A
Dissertation
On

Energy Efficient Cluster Based Adaptive Threshold Sensitive Protocol in Wireless Sensor Network

Submitted in Partial Fulfillment of the Requirement
For the Award of the Degree of

Master of Technology

in

Computer Science and Engineering

by

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2013-2015

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ACKNOWLEDGEMENT

First of all, I would like to express my deep sense of respect and gratitude to my project supervisor Mr. Rajesh KumarYadav for providing the opportunity of carrying out this project and being the guiding force behind this work. I am deeply indebted to him for the support, advice and encouragement he provided to me without which the project could not have been a success.

I am also grateful to Dr. O.P Verma, HOD, Computer Science and Engineering Department, DTU for his immense support. I would also like to acknowledge Delhi Technological University library and staff for providing the right academic resources and environment for this work to be carried out.

Last but not the least I would like to express sincere gratitude to my parents, friends and seniors for constantly encouraging me during the completion of work.

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CERTIFICATE

This is to certify that the dissertation entitled "**Energy Efficient Cluster Based Adaptive Threshold Sensitive Protocol in Wireless Sensor Network**" is a bonafide record of work done by **KshitizRohatgi, Roll No.- 2K13/CSE/07** at **Delhi Technological University**for the partial fulfillment of the requirement for the degree of **Master of Technology** in **Computer Science and Engineering**. This project was carried out under my supervision and has not been submitted elsewhere, either in part or full, for the award of any other degree or diploma to the best of my knowledge and belief.

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ABSTRACT

The Wireless Sensor Network consists of a large number of limited battery powered sensor nodes. These networks have wide range of applications related to areas like weather monitoring, forest monitoring, security and target monitoring, etc. The limited powered battery affects the network's lifetime. Various protocols have been developed to increase the network's lifetime.

In this dissertation, we developed EECHR protocol, a clustering protocol for reactive network with threshold sensitive homogeneous sensor nodes. It includes an energy efficient cluster head selection and cluster formation techniques. It also includes an adaptive feature to make the BS aware of the status of nodes in the network which remains idle for long time. It also provides preference to the nodes sensing critical information to directly send their information to the BS. The nodes sensing critical information are released from the burden of becoming CH and they don't take part in CH selection. Our proposed protocol performs better than the other conventional protocol like LEACH, E-LEACH, I-LEACH.

We also develop a multi hop routing protocol ATEEM for the homogeneous reactive network. It provides an energy efficient data transfer mechanism which is used by the critical nodes to transfer data to BS, by CHs to transmit data to BS and also by Non- CH node to transmit data to CH node. It includes an energy efficient cluster formation mechanism. We have also developed a mechanism to find the critical region in the given network area on the basis of information stored in the BS. It performed better than the EECHR protocol and TEEN protocol.

Keyword: Critical region, Energy efficient, Cluster head, homogeneous, Critical information, Adaptive meter

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List of Abbreviations

WSNs	Wireless Sensor Networks
BS	Base Station
CH	Cluster Head
DES	Data Encryption Standard
AES	Advance Encryption Standard
MTE	Minimum Transmission Energy
WANET	Wireless Adhoc Network
TCP/IP	Transmission Control Protocol/ Internet Protocol
ADC	Analog to Digital Converter
SHLM	Self Healing Land Mines
GDI	Great Duck Island
TDMA	Time Division Multiple Access
EOFS	Environment Observation and Forecasting System
GPS	Global Positioning System
CORIE	Columbian River
ALERT	Automated Local Evaluation in Real Time
SHM	Structural Health Monitoring
SPIN	Sensor Protocol for Information via Negotiation
ADV	Advertisement message
REQ	Request message
DD	Direct Diffusion
GAF	Geographic Adaptive Fidelity protocol

GEAR	Geographic and Energy Aware Routing protocol
PEGASIS	Power Efficient Gathering in Sensor Information System
LEACH	Low Energy Adaptive Clustering Hierarchy protocol
LEACH-C	Low Energy Adaptive Clustering Hierarchy protocol- Centralize
E-LEACH	Energy- Low Energy Adaptive Clustering Hierarchy protocol
M-LEACH	Multihop- Low Energy Adaptive Clustering Hierarchy protocol
I-LEACH	Improved- Low Energy Adaptive Clustering Hierarchy protocol
TEEN	Threshold sensitive Energy Efficient sensor Network protocol
EECHR	Energy Efficient Critical Homogeneous Reactive protocol
ATEEM	Adaptive Threshold sensitive Energy Efficient Multihop routing protocol
HV	Hard Value threshold
SV	Soft Value threshold
CV	Critical Value threshold
CSV	Current Sensed Value
PSV	Previous Sensed Value
A_m	Adaptive meter
MCE	Minimum Communication Energy
HN	Helper Node
GN	Gateway Node

CHAPTER 1

INTRODUCTION

Wireless Sensor Networks is a network of autonomous devices called sensor nodes that are distributed randomly over the entire field area to sense and communicate the useful information among each other in an effective way. These sensor nodes are deployed randomly in a given sensing area such as agriculture land or forest land. They can also deploy statically with some strategy to fulfill the condition of WSNs. These nodes are limited battery constrained, memory constrained, having short communication range and have limited processing capability. Also the node's battery is not rechargeable. Although, sensor node has limited processing capability, but when these nodes work in a collaborative manner, they can analyze the desired environment in great detail [1, 3, 5]. All the nodes create a communication network among themselves using various optimized mechanisms to transfer the sensed information related to the environmental and physical conditions as motion, temperature, sound etc. to the central body in an effective manner. The central body is also known as sink node or BS, which collects information from all the nearby nodes and finally operates on that information. The BS has ample amount of power supply and is working continuously to operate on the provided information [2]. Recent advances in technology have made the sensor node to work effectively at low cost in areas such as weather monitoring, cyclone monitoring, security- surveillance, health care applications, in vehicle tracking and in widely used smart phones etc [3, 4].

Wide range of applications and recent advancement in WSNs made it a popular area of research and lots of research is happening in this area. Major research is done on how to increase the network's lifetime by making the effective use of the node's energy in sensing the information and reducing the number of transmissions by the node. Since the sensor node has limited battery and in the absence of energy efficient technique, it will drain out very fast and decrease the network's lifetime as well as the throughput of the network. A large number of routing techniques have been proposed in the recent days to increase the network's lifetime [18, 19, 20, 21, 28, 29, 30]. These routing algorithms have made the communication very effective and also increase the throughput of the network.

Various routing protocols use different data aggregation technique to increase the lifetime of the network and make it energy efficient. Data Aggregation techniques [6] helps the sensor nodes by not transmitting the redundant data to BS. It removes the redundant data from the whole data and then sends it to BS. Hence, data aggregation is another field of research in WSNs. Data Compression [8] is one of the fields of research, in which the information gathered by the sensor node is compressed first and then transmitted to the BS. The compressed data reduces the cost required to send data as well as reduce the energy required by sensor node to transmit the data to the BS. The sensor node gathers the local area information and transmits only the compressed data to the sink node which increases its lifetime as it is sending the compressed data and not the whole data as it is.This makes the network an energy efficient network. Security [2] is another major area of concern in WSNs. The data transmitted by the sensor node is not secure any one can sense that data in between and can tampered that data. To make data remain intact various encryption techniques are used. Encryption techniques like DES and AES use by the sensor node while transmitting data to BS.

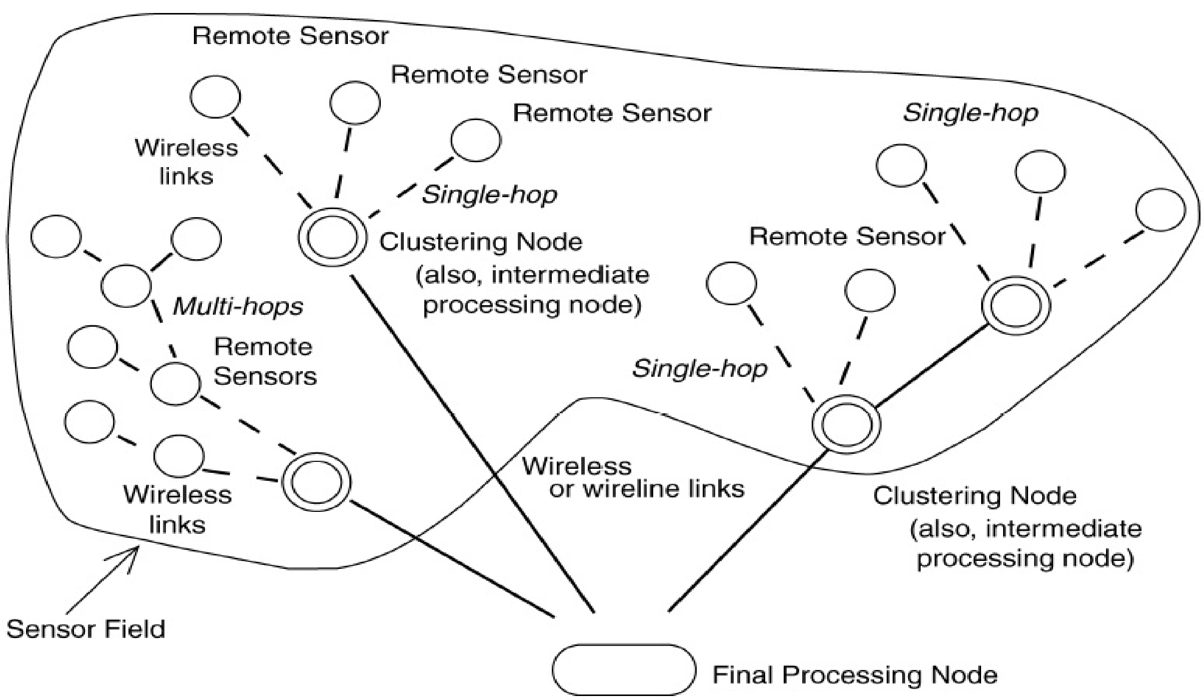

Figure 1.1 Wireless Sensor Network

Figure 1.1 represents the structure of WSN. Final processing node resembles the sink node or BS. In this scenario, BS is located outside the sensor field and gathering the information from the various CH through single hop or multi hop. In the above figure nearby remote sensor form the cluster and select one of the remote sensors as a CH for that particular cluster. All the other nodes in the cluster after sensing the data send their sensed data to this CH in a single hop transmission. After receiving data from all the nodes in cluster CH aggregate that data and transmit it to the BS via a single hop or multi hop transmission. This process of transmission is periodic in nature and in each round the CH selected is not the one which is selected in the previous round.

