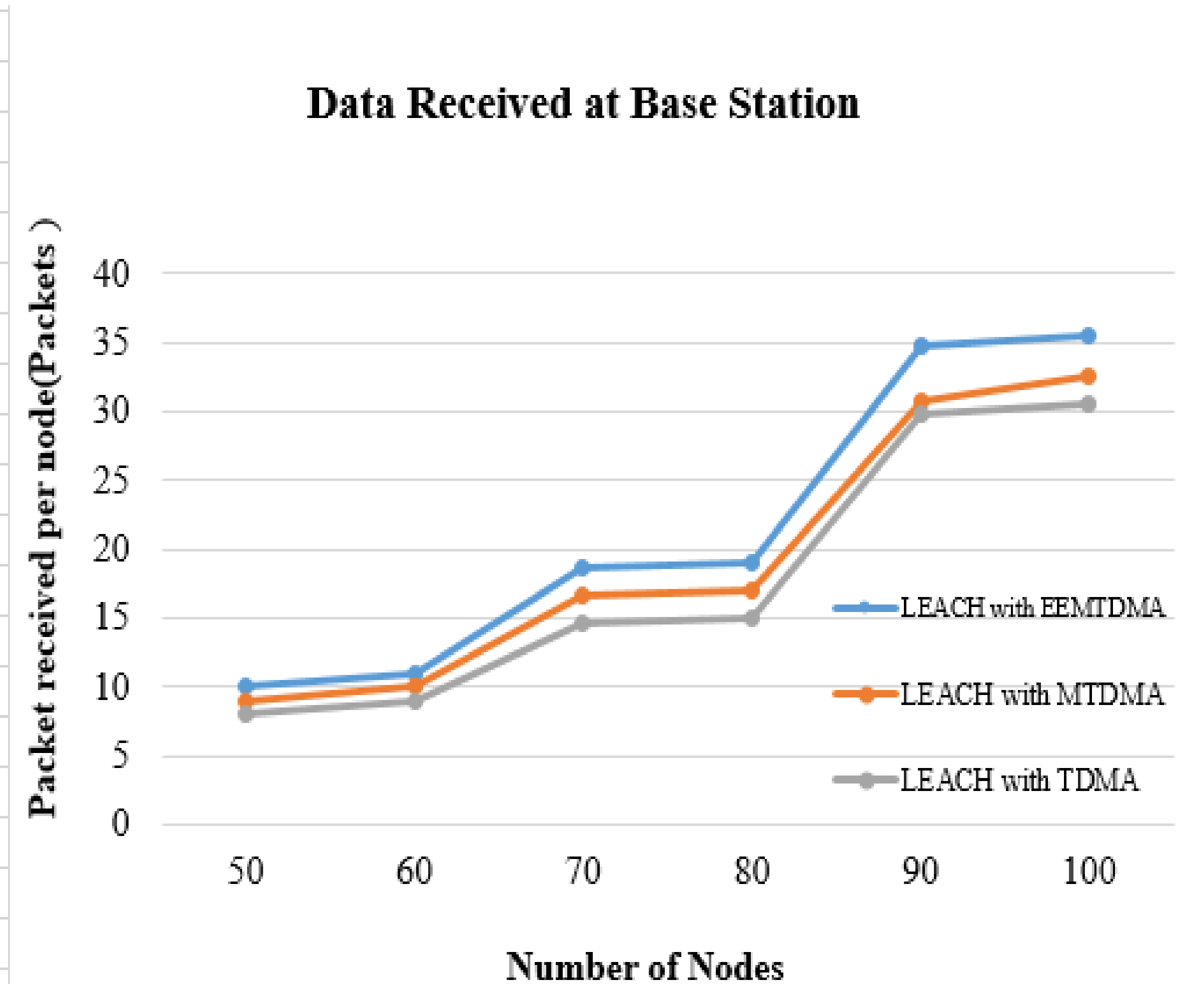

Figure 4. 5 Packet Received Per Node by Varying Number of Node

Figure 4.6 illustrates the average consumed energy of both LEACH with MTDMA, LEACH with EEMTDMA, and LEACH with TDMA. In both cases the average consumed energy increases as the number of nodes increases. As clearly shown from the graph, the average consumed energy of the MTDMA schedule is higher compared to the EEMTDMA schedule. Since as the numbers of clusters grow, the numbers of nodes also grow and farther, communication between CHs grow as well. In other words, as the number of clusters increase the numbers of CHs also increase, as a result, number of communication between CHs. Thus, the energy consumption increases to know the largest capacity of the cluster in case of MTDMA since each CH consumes more energy when they communicate each other in than EEMTDMA. Despite the fact that the number of clusters in the proposed work grows, there is no communication between CH to determine the cluster's largest capacity EEMTDMA. As a result, the proposed work's energy consumption is lower than that of MTDMA, and TDMA.