Traditionally, two conventional approaches are used for transmission of data to BS. First is Direct transmission protocol [20], each sensor node sends data to BS directly without any delay. This protocol suffers when BS is positioned very far from the remote sensor. Each sensor node has to use large amounts of energy to transmit data, and decreases the network's lifetime. The other approach is MTE protocol [20], in this protocol data meant for BS will reach to it via intermediate nodes. These nodes act as a router for routing the data to BS.

Thus, various routing protocols have been proposed to prolong the network's lifetime. One such class of routing protocol is a cluster routing protocol [18, 19, 20, 28] in which research has been done at various levels. Clustering is a technique in which nearby sensor node forms the cluster and select one of the nodes as a CH for that particular cluster, then all the other node transmit their data to that CH. CH will then send the data to the BS. The CH selection is done on the basis of probability.

These clustering protocols are different from the traditional routing protocol as they operate on the sensor networks not on the wireless ad hoc networks. Sensor networks are different from the wireless ad hoc network under various properties as listed below [1, 3]:-

- **Node Density:** The number of nodes in sensor networks is very large as they are sensing the environment's information, whereas in WANET number of nodes is limited as the nodes here are laptop, desktop, smart phones etc.
- **Resources:** In WSNs the resources are limited as sensor nodes have limited battery, low processing power and less memory space. Also, their batteries are not rechargeable. But in WANET nodes does not suffer from all these issues.

- **Node's Identity:** In case of WANET every node connected to the network has a global identifier which helps them to be identified globally outside the particular network. This global identifier is known as an IP address. But in WSNs every node has a local identifier but they don't have a global identifier as the amount of nodes in the network is very large.
- **Change in Topology:** The topology in WSNs changes very frequently due to failure of node, node movement and environmental interference. But in case of WANET node can't leave or add without permission, it requires human intervention for the change in topology whereas in the WSNs sensor node are very far from human reach.

1.1. Component of WSNs

The various components of the WSNs are given below:

- **Sensor Node:** Sensor node is a main component of WSNs. It performs various roles in networks such as data gathering, data processing, routing or storing of data. It senses the information from the surroundings and converts this information into electrical signals for transmission to BS. **Figure 1.2** shows the architecture of a wireless sensor node. It consists of four major components.
  1. **Sensing subsystem:** It includes one or more sensor nodes, which sense the data and produce the analog signal. These analog signals are converted to digital by ADC, which is also the part of sensing subsystem.
  2. **Processing subsystem:** It includes the micro controller unit to control the processing of the digital data provided by the sensing subsystem. This subsystem has an associated memory unit to store the input data.
  3. **Radio subsystem:** This is used to connect the node to the network and for the communication of data between the nodes.
  4. **Power Supply subsystem:** This system provides the power to the sensor node to perform various tasks. The power given is in the form of DC. The battery of the node is not rechargeable.

Other additional components are power generator, mobilizer to change their location and location finder to find their exact location [7].

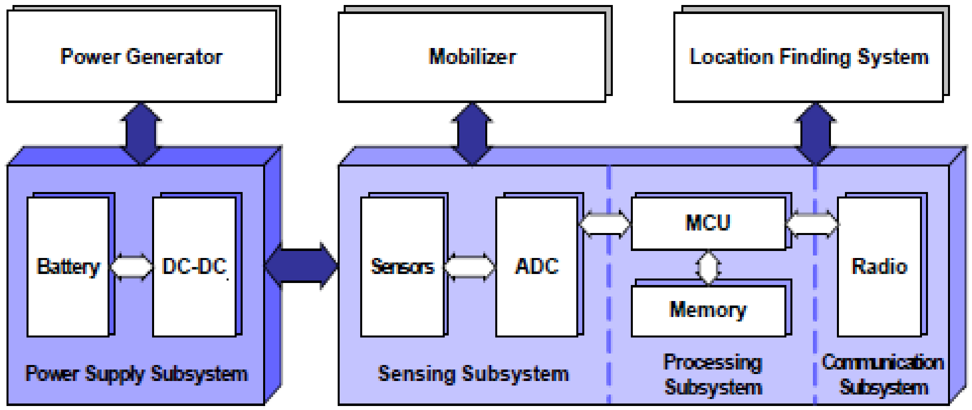

Figure 1.2 Architecture of Wireless Sensor Node

- **Cluster:**The cluster is a group formed by the nearby nodes in the network area to increase the network's lifetime. As the node density is high in these networks, clusters are formed to simplify the task of communication.
- **Cluster Head:** The CH is the leader of the cluster. It is also a sensor node given additional task to perform in the cluster. All the Non- CH nodes in the cluster have to transmit their data to the CH node. CH node aggregated all the data, perform the compression technique to compress the data and send that data to BS [14].
- **Base Station:** The BS is also known as sink node. It is an interface between the end user and wireless sensor networks. It has unlimited resources having unconstrained computing power and energy supply. It gathers data from all the nodes in the wireless sensor networks. There can be single or multiple base stations [14].
- **End User:** The information sensed by these nodes is used by various applications. The information gathered can be uploaded on the internet and can be used by various applications. The query generated information requires the query sent from end user to network, based on the query the data is gathered by the network and sent back to end user [14].

1.2. Sensor Network Protocol Stack

The protocol stack of WSN is somewhat similar to that of TCP/IP protocol stack, but it has three planes to handle the issues of sensor networks as shown in **figure 1.3**.

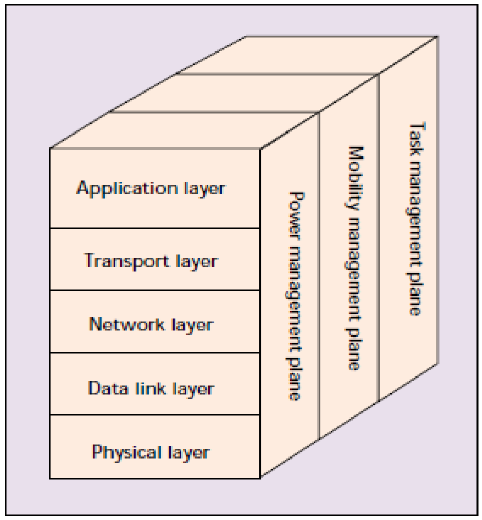

Figure 1.3 Sensor Networks Protocol Stack

The physical layer needs to take care of robust transmission, modulation and receiving techniques. As the environment is noisy and sensor node may be mobile which require the data link layer to be power aware and be able to detect collision from the neighbor's broadcast. The network layer manages the routing of data in the network, which it gets from the transport layer. The transport layer controls the flow of data to the network layer. The sensor networks are application specific so they required various application software designed for the application layer.

But in addition [7], it has three planes to monitor the position, movement, power and task distributions among the sensor nodes. The power management plane is used to manage the power of the sensor node as sensor node has limited battery. It is used to manage the power of a node efficiently, for example, in case that it will turn off the receiver after receiving a message from one of its neighbors, and also when the node is running out of battery in that case it will stop its transmission and used all its available battery for sensing purposes. The mobility management plane is used to monitor the movement of a node and sensor node can keep the track of all its neighboring nodes which help it in utilizing its power efficiently. The task management plane schedules the various tasks among the sensors in such a way that their power is utilized efficiently. Also not all the sensor nodes in a particular region have to sense the data at the same time. This helps in increasing the network's lifetime. These all management planes are needed in sensor networks because these networks have limited resources. These planes help sensor networks to utilize these limited resources in a better way so as to increase the efficiency of the networks.

1.3. Characteristics of WSNs

The different characteristics of WSNs are given below [1,3]:

- **Limited storage:** The sensor nodes are very small devices specially built to sense the data in their vicinity and store that sensed data in their limited memory. Limited memory reduces their storage capacity, but also reduces their cost which helps to increase the amount of sensor in a specified region.
- **Densely self deployed network:** As they have low cost they can be used in large number, scattered randomly or statically in the network area. Sensor node can configure itself easily and can manage its self communication in the network.
- **Sensor heterogeneity:** As sensor node existence in the networks is not guaranteed due to limited resources, environmental conditions or physical damages.
- **Application Specific:** It is tough to modify in the WSNs once they are deployed for an application. Due to which these networks are designed on the basis of application.
- **Data redundancy:** Since they are deployed densely, which means a large number of sensors are sensing information about small region. This increases the probability of data redundancy in that region. Data redundancy affects the efficiency of the networks. Various techniques are used to remove redundancy from the network.
- **Limited processing and battery:** They have limited processing capability as well as their batteries are not rechargeable.
- **Topological inconsistency:** Networks topology changes very frequently due to harsh environmental conditions and limited power of sensor node.

- **Limited communication range:** The communication range of the sensor nodes is limited.

1.4. Motivation

Since the sensor nodes have limited battery resource, various hierarchical routing protocols have been developed to utilize the limited energy of the sensor node in the most efficient manner. The routing protocols developed use various techniques like multi hop routing, cluster formation, single hop routing, etc. In clustering protocols [18, 19, 20, 21] sensor nodes form the clusters to efficiently utilize the energy of the nodes. Wireless Sensor Networks is divided into two categories on the basis of the initial energy of the nodes. Homogeneous networks, where all the nodes have same initial energy. Heterogeneous networks, where the nodes are grouped into sets and each set is given different initial energy.

These developed WSNs are used for different applications. The WSNs are divided into two categories based on the type of applications.

Proactive Protocols: Those applications which require information to be transmitted periodically, uses proactive protocols [18, 19, 20]. The data are sent to the BS after every fixed interval.