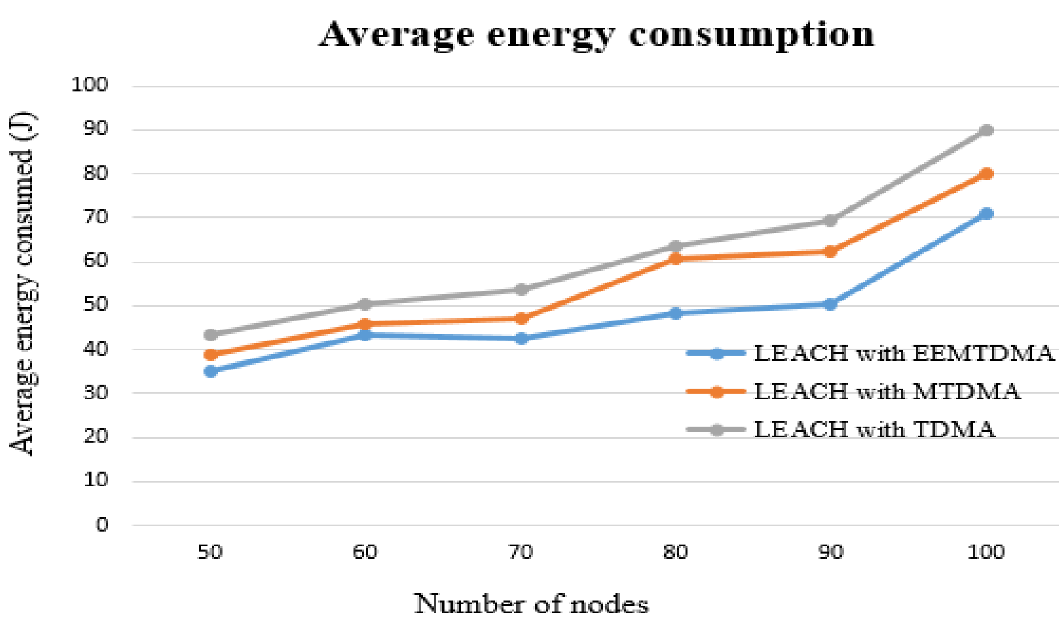

Figure 4. 6 Average Energy Consumption by Varying Number of Nodes

Chapter Five: Conclusion and Future Work

5.1 Conclusion

In this thesis work, Energy Efficient Modified TDMA algorithm has proposed to reduce unnecessary energy consumption for WSN. This algorithm aims to enhance way of assigning TDMA schedule by reducing the communication between CHs when they exchange the number of member nodes within their cluster. The announcement of their number of member nodes helps to know the largest capacity of the cluster within the network. In EEMTDMA algorithm each CH compute the number of their member nodes based on number of received join request and announce to base station then after, base station selects the largest capacity of the cluster and announce it for all CHs. Finally, each CHs use this largest capacity and assign TDMA schedule for their member nodes.