*Reactive Protocols:*Those applications which are time critical and require data transmission when there is a drastic change in the sensing environment, uses reactive protocols [22, 23]. The data are sent to BS when drastic change occurs in the sensing environment.

Thus the lots of researches are done in developing an energy efficient clustering protocol for various types of networks. We in this dissertation put emphasis on developing an energy efficient clustering mechanism for homogeneous reactive networks and also address some of the drawbacks of reactive protocols.

1.5. Research Objective

The objectives of the research work are given below:

- To develop an energy efficient mechanism for the cluster head selection procedure and cluster formation procedure.
- To develop a mechanism for finding the critical region in the given network field.
- To make BS aware of the status of every node in the network when node remains idle for long duration.
- To provide highest priority to the critical information and route the information in the most efficient manner.
- To transmit the information to BS in the efficient way by using the multi hop routing at various levels.
- To allow the user to change the value of certain parameters which are broadcast by the BS.

1.6. Thesis Organization

We start this dissertation with the introduction given in the Chapter 1. In Chapter 2, we provide the detailed description about the WSNs which includes characteristics, issues and applications. Chapter 3 gives the detail of the conventional protocols which are related to our work. In chapter 4 we explain the working of the two proposed protocols EECHR protocol and ATEEM routing protocol. In the chapter 5, we evaluate the performance of our proposed protocol with the conventional protocols. Finally, we conclude about the work done and observations in the Chapter 6.

CHAPTER 2

LITERATURE SURVEY

2.1. Applications of WSNs

Recent researches in wireless communication make it a pragmatic vision to deploy inexpensive, low power sensor networks. There are numerous applications which use sensor to sense the information as per the application. The activity of sensing can be periodic or sporadic. In periodic sensing these sensors can use to sense various environmental conditions like temperature, humidity, noise level, soil fertility, nuclear radiations, etc. Whereas in sporadic sensing, activities like detecting border intrusion, sensing the rise in temperature of the furnace, measuring stress on structures or machineries. Some of the domain applications of WSNs are military application, habitat monitoring, precision agriculture, environmental monitoring, health application or industrial application.

- **Military Applications:** The main motive to develop the sensor network is to fulfill the needs of military operations. Military require the cost effective surveillance in inhospitable terrains. The various properties of sensor networks like low cost, dynamic changes in topology, self configuration, fault tolerance justify them being suitable for battlefield surveillance. Military communications require networks must be reliable, efficient, secured and support multicast routing. All these requirements can be easily fulfilled by sensor networks in a cost effective manner. Deployment of sensor network in the battleground was quite easy and very effective in providing information even at the time of battle. If some nodes are destroyed during the battle, then the sensor network has a capability to reconfigure itself depending on the nodes which are active at that time. Other military operations are like target tracking, target detection requires the use of sensors. Sensors are also used in the guidance system of intelligent missiles to help it in locating the target precisely and also in detection of attack from the mass destruction weapon such as chemical, nuclear, biological. They can be used in accessing damages in areas which are not in range of humans after the battle. Other than war, they are used in disaster relief and peacekeeping. One of the applications is SHLM [9], use acoustic and accelerometer sensor which help antitank mine sense threat and respond autonomously by moving.

- **Habitat Monitoring:** Researches describe habitat monitoring as a driver application for WSNs. One such application is the GDI [12] system, running efficiently, to gather information about environmental conditions during the 7 month breeding period of ducks. Minimal human interference is required while monitoring seabird colonies. Human presence can distort the results by changing behavioral patterns. WSN is the best way to monitor these colonies. These networks are used to gather information about the environmental factors which can help in making good nest, what is their occupancy pattern during incubation and environmental changes occur in burrows during breeding season. In August 2002, researcher deploys sensor network in GDI to monitor Leach storm petrel behavior. Another application ZebraNet is used to track the movement of zebras on the field. The modus operandi of this application is to gather dynamic data about the position of zebra in order to understand their mobility pattern. Biologists deploy sensors in the collar, carried by animals.

- **Health Application:** Application in this field includes tracking of doctor or patient in hospital, telemonitoring of patient physiological data, administrating medical drugs in hospital, cancer detection, glucose level monitor, heart beat indicator, organ monitor etc. One such research project is the development of artificial retina [12]. In this project, retina prosthesis chip consisting of 100 sensors is implanted in human eyes. This help patient with no vision to see at an acceptable level. Wireless communication is needed for image identification, feedback control and validation. The communication is periodic, so TDMA communication suits best to conserve the energy. Embedding sensors inside the human body is challenging issue as the system must be safe and reliable, require minimal maintenance.

- **Environmental Monitoring:** EOFS is one of distributed system that span over a large geographical area to monitor the environmental pollution, flooding, etc [12]. WSNs are used to reduce the loss in natural calamities or disasters. They are used to prevent and detect forest fires. Sensors are deployed in forest to detect flames, heat and gases which help in identifying the molecule of chemical compound released during combustion and with the GPS the geographical location of fire can be easily identified. Prevention of fire is done by periodic monitoring of the temperature of a given area if certain level of changes occurs in the temperature reading, then the signals are sent to the BS about the status of that area. CORIE [12] is one such model deployed over the Columbian river. It has 13 stationary sensor nodes deployed across the river and 1 mobile sensor station drift off shore. It suffers from practical difficulties. Another well known Wireless Senor Network is ALERT [12]deployed in real world in 1970's to provide the information about rainfall and water level which help in evaluating the probability of flood. ALERT is equipped with hydrological, water level, temperature and wind sensors, which sense data and transmit it via light of sight radio communication to BS. It is effectively used in California and Arizona.

- **Structure Health Monitoring System:** SHM is one of the domain application of WSNs. Usage of sensor nodes includes detecting the damage to the building, localizing damage, measuring the extent of damage, and predicting the life of the structure. Sensors are deployed on highway bridges or multi story building to monitor their stability condition. Sensors sense the stress or strain value, temperature value of specific points to monitor the damage. US and Canada develops these systems in early 90's. New York becomes the first state which has a wireless bridge monitoring system. India to use an application named Bri-Mon.

- **Precision Agriculture:** The recent technological development in WSNs has made it possible to monitor the greenhouse effect in precision agriculture [11]. Recent changes in climatic conditions and uneven distribution of rainfall have compelled the farmer to use effective measures to protect their crop from damaging. Sensors sensing the humidity, temperature, pressure and light are deployed in agriculture field to detect the possible plant disease, the risk of frost and finding watering requirement based on soil humidity.

They are used to control and monitor the growth of delicate crops like vines or tropical fruits, where a sudden or a slight change in environmental condition can affect the result.

- **Industrial Application:** This application requires sensor networks to monitor the Process control and factory automations [10]. There are other areas in this field which requires monitoring are supply chain management system, real time monitoring of machine's health, checking of air pressure and leakage of gas, real time monitoring of inventory system and remote monitoring of contaminated areas.

- **Home Appliance and Other Applications:** Through electronic appliance the sensors are used by common people to enhance their standard of living [12]. They are used in smart phones, smart televisions to detect motion or movement of hands. Touch sensors, gyrometer sensors, location sensors are used by these appliances. They are also used in street traffic monitoring and parking assistance by automobiles. Smart kindergarten is an application for building an effective childhood education process.

2.2. Routing Challenges and Design Issues in WSNs

Despite of various applications of Wireless Sensor Networks, these networks suffer from different routing challenges and design issues. Design of WSNs is application specifics as every application has different requirements. One such general requirement is to carry out an effective transmission of sensed data while trying to prolong the network's lifetime by using some energy efficient techniques. The design of routing algorithm suffers from numerous challenging factors. The following are the most common design issues and challenging factors faced by WSNs [1, 15]:

- **Deployment of Node:** Node's deployment in WSNs is application dependent. It can be either static or dynamic node deployment. In static node deployment, the nodes are placed manually at the time of network setup and the data is routed through a predefined path. While in dynamic deployment the nodes are scattered all over the network area randomly and also the resultant distribution is non uniform. Therefore, the efficient routing technique is required for network connectivity and effective network operation. Sensor nodes have limited bandwidth which makes them to use effective short range transmission for the routing of data to BS via multi hop.

- **Energy consumption without losing accuracy:** Sensor node uses all its available energy for performing computation and transmission of information in the network environment. Since the sensor node has limited battery various energy efficient clustering techniques are used for prolonging the network's lifetime. In a multi hop network, the data is reached to BS via multiple nodes each node also acts as a router to route data to their destination. The failure of a particular node can cause a change in a topology of the network and might require rerouting of that packet and reorganization of a network.

- **Data Reporting Model:** Reporting models depend on the type of application and time criticality of the sensed data. These are grouped into event driven, query driven, time driven (continuous) or hybrid. Time driven model is suitable for periodic monitoring of the network. These networks are called as proactive networks. In these networks nodes, switch on their sensor and transmitter after every regular interval of time to sense and transmit the information on a periodic basis. In event driven or query driven model the sensor reacts to sudden or drastic change in the environment due to the occurrence of a certain event or a query generated by end users. These models are used in reactive networks and are suitable for time critical applications. These models can be combined to produce a hybrid model. These models help in routing data very effectively.

- **Node Heterogeneity:** Mostly in WSNs all the nodes are homogeneous, which means having equal capability of processing, transmitting and power. But in some applications we have nodes with different capability or role. However, the heterogeneity has raised some issues in the networks. There are applications which require different set of sensors for monitoring humidity and pressure in a particular area, detecting motion, capturing images or video tracking of a moving object. These nodes can be deployed statically or randomly. Also, these nodes gathered data a different rate, but the size of packets transmitted by each node is same. For example, in clustering technique cluster head node can be chosen among the deployed nodes or is given some extra energy, processing and transmitting power and additional memory to store the data gathered from different nodes in the cluster.

- **Fault tolerance:** It is the ability of the network to work effectively even in case of individual node failure or network congestion in some region of the network. The node failure may occur due to low power, physical damage of that sensor node or the node might get blocked due to environmental interference. Thus the failure of a particular node should not affect the whole network. The network must have a capability to change its topology immediately so as to reroute the data which is meant for that particular node and to save the network from the loss of data.

- **Scalability:** In WSNs the amount of sensor nodes is in the order of thousands or hundred deployed in a small region. Thus, the designed routing algorithm must have the ability to scale as the network's size changes. Also, the scalability must not affect the performance of the algorithm.

- **Network Coverage:** In order to increase the efficiency of the network, network coverage range should be determined selectively. Every node in the network has a certain environmental view. This view has limited range and accuracy. The limited range transmission between the sensor nodes will decrease the amount of energy spent in data transmission to BS. The huge coverage area increases the probability of eavesdropping. Hence, it is an important design issue.

- **Network Connectivity:** Maintaining the connectivity among all the sensor nodes through the network's lifetime is a huge challenge. The energy of each node is used in an efficient way by allowing some node to go into sleep mode in between the successive transmission. Various routing techniques are used to route the data in an energy efficient manner to the BS.

- **Transmission Media:** In a cluster based sensor networks, the nodes communicate with each other via wireless link. They transmit data through the wireless medium. But the wireless medium has certain problems (fading, high error rate), which also affect the operation of sensor networks. Generally nodes have low bandwidth. To conserve the energy the sensor networks use TDMA based protocol. Bluetooth is another technology used for the communication.

- **Mobility:** Mostly all the nodes in WSNs are stationary. But in some specific application require the node to move inside the network throughout its lifetime. Some applications require the BS to change its position on a regular basis throughout the network's lifetime. In addition, routing of packet from or to the moving node is a more challenging issue. Also, the sensed phenomenon of the sensor node can be either dynamic or static, depends on the application for which it is used for example, target detection requires dynamic sensing and forest monitoring to require static sensing. Static event sensing is done when the network is reactive in nature. While dynamic event sensing requires periodic reporting of data.

- **Data Aggregation:** Since a large number of nodes is sensing the particular region in the network, this increase the probability of redundancy in data sensed by these nodes. Data aggregation [6] is a technique in which data from multiple nodes is aggregated so as to reduce the number of transmissions to the BS. This will help in increasing the network's lifetime. Different type of aggregation functions is used, for example maxima, minima and average. This technique is used to increase the energy efficiency and optimized the number of data transfer to the BS. Data fusion is another technique, in which incoming signal from different nodes are combined to produce a more accurate output signal and also help in reducing the noise from the signal.

- **Quality of Service:** There are some applications which require the data sensed should be delivered within a certain period of time, otherwise it will become useless. Some of real time application required data must be delivered as soon as it is sensed. Whereas some application give more importance to energy conservation than to the quality of data sent. Usability and reliability usually depend on QoS.

- **Security:** As the wireless medium is an unsecure transmission medium. The data sent over it can be easily intercepted and tampered. The applications used for military purpose have security of data as their utmost priority. But developing secure energy efficient cluster based routing technique is one of the major challenging issues.

2.3.Routing in WSNs

Routing is a technique of determining an efficient path between the source node and the receiving node for transmitting data. Due to the scarcity of energy resource in the sensor network, increasing the lifetime of the network is a huge challenge. So to increase the efficiency of network routing is often used in WSNs at the network layer. However, limited battery power, non- rechargeable battery, the distance between the nodes, load balancing on a particular path and reliability of that path mainly affects the lifetime of the network. Also in WSNs many nodes are deployed in a specified region to sense the information about that region, this increases the probability of data redundancy in the sensed value. To remove this redundancy the various data aggregation techniques are used by the node which gathered the data from the various nodes. After performing data aggregation technique on data, data compression technique is applied to the data to compress it. This compressed data are transmitted to the sink node by various routing techniques. But the WSNs cannot use the traditional routing algorithm to address its need.

Figure 2.1 represents the classification of routing algorithms which are used by WSNs to address their needs [13]. According to this classification routing techniques are mainly classified into two categories: Network structure based routing and Protocol operation based routing. Flat based routing, hierarchical routing and location based routing come under the section Network structure based routing. While negotiation based routing, multipath routing, query based routing, QoS based routing, coherent based routing comes under Protocol operation based routing. In addition to the above, the routing protocols are divided into three sections, namely Proactive, Reactive and Hybrid routing protocol. In proactive protocols the routing table is maintained for all the nodes using periodic dissemination of routing information. All the routes are computed before their actual need. While in reactive protocols, nodes do not maintain the global information of all the routing routes to all the nodes, rather route selection is done on demand dynamically between the source node and the destination node. Hybrid is the combination of the above two protocols.

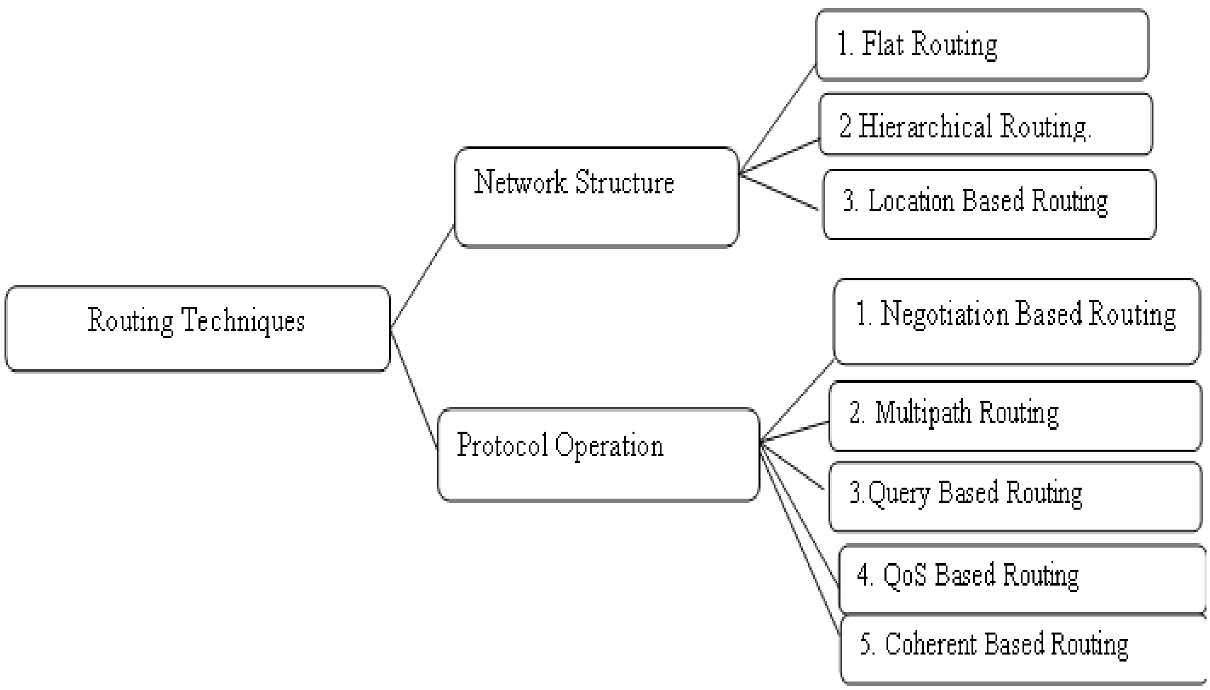

Figure 2.1 Classification of Routing Techniques

2.3.1. Network Structure Based Routing

Network structure based routing is further classified into given below categories:

- **Flat Based Routing:** In flat based routing, each node plays a similar role and functionalities, sensing task is performed in collaboration among these identical nodes. Although the nodes are identical, but the node distribution in the network is random and not fixed [13]. In addition, these nodes are not given any global identifier because they are distributed in very large numbers over the entire network. Nodes can communicate to

BS either directly or indirectly. It uses data centric mode in which the BS sends the query to a particular region and waits for the reply from the sensors placed in that region. Each node sense the nearest neighboring node and transmit data in a data centric mode. The main purpose of using flat based routing is its simplicity and it incurs no overheads. In addition the networks are easily scalable as the nodes have identical properties. However, multi-hop routing is used to maximize the network's lifetime by balancing the carried load. But the main drawback of this routing protocol is that fairness among the nodes is not maintained and may lead to the generation of hotspot during the uniform distribution of nodes in the network. As if there is only one BS in the network, then the nodes near the BS have their energy consumed very fast and minimize the network lifetime. Flooding and Gossiping are the two famous routing protocols. In flooding, the node sends its data to all the other nodes in the network and further the receiving node will resend it to all its neighboring nodes, this result in data redundancy. Gossiping is somewhat similar to flooding, but here only one of the neighbors is selected randomly to forward the sensed data and hence reduce the energy consumption.

SPIN [15] is an adaptive protocol that distributes all the information to every node in the network and each node is considered as a potential BS. This makes simple for user to query any of the nodes and gets the required information easily. This protocol uses a data negotiation technique, that nodes in the nearby vicinity sense similar data and hence there is a need to transmit that data which other nodes do not posses. Nodes in SPIN protocol perform the metadata negotiation technique before its transmission to other nodes. This provides an assurance that no redundant data will be transmitted. SPIN is the three stage protocol. The node which is willing to send its data to other nodes will first broadcast ADV message to all the nodes. ADV message contains information about metadata. If the other nodes are interested in that information, then they can send the REQ message to that node. After receiving REQ message from all the nodes, the node sends DATA to all those neighboring nodes. The neighbor nodes repeat this process.

DD [15] is another data aggregation protocol paradigm for sensor networks. It is data centric and application aware protocol, which means all the information generated by sensor node are named by attribute value pair. The basic idea of DD is to merge the data from all the source nodes by removing the redundancy from it, and help in minimizing the number of transmissions, thus increasing the network's lifetime. The BS broadcasts the interest to all the nodes. As the interest propagates inside the network, a gradient is set up towards the nodes from which it receives the request. Data dissemination will start after the gradient is set up between the source nodes and sink node.