The implementation results of the proposed work have been verified using Castalia 3.3 simulator with OMNET++ framework. The proposed work has been compared to LEACH with MTDMA and LEACH with TDMA algorithm in terms of energy usage and packets received at the base station, and it has shown better results than the LEACH with MTDMA algorithm and LEACH with TDMA.

5.2 Future Work

This paper focuses solely on the issue of energy consumption in homogeneous, small-area WSNs. We are not providing data privacy and protection to the WSN at this time, but we will expand this work to include security principles in the future. We will also conduct more research into applying this algorithm to mobility of nodes, heterogeneous and large-scale area networks, as well as other LEACH variants.

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Appendix

A: Configuration File for both Algorithms

```
[Generall]

#########################
## Network          #####
########################
include ../Parameters/Castalia.ini
include ../Parameters/MAC/CSMA.ini
sim-time-limit = 1000s
SN.field_x = 100                                   #40
SN.field_y = 100                             #10
SN.numNodes = 100
SN.deployment = "[1..99]->uniform"
SN.node[1..99].ResourceManager.initialEnergy = 1000

#########################t
## Traces          #####
########################
SN.wirelessChannel.collectTraceInfo = false
SN.node[*].Communication.Radio.collectTraceInfo = false
SN.node[*].Communication.MAC.collectTraceInfo = false
SN.node[*].Communication.Routing.collectTraceInfo = true
SN.node[*].Application.collectTraceInfo = false
SN.node[*].SensorManager.collectTraceInfo = false
SN.node[*].ResourceManager.collectTraceInfo = false

#########################
## MAC             #####
########################
```

```
#-----CSMA-CA-----#

#########################
## Routing        #####
########################
SN.node[*].Communication.RoutingProtocolName = "LeachRouting"
SN.node[*].Communication.Routing.netBufferSize = 1000
SN.node[0].Communication.Routing.isSink = true
SN.node[*].Communication.Routing.slotLength = 0.2
SN.node[*].Communication.Routing.roundLength = 20s
SN.node[*].Communication.Routing.percentage = 0.05
SN.node[*].Communication.Routing.powersConfig = xmldoc("powersConfig.xml")

#########################
## Application     #####
########################
SN.node[*].ApplicationName = "ThroughputTest"
SN.node[*].Application.packet_rate = 1
SN.node[*].Application.constantDataPayload = 2000

#########################
## Wireless Channel #####
########################
SN.wirelessChannel.onlyStaticNodes = true
SN.wirelessChannel.sigma = 0
SN.wirelessChannel.bidirectionalSigma = 0
SN.wirelessChannel.pathLossExponent = 2.0          # Free Space

#########################
## Radio          #####
```

########################
SN.node[*].Communication.Radio.RadioParametersFile = "../Parameters/Radio/CC2420.txt"#