- **Hierarchical Based Routing:**Different role, functionality and capabilities are given to all the nodes in the network, when using this type of routing algorithms [1]. Nodes are divided into sets. Each set of nodes is given different role and functions to perform. The whole network is divided into clusters. The size of the cluster is not uniform throughout the network. Each cluster has some nodes out which one is nominated as head of the cluster (cluster head). Data packets from the nodes are sent to their CH and it's the responsibility of CH to send it to the BS. The CH manages, collect, aggregate the data from all the nodes inside the cluster. The cluster formation and CH selection are performed periodically so as to utilize the energy effectively and prolonging the network's lifetime. The rotation of CH periodically ensures the uniform energy consumption and prevents the network from the hotspot. The cluster head selection is done on the basis of probability.

The main advantage of these protocols is that, they require minimal number of transmissions to the BS and hence reduce the data redundancy at the BS. The data aggregation techniques are performed by the CH over the gather data from the nodes in the cluster and transmit that aggregated data as a single unit to the BS. Although the CH has to bear the cost of aggregation, but this cost is smaller than cost bears by all the nodes for transmitting their data to BS directly. However hierarchical routing suffers from some drawbacks as creation of hotspot due to the CH election procedure, need of extra energy by CH for performing aggregation, the scalability of the network increases the overhead of the CH. Some of the examples of hierarchical based routing are LEACH [20] protocol, TEEN [23] and PEGASIS [24] protocols. LEACH protocol forms the cluster based on the received signal strength and perform, a CH election on the basis of probability. Thus CH form is used as a gateway to the sink node. TEEN is responsive protocol react to sudden and drastic change in the sensed value such as temperature, pressure, humidity, etc. PEGASIS forms the chain of sensor nodes to transmit data to the sink node. Each node can transmit or receive data from its neighbor and only one node is selected to transmit to BS.

- **Location Based Routing:** In this type of routing sensor nodes are represented by their location. The position of the nodes is used to route packet to the BS[1]. This information is used to select and maintain the optimal path between the source nodes and sink node. To find the optimal path the distance between the nodes is calculated and estimation of the consumed energy is done. To reduce the energy consumption and increasing the network's lifetime various power management techniques is used such as allowing the sensor node to go into sleep mode when not sensing new data. Mainly efficiency of routing protocol depends upon location information and area partitioning. The advantage of location routing protocol is finding an optimal path between the source node and destination which prolong the network's lifetime. However the drawback of this type of protocols is the challenges in designing the sleep mode for the node.

GAF[15]is mainly the energy aware location based routing protocol used in mobile ad-hoc network, but can be applied to sensor network as well. In this routing protocol the whole network area is divided into zones. In each zone only one node is active at a particular time rest all are in sleeping mode, this helps in utilizing the energy of nodes effectively. The node which is active is responsible for sensing the information in that zone and transmits that information to BS. Each node has GPS to associate itself with the zone. GAF lifetime increases as the number of nodes increases. Each node has to perform three tasks, determining its neighboring node in a particular zone, reflecting active participation in data transmission, using of sleep mode when not transmitting. GAF can be used in non mobility or mobility of the nodes. In the mobile network, each node has to estimates it's leaving time for that zone and sends this to their neighbor in the zone. If the active node leaving time is going to expire, then one of the sleeping nodes must become active before the previous active node leaves the zone.

GEAR [15] is a protocol which uses geographic information while distributing the queries to the specified region. Here queries also include the geographic information. The key here is to optimize the concept of DD by using the geographic information. Here the query is sent to a certain region and not to all the regions in the network this helps in conserving energy. Each node in GEAR has two types of cost estimated cost and learning cost. The estimated cost is calculated on the basis of residual energy and the distance from the destination node. The learning cost is the sum of estimate cost and cost incurred due to holes in the network. The hole occurs when a node does not have neighboring node closer to the target zone and it has to transmit the data to that zone. If there is no hole, then learning cost is equal to estimate cost.

2.3.2. Protocol Operation Based Routing

The routing described in this section is based on the operation of the protocol. Some of them are given below [1, 15]:

- **Negotiation Based Routing:** This type of routing protocol uses a series of negotiation messages before the actual transmission of data. These messages reduce the data redundancy and prevent the neighboring node and BS from getting the duplicate data. They use high level descriptor to avoid the transmission of redundant data. The above described SPIN protocol uses these negotiation messages to avoid data redundancy in the transmission. The motivation comes from the flooding protocol in which data is flooded to all the nodes even if they have got that data from the other node and increase data redundancy at the BS. The SPIN protocol prevents redundant data from transmission to the next node by the help these negotiation messages. These messages contain information about the data. Sequential assignment routing protocol uses these messages to transmit information.

- **Multipath Based Routing:**In this type of routing there exist multiple paths between the source node and the destination node. The objective is to select an optimal path from the existing multiple path every time when there is the need for data transfer. The resilience of these protocols is very high as there exist, an alternate path between the source node and the destination node if the optimal path fails. Multiple path helps in reducing the traffic over the particular path. This increases the network reliability, but at the expense of overhead incurs in maintaining these alternate paths.

The author of [16] proposed an energy efficient routing algorithm which will route packets from the path whose nodes have the largest residual energy. This path remains in existence until the energy of the nodes in this path falls below the energy of the alternate path. If it falls below it from then onwards the alternate path is used for transmission.

The author of [17] uses set of sub optimal path to prolong the network's lifetime. It uses a tradeoff between the minimal aggregated power consumed and the total remaining energy of the network.

- **Query Based Routing:**In query based routing the query is generated from the destination node with the help of end users. This query is transmitted to the node of interest and that node after matching its interest sent back the result of the query to the destination node. The query is generated in high level or natural language. The advantage of this type of routing is that it removes redundancy and allows a minimal number of transmissions across the sensor network. But it is not suitable for the applications which require continuous monitoring of the environment.

  DD is one the protocol, which uses a query based routing approach. In this protocol the BS sends the query of interest to all the nodes, every nodes match the query with its interest. Only the node which interest matches the query transmits the result of the query to the BS. For data transmission a gradient path is set up between the source node and the sink node.

- **QoS Based Routing:** In this type of protocols the balance should be maintained between the quality of data and energy consumed. There are certain quality metrics like energy, bandwidth, delay, priority level, which are needed to be satisfied by the network. If these QoS metrics are not met in time, then it will become a drawback for the protocol. Sequential Assignment Routing is one of the protocols, which uses QoS based routing and create a multiple tree to build a multiple path from every node to BS.

- **Coherent Based Routing:** Routing technique is divided into two types on the basis of data processing, Coherent or Non coherent. In Coherent technique, the data are processed minimally on the node and is forwarded to the aggregator for further processing. For energy efficient routing we use coherent technique. While in Non coherent technique, local processing is done at the node level before sending the data to the aggregator. It has three phases target detection phase, membership phase and central node election phase.

CHAPTER 3

RELATED PROTOCOLS

Recent advances in sensor technology have given rise to its usage in a large number of applications. Since the sensor node suffers from lots of constrained, which affect it performance. So to prolong the lifetime of the network various clustering techniques are used by these networks to perform routing of data efficiently. It's become essential for the network where sensors are deployed randomly over a large area. To remove the data congestion in the network clustering techniques is used by the sensor network. These techniques don't require all the nodes to send their sensed data to the BS. If all the nodes send data to BS their energy gets drained out very quickly. In the sensor network which uses clustering algorithms, some sensor nodes are selected as the CHs which are used to divide the whole network into some clusters. Each cluster has some set of nodes out of which one is elected as cluster head for that particular cluster. Nodes in a cluster, after sensing the data transmit it to their cluster head (CH) and not to the BS directly. The task of CH is to aggregate the data from all the nodes inside the cluster and perform aggregation technique on this data to remove the redundancy from the data. After performing aggregation it transmits the data to the BS. This technique helps in efficient utilization of the given energy of the nodes and help in prolonging the network's lifetime. To remove the extra burden on the CH, the periodic selection of cluster head is performed by these algorithms. The periodic selection of cluster head is done on the basis of probability or residual energy of the nodes. Clustering provides the efficient utilization of energy of the sensor node by reducing the number of transmissions to the sink node. Clustering provides network stability and scalability, also it helps in removing data duplication by aggregating the data at CH node. However, these algorithms suffer from some disadvantages like extra overhead incur during CH selection, assignment and cluster formation.

Clustering Process: Clustering process is divided into two main steps, Cluster head selection and cluster formation. Selection of CH is done in three ways: Centralization by BS, by the sensor nodes or hybrid [2].

The major concerns in electing CH are:

- An elected CH node must not be too far from the sink node, it will make communication expensive between the CH nodes and sink node.
- Uniform distribution of cluster head over the entire network area. Non uniform distribution can lead to high consumption of energy in intra cluster communication.
- The CH re-election is done on the periodic basis, otherwise its energy gets drained out very quickly.
- Concept of residual energy can be used in the CH re-election.
- Delay in time during CH selection and cluster formation is one of the areas of concern.

The major concerns in cluster formation are:

- Distance between the normal node and a CH.
- Number of hops required to transmit data to CH from the given node.
- Size of cluster and number of nodes inside the cluster.

Lots of research work is going on in finding the energy efficient clustering technique for WSNs. Our work is focused on finding the energy efficient homogenous reactive clustering protocol. We in this dissertation work on addressing the issues regarding the homogeneous clustering protocol and finding an efficient adaptive homogenous clustering protocol for time critical applications. Here we give the brief about the related routing protocols for the better understanding of proposed work.

3.1. LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) protocol proposed by Heinzelman [20] is the root of all the clustering protocols in wireless sensor network. The main motive of the LEACH is to reduce the energy consumed by the given node for transmitting data to the sink node. In LEACH, initially all the nodes are given the same amount of energy and have the same physical properties. These nodes organized themselves into clusters with one node out them acting as CH. All the Non-CH nodes transmit their data to their respective cluster head (CH).

The function of CH is to perform data aggregation functions or data fusion functions on this data, after performing these functions CH transmit the data to the BS. The cluster head are re-elected periodically to balance the load of the network.

The working of LEACH protocol breaks down into rounds and each round consists of two main phases: Set up phase and Steady state phase. The LEACH performs data gathering on the periodic basis.

Set up phase, in this phase, each node decides whether it wants to become a CH or not for the ongoing round. The selection of cluster head is done on the basis of probability function. In each round, every node generates a random number within the range of 0 and 1. This random number is then compared with the *T(n)* value for that given sensor node. If the value is less than the *T(n)* value, the node is elected as CH for the current round. For every node this *T(n)* value is generated in each round on the basis of probability and is given in equation 3.1:

$$T(n) = \begin{cases} \frac{P_{ch}}{1-P_{ch} \times (r \bmod \frac{1}{P_{ch}})} & if\ n \epsilon G \\ 0 & otherwise \end{cases} \qquad (3.1)$$

Where, P_{ch} is the cluster head probability, 'r' is the current round and G be set of nodes which are not elected as cluster head in $1/P_{ch}$ rounds. After the selection of cluster heads, each CH creates a TDMA schedule for data transmission and send this schedule to all the nodes in its cluster. This completed the Set up phase of LEACH protocol.

Steady state phase, during this phase data transmission takes place between the Non-CH node and CH node and between the CH node and BS. Each Non-CH node collects their sensed data and transmits it to CH at once per frame allocated to them. Thus the node after transmission, go to the sleep mode until the next allocated transmission slot, to conserve the energy. This assumes that the node transmit data on a regular basis. CH after receiving data from all the nodes performs an aggregation function on it and transmits it to the BS [25].

Advantages of LEACH protocol

- Each node is given a fair chance to become a cluster head, but a node cannot become a CH in consecutive rounds so as to balance the load.
- Use of TDMA by CH prevents from data collision at cluster head.
- LEACH conserves huge amount of energy of a node by allowing it to go into the sleep mode until the next allocated transmission slot.

Disadvantages of LEACH protocol

- The idea of dynamic clustering brings additional overhead.
- LEACH uses single hop communication between the Non-CH node and CH node and between the CH node and BS, which make it not suitable for large area.
- Cluster head selection purely on the basis of probability does not provide actual load balancing.
- Uniform distribution of CH cannot be ensured as the cluster head selection depends upon the probability.

Some of the other variants of LEACH protocol are described below:

LEACH-C[19], in this protocol the BS is used as a central body to regulate the selection of CH in each round. In each round, every sensor node has to transmit its local information to the BS. BS will decide whether the node can become the cluster head or not on the basis of that information. But the centralized control becomes one of the drawbacks of this protocol.

Another variant of LEACH is **E-LEACH** [21]**,**in this protocol current energy of the node is given preference for CH selection. The node having more current energy has more chance to become a CH in the current round. This provides an effective rotation of cluster head. The number of cluster heads is fixed in each round. But this protocol does not provide uniform distribution of cluster head.

3.2. I-LEACH

I- LEACH [18] protocol is an improvement of LEACH protocol. LEACH and many of its variants do not give much importance to the various attributes associated with the sensor nodes, for example energy, distance from sink node, location, number of neighbors in selection of cluster head node, cluster formation and the data transfer phase. This protocol has considered all these attribute to obtain an effective reduction in the energy consumption and hence increasing the network's lifetime. This protocol has three phases. In the first phase, the cluster head selection is done on the basis of probability which depends on some concepts like residual energy of the node, the location of the node, the number of neighbors of the node.In the second phase, Cluster formation is done by taking into account distance of CH node to BS and Non- CH node to CH node, but priority is given to a distance of CH node to BS. In the last phase, data transmission is done, all the Non-CH nodes transmits data to their CH but some of the Non-CH nodes can directly transmit data to base station if they are closer to BS than that of the sink node.

But it has some drawbacks such as the size of the cluster is unequal and this protocol is not suitable for time critical applications. Also the attributes used for CH selection are not so effective in increasing the network's lifetime.

3.3. TEEN

TEEN is a reactive homogeneous hierarchical protocol for wireless sensor networks proposed in [23]. TEEN is designed for those applications which are time critical and does not require periodic transmission of the information to the sink node. It is also suitable for query based applications, which require a query to be submitted by the user to the sink node and wants its result back as soon as possible from the network. Since it transmits data to the sink node in a non-periodic manner, the number of transmission gets reduced. The main motive of this protocol is to maintain a tradeoff between the response time and energy efficiency.

In TEEN, there are two phases in each round cluster setup phase and steady state phase. In cluster setup phase, the cluster head is selected on the basis of probability as in case of LEACH protocol and the cluster formation is done in a similar way as in LEACH protocol. Besides these, the cluster head broadcasts some parameters which are Hard threshold and Soft threshold value. Hard threshold value is an absolute value which is used to trigger the transmission of data by the nodes. If the current sensed value of the nodes is equal to or greater than the Hard threshold value, then only the node is allowed to transmit data to its cluster head by switching on its transmitter. Soft threshold value is a small value which is used to trigger the transmission. If the difference between the current sensed value and the previous sensed value of the node isgreater than or equal to the Soft threshold value, then only the node is allowed to transmit data to its cluster head by switching on its transmitter. In steady state phase these parameters are used for data transmission by the node, the node will sensed data continuously, but will transmit it to the cluster head on the basis of these parameters. Since the transmission is threshold dependent, it reduces the number of transmissions and network traffic.

But TEEN suffers from certain drawbacks if the threshold is not met, the nodes will never communicate and the BS is not aware of the status of the network and will not come to know whether the nodes are still alive or die. Also, these threshold parameters are broadcast by the cluster head in each round which increase extra overhead for the cluster head. This protocol is not suitable for the applications which require periodic transmission of information.

CHAPTER 4

PROPOSED PROTOCOLS

In this chapter, we have introduced two new routing protocols for homogeneous networks, which give priority to critical data and are adaptive in nature. Our work is divided into two parts.In the first part, we present an Energy Efficient Critical Homogeneous Reactive protocol for wireless sensor networks. This protocol considered energy of a node as a key factor for prolonging the network lifetime. In the CH selection process, we introduced two new concepts which help in improving the network's lifetime. The node is elected as CH on the basis of its average distance from its neighboring nodes and its distance from the sink node. This protocol is reactive in nature and is suitable for time critical applications. In the second part, we present an Adaptive Threshold Sensitive Energy Efficient Multi hop routing protocol, which helps in the effective transmission of data packets from the nodes sensing critical information to the BS or from the Cluster Head to the Base Station or from the cluster node to its CH. In this protocol, we also introduce a technique for finding a critical region in the prescribed network area. This protocol increases the network lifetime by balancing the load distribution.

First, we explain the system model used and assumptions made for the proposed work. Later, we analyze the performance of our proposed protocols with the conventional protocols.

4.1. System Model

The system model for the proposed protocols is consisting of two different models: network model and energy model. Network model describes the network environment and sensor node capabilities. While energy model describes how the sensor node utilizes its energy during communication with other nodes.

4.1.1. Network Model

The network is consisting of *one* BS and *N* nodes which are randomly distributed over the entire network having *AX A* area. Some of the following specifications are assumed for the network deployment:

- All the sensor nodes do not change their positions and remain fixed. They are distributed randomly over the entire area.
- The BS is positioned at the center of the network field and has an unlimited power supply and resources.
- The BS broadcasts some of the threshold parameters over the entire network area.
- Initially, all the sensor nodes have been given the same amount of energy.
- But the energy of these nodes is limited and cannot be recharged or replaced.
- All the nodes in the network are given unique identification number and they have the same capabilities in regards to processing, sensing and transmission of data packets.
- The communication range of all nodes is variable and depends upon the current energy of the node.
- The sensor node senses the environment continuously, but only transmits the data on the occurrence of a desired event which depends upon the broadcast threshold values.
- All the nodes transmit their sensed information to BS directly or via CH. The responsibility of BS is to process that data and generate the information which is desired by the end user.

4.1.2. Energy Model

We have opted for the First Order Radio Energy model which is used by the following protocols [18, 20, 26, 27, 28, 29]. As shown in **figure 4.1**it has three major components: transmitter electronics, power amplifier and receiver electronics.

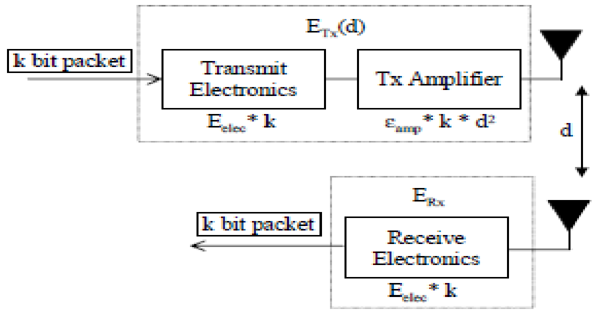

Figure 4.1 First Order Radio Energy Model

There are two propagation models which are considered by this energy model: Free space propagation model and Two ray ground propagation model. These models differ from each other in terms of line of sight path between the sender and the receiver. According to the free space propagation model, there is a direct line of sight transmission between the sender and the receiver. But in the two ray ground model, the data packet reaches to receiver via different paths without the direct line of sight communication.

The Power amplifier is used to amplify the signals for compensating the propagation loss during communication. Energy dissipated by the node for transmitting 'k' bits of data to the node which is 'd' distance away from it, is given by:

$$E_{Tx}(k,d) = \begin{cases} k * E_{elec} \;+\; k * \epsilon fs * d^2 & , d < do \\ k * E_{elec} \;+\; k * \epsilon mp * d^4 & d \geq do \end{cases} \tag{4.1}$$

Where, $E_{Tx}$is the energy dissipated by the sender node for transmission of data and it is directly proportional to 'k' and 'd'. $E_{elec}$is the electrical energy required to run the transmitter or the receiver circuit perfectly for each bit of data. $\epsilon fs$is the amplifier parameter required for free space propagation model and ϵmp is the amplifier parameter for two ray ground propagation model. $d_o$is the optimal distance given by:

$$d_o = \sqrt{\frac{\epsilon fs}{\epsilon mp}} \tag{4.2}$$

If the distance between the communicating node is less than $d_o$the free space propagation model is used otherwise two ray propagation model is used. To receive the 'k' bit data, the energy dissipated by the node is given by:

$$E_{Rx}(k) = k * E_{elec} \quad (4.3)$$

4.2. Proposed Protocol - EECHR

4.2.1. Problem Statement

We have focused our work on reactive protocols for homogeneous networks. The network model used for the proposed work is explained above. Thus the problem for which we have found the solution in terms of our proposed work is given below:

Development of an energy efficient threshold sensitive protocol for homogeneous networks which provide an efficient cluster head selection technique, can help in prioritizing the critical information and can keep the base station updated with the network status.