B: Modified Code for LEACH Routing with EEMTDMA

B.1 LeachRouting.cc Code for LEACH Routing with EEMTDMA

```
#include "LeachRouting.h"

Define_Module(LeachRouting);

void LeachRouting::startup()
{
  clusterLengthPacketSize = par("clusterLengthPacketSize"); LargestclusterlengthPacketSize = par("LargestclusterlengthPacketSize");

        /*--- Class parameters ---*/

    Clusterlength.clear();
}

            case LEACH_ROUTING_CLUSTERLENGTH_PACKET:{
                        string dst(netPacket->getDestination());
                        if(dst.compare(SINK_NETWORK_ADDRESS) == 0 && isSink){

        Clusterlength.push_back(netPacket->getClusterLength());
                        }
                        break;
                  }
           case  LEACH_ROUTING_LARGESTCLUSTERLENGTH_PACKET:{
                    if(isCH){
     Largestclusterlength = netPacket->getLargestclusterlength();
```

```
                }
                break;
        }
case  SEND_CLUSTERLENGTH:{
        if (clusterMembers.size()!=0){
                LeachRoutingPacket *crtlPkt = new
LeachRoutingPacket("Clusterlength Announcement Packet",
NETWORK_LAYER_PACKET);
crtlPkt->setByteLength(clusterLengthPacketSize);
crtlPkt-
>setLeachRoutingPacketKind(LEACH_ROUTING_CLUSTERLENGTH_PACKET);
crtlPkt->set Source(SELF_NETWORK_ADDRESS);
crtlPkt->set Destination(SINK_NETWORK_ADDRESS);
    clusterLength = clusterMembers.size();
    crtlPkt->setClusterLength(clusterLength);            }
                break;
        }
    case   SEND_LARGESTCLUSTERLENGTH:{
         if (Clusterlength.size()!=0){
                LeachRoutingPacket *crtlPkt = new
LeachRoutingPacket("largestClusterlength Announcement Packet",
NETWORK_LAYER_PACKET);
     crtlPkt->setByteLength(LargestclusterlengthPacketSize);
crtlPkt->
setLeachRoutingPacketKind(LEACH_ROUTING_LARGESTCLUSTERLENGTH_PACK
ET)
crtlPkt->setSource(SELF_NETWORK_ADDRESS)
crtlPkt->setDestination(BROADCAST_NETWORK_ADDRESS);
  for (int i = 0; i < Clusterlength.size(); i++)
           {
Largestclusterlength = *max_element(Clusterlength.begin(),Clusterlength.end());
```

```
        crtlPkt->setLargestclusterlength(Largestclusterlength);
}

                    break;
            }
```

B.2 LeachRouting.h Code for LEACH Routing with EEMTDMA

```
#ifndef _LEACHROUTING_H_
#define _LEACHROUTING_H_

#include <queue>
#include <vector>
#include <omnetpp.h>
#include <algorithm>
#include <string>
#include <math.h>
#include <stdlib.h>
#include <stdio.h>
#include <iostream>
#include <sstream>
#include "VirtualRouting.h"
#include "VirtualApplication.h"
#include "LeachRoutingPacket_m.h"
#include "ApplicationPacket_m.h"
#include "NoMobilityManager.h"


using namespace std;

enum LeachRoutingTimers {
        START_ROUND = 1,
        SEND_ADV = 2,
```

```
        JOIN_CH = 3,
    SEND_CLUSTERLENGTH = 4,
    SEND_LARGESTCLUSTERLENGTH = 5,
        MAKE_TDMA = 6,
        START_SLOT = 7,
        END_SLOT = 8,
};
private:
        string applicationID;
        int advPacketSize;
        int tdmaPacketSize;
    int clusterLengthPacketSize;
    int LargestclusterlengthPacketSize;
        int dataPacketSize;
        int joinPacketSize;
        double maxPower;
        double sensibility;
        double aggrConsumption;
        double slotLength;
        int clusterLength;
    int Largestclusterlength;
        double percentage;
        double probability;
        double roundLength;
        int roundNumber;
        int dataSN;

        bool isCH;
        bool isSink;
        bool isCt;
        bool endFormClus;

        vector<RoutingPacket> bufferAggregate;
        vector<int> powers;
```

```
            queue <cPacket *> tempTXBuffer;
            vector <int> clusterMembers;
            list <CHInfo> CHcandidates;
     vector <int> Clusterlength;

};
```

B.3 LeachRouting.ned Code for LEACH Routing with EEMTDMA

```
      parameters:
            string applicationID = default ("throughputTest");
            bool collectTraceInfo;
            int maxNetFrameSize = default (0);
            int netDataFrameOverhead = default (14);
            int netBufferSize = default (32);
            bool isSink = default (false);
            double percentage;
            double roundLength @unit(s);
            double slot Length;
int advPacketSize = default (9); bytes
            int joinPacketSize = default (9);
        int cluster Length = default (9);
        int Largestclusterlength = default (9);
            int tdmaPacketSize = default (150); // Type + Source + Destination + tdma = 150 bytes
            int dataPacketSize = default (9);
gates:
            output toCommunicationModule;
            output toMacModule;
            input fromCommunicationModule;
            input fromMacModule;
            input fromCommModuleResourceMgr;
}
```