To find the solution of the above problem we have proposed a protocol which is given below:

4.2.2. Proposed Solution

In this section, we have discussed in detail the proposed protocol *"EECHR"*, which we have developed to address the above given problem statement. Our protocol is reactive and perfectly suitable for time critical applications. It is meant for homogeneous networks where every node is given the same amount of energy during the deployment of the network. The selection of CH is done on the basis of probabilistic model with some new factors being introduced. After the cluster formation the nodes in the cluster, which are sensing low priority information will transmit their information to their respective CH using single hop data transfer mechanism. All the nodes have the same computational capability, but only the cluster heads use their computational ability to aggregate the data which they receive from all the nodes in the cluster. The data transmission is an event or query driven as the EECHR protocol is reactive in nature. We give the detailed description of the EECHR protocol in the following section:

4.2.2.1. Features

The proposed solution has some key features which are given below:

- Introduction of a new factor in the CH selection procedure, a node is elected as a CH on the basis of its average distance from its neighbors.
- CH selection also depends on the distance of the node from the sink node and on current energy of the node.
- The Critical information is given utmost priority and is communicated to BS instantly.
- The node sensing the critical information does not take part in CH selection and cluster formation phase.
- With the introduction of Adaptive meter, the sink node is aware of the status of every node in the sensor network.
- All the parameters related to threshold values (Hard & soft threshold, Critical threshold and Adaptive meter) are broadcast by the sink node.
- The concept of remaining energy of the Non-CH node and that of CH node is introduced in the cluster formation phase.
- Some of the nodes which are closer to the sink node than that of their respective cluster head will directly transmit information to the sink node.
- The proposed protocol is reactive in nature and is suitable for the time critical applications.

4.2.2.2. Cluster Head Selection Phase

In the EECHR protocol, nodes are organized into local clusters. Every cluster has some sensor nodes as its member and amongst them one is elected as a CH for that cluster. All the selected CHs have to perform many tasks like aggregating data from all the member nodes of the cluster and performing various compression techniques if needed on that aggregated data. Hence, the CH has to use its energy to perform these tasks which results in the loss of more energy by CH node. Thus, it becomes necessary to implement a rotation policy for the CH which utilizes the energy of the network in an efficient manner.

In EECHR protocol, the cluster head selection is done on the basis of probabilistic model with the inclusion of other important factors related to a node. Every node has a information about its remaining energy, its average distance from all its neighbors, its distance from the sink node and the data which it sense has low priority or high priority. On the basis of this information the node is elected as a cluster head.

During this phase, every node in the network has to generate a random number within the range of 0 and 1. This number is then compared with the threshold value *T(n)*generated using the equation (4.4). If the generated random number is less than the *T(n)*value, then that node is elected as CH for that round. After its selection as CH the node has to leave the set 'G' for the next 1/P_{opt} rounds to prevent it from reelection as a CH. The *T(n)*value is given by:

$$T(n) = \begin{cases} \frac{P_{opt}}{1-P_{opt}\ (r\ mod\ (\frac{1}{P_{opt}}))}\ X\ \frac{E_{rem}}{E_{avg}}\ X\ \frac{dis_{toCHavg}}{S_{distoNBRavg}\ \ (n)}\ X\ \frac{|dis_{max}\ -dis\ (n\ ,\ \ BS)|}{dis_{toBSavg}} & n\ \epsilon\ G \\ 0 & otherwise \end{cases} \quad (4.4)$$

Where 'r' is the current round, 'G' is the set of those nodes which are not selected as CH in the last 1/P_{opt} rounds. 'E_{rem}' is the remaining energy of the node and 'E_{avg}' is the average energy of all the alive nodes in the network.

'P_{opt}' is the percentage of cluster heads in the network and it depends upon the number of nodes in the network and the optimal number of clusters in the network. It is given by:

$$P_{opt}\ = \frac{K_{opt}}{N} \quad (4.5)$$

Where 'N' is the number of sensor nodes in the network and 'K_{opt}' is the optimal number of clusters in the network. The value of 'K_{opt}' depends upon the number of nodes in the network, length of the network and on the average distance of all the nodes from the sink node. It is given by:

$$K_{opt}\ = \left(\sqrt{\frac{N}{2\pi}}\right) * \left(\sqrt{\frac{\epsilon fs}{\epsilon mp}}\right) * \frac{A}{\left(dis_{toBSavg}\ \right)^2} \quad (4.6)$$

Where, '$dis_{toBSavg}$' is given by:

$$dis_{toBSavg} = \frac{1}{N}\sum_{i=1}^{N} d(i, BS) \quad (4.7)$$

The other terms in equation 4.4 are '$dis_{toCHavg}$' and 'dis_{max}'. '$dis_{toCHavg}$' is the average distance of the cluster head from all its member nodes in the cluster and 'dis_{max}' is the maximum distance from the sink node. They are given by:

$$dis_{toCHavg} = A/\sqrt{2K_{opt}\pi} \quad (4.8)$$

$$dis_{max} = \sqrt{\left(\frac{A}{2}\right)^2 + \left(\frac{A}{2}\right)^2} \quad (4.9)$$

'$dis_{toCHavg}$' depends upon the length of the network and the optimal number of clusters in the network. While 'dis_{max}'is calculated using the Pythagoras theorem as the sink node is positioned at the center of the network area.

'$S_{distoNBRavg}$'is given as the average distance of the node from all its neighbors. The node is considered as a neighbor of the given node 'n', if it comes under the confined area of the given node. The confined area of the node depends upon radius 'R_{node}' of the neighborhood. The '$S_{distoNBRavg}$' is given by:

$$S_{distoNBRavg}(n) = \frac{1}{N_{nbr}}\sum_{j=1}^{N_{nbr}} dis(n, j) \quad (4.10)$$

Where, 'N_{nbr}' is the number of neighbors of the given 'n' node. The number of neighbors is counted on the basis of radius 'R_{node}' of the neighborhood. The radius of the neighborhood depends upon the area of the network '$A X A$' and the optimal number of clusters in the network. It is given by:

$$R_{node} = \sqrt{\frac{A X A}{\pi X K_{opt}}} \quad (4.11)$$

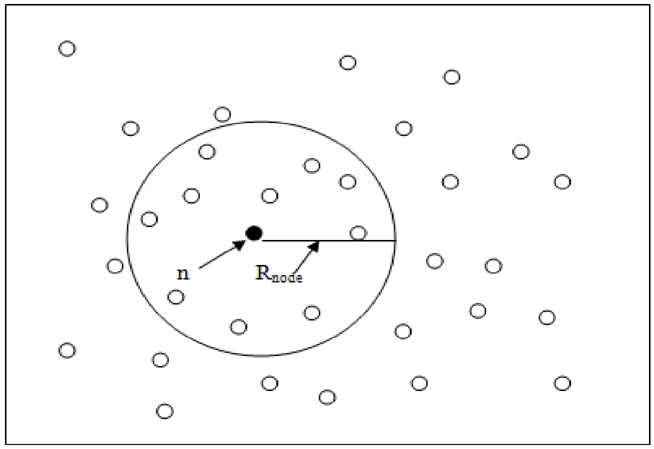

Figure 4.2 Radius of neighborhood of a given node 'n'

The **figure 4.2**shows the confined area of the given node 'n'. All the nodes which come under this circle are considered as a neighbor of the node 'n'. The nodes which lie outside this region are not considered as the neighbor of the node 'n'. The radius of this region is given by the above equation 4.11 and it remains fixed throughout the network's lifetime.

In addition, the cluster head selection also depends upon the remaining energy of the node, the more the remaining energy of the node more its chance to become CH in the given round.

4.2.2.3. Cluster Formation Phase

After the selection of CH nodes, the Non-CH nodes have to decide one of the CHs as their head and become the member of that cluster. Earlier in conventional protocols [19, 20, 21], the decision of selection of a cluster depends upon the distance of the Non-CH node from the CH node. But it has certain drawbacks as the CH node selected by the Non-CH node is closer to the Non-CH node but it is far from the BS. Hence, it results in more loss of energy during data transfer.

Later a protocol [18] is proposed to remove the above drawback. According to this protocol the selection of clusters phase gives high priority to the distance between the CH node and the BS and low priority to the distance between the Non-CH node and CH node. But this procedure also suffers from certain drawbacks as it not considered the residual energy of the CH node and that of Non-CH for the cluster selection. The drawback is explained in detail in below example.

Now, to remove above drawbacks we have introduced a new selection procedure. According to our procedure the selection of clusters depends upon the four factors distance of the BS from the cluster head, distance of the cluster head from the Non-CH node, remaining energy of the Non-CH node and that of the cluster head. The Non-CH node will join the cluster head for which the output of the below equation is minimized.

$$\frac{dis_{BS-CH} * \sqrt{dis_{CH-n}}}{(E_{rem}(n) * E_{rem}(CH))} \tag{4.12}$$

Where, '$dis_{Bs\text{-}CH}$' is the distance between the sink node and the cluster head. '$dis_{CH\text{-}n}$' is the distance between the normal node and the cluster head. 'E_{rem}(n)' is the remaining energy of the normal node and 'E_{rem}(CH)' is the remaining energy of the cluster head.

Let us take an example given in **figure 4.3** to justify the above selection procedure. The node 'A' has 0.45J as its remaining energy and its distance from the node 'CH_1' is 40m and from the node 'CH_2' is 20m. The node 'CH_1' has its remaining energy 0.3J and its distance from the BS is 40m. While the node 'CH_2' has its remaining energy 0.45J and its distance from the BS is 60m.

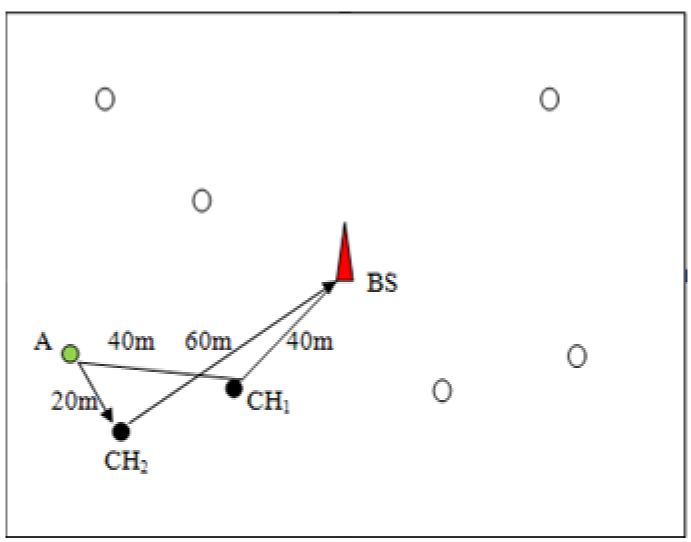

Figure 4.3 An example of implementing a EECHR protocol

If we use the selection procedure given in [18], we result in the selection of ‘CH_1’ as a cluster head for the node ‘A’ which has very low remaining energy as compared to ‘CH_2’ and also it is far from the node ‘A’. This results in more loss of energy by the node ‘A’ and also decrease the energy of ‘CH_1’ very fast which results in reduction of network’s lifetime.

But, if we use our selection procedure, then ‘CH_2’ is elected as a cluster head for the node ‘A’ which helps in increasing the network’s lifetime.

4.2.2.4. Data Transmission Phase

In data transmission phase, the BS broadcasts some threshold parameters in the network:

1. **Hard Value Threshold (HV):**It is a constant value which will allow the node to transmit the sensed data to sink node or CH node. If the CSV (current sensed value) of the node becomes equal to or greater than the HV, then the node will transmit its data to the CH or sink node by switching on its transmitter.
2. **Soft Value Threshold (SV):** It is a small constant value which will also trigger the sensor node’s transmission. If the difference between the PSV (previously sensed value) and CSV is equal to or greater than the SV, then the node will transmit its data by switching on its transmitter to the CH or the sink node.
3. **Critical Value Threshold (CV):** Some applications are time critical and sense some critical information which will be transmitted to the BS as soon as possible. For this type of information we have used a parameter called a critical value threshold. It is a constant value which decides the priority of the information.If the node CSV is greater than the CV, then the node is considered as critical node and the data it sensed is critical data. This data is transmitted to the sink node directly without any delay. Also the critical node does not take part in CH selection and cluster formation phase.
4. **Adaptive Meter (A_m):** The EECHR protocol is reactive in nature and data transmission by the node is not on the periodic basis. The data transmission is an event or query driven in these types of protocols. Thus there arises the situation in which the sensor node has not transmitted its data for too many consecutive rounds and makes the BS unaware about its status. The ‘A_m’ meter is used to make the BS aware of the status of the node in

the network. The value of 'A_m' is calculated by the BS and it depends upon the percentage of CH in the network. It is given by:

$$A_m \;\alpha\; \frac{1}{P_{opt}} \tag{4.13}$$

$$A_m = \frac{\lambda}{P_{opt}} \tag{4.14}$$

Here 'λ' = 1. If the node does not send its data to sink node for consecutive 'A_m' number of rounds. Then the sensor node initiates its transmission by sending data to its CH node or BS depending upon the situation and informs the BS about its status.

These parameters initiate the transmission of data from the node only when it senses something new or critical information and helps in reducing data redundancy at the CH level. In addition, the nodes which are closer to BS than that of their respective cluster head will transmit their data to the BS directly.

These parameters are monitored by the BS. As our protocol is suitable for query or event driven applications, the values of these parameters can be changed if needed. The BS controls all the values of these parameters. User if wants to change the value of certain parameter he can do so by just putting a query to the BS. In our protocol the value HV, SV and CV remains fixed as set by the BS, but the value of 'A_m' depends upon the number of cluster heads on the network. The value of 'A_m' can also be taken as constant.

The introduction of adaptive meter can decrease the network lifetime as the node which is not transmitting data from the last 'A_m' rounds have to transmit data to make BS aware about its existence in the network, which results in loss of energy by node for the transmission of non useful information to the BS. But it has an advantage that BS gets updated with the status of the node.

We have demonstrated the applicability of the EECHR protocol on the temperature sensing applications with more emphasis on the introduced features. The performance of the protocol is good and addressed our objective.

4.2.2.5. Flow Chart

In this section, we provide the flow chart for the data transmission phase of EECHR protocol.

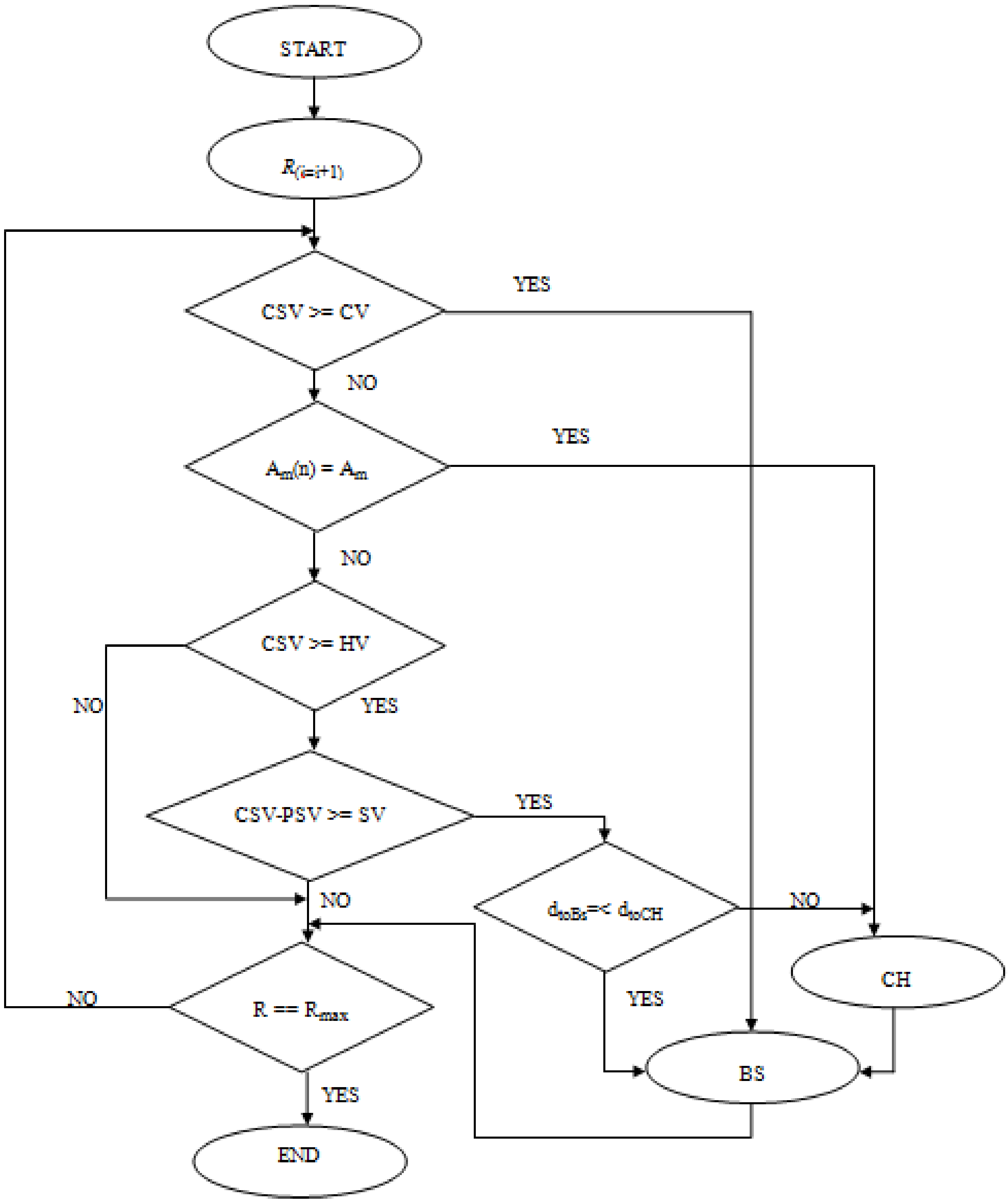

Figure 4.4: Data transmission phase of EECHR protocol

4.3. Proposed Protocol – ATEEM

4.3.1. Problem Statement

We have focused our work on threshold sensitive protocol for homogeneous networks.The network model used for the proposed work is explained above. Thus, the problem for which we have found the solution in terms of our proposed work is given below:

Developing a threshold sensitive multi hop routing protocol for homogeneous networks, which provides an energy efficient data transmission technique to increase the network's lifetime and utilize the information gathered by BS for finding the critical region in the given network area.

To find the solution of the above problem we have proposed a protocol which is given below:

4.3.2. Proposed Solution

In this section, we have discussed in detail the proposed protocol "ATEEM", which we have developed to address the above given problem statement. Our protocol is suitable for time critical applications and provides an energy efficient load balancing technique in terms of multi hop routing of data packets. It is meant for homogeneous networks where every node is given the same amount of energy during the deployment of the network. The CH selection is same as in the previous proposed protocol "EECHR". But in cluster formation phase, we have introduced a concept of Minimum Communication Energy (MCE). As our protocol is reactive in nature the Non-CH node transmits their information to their CH node on the occurrence of a desired event via a single hop or multi hop depending on the situation. The nodes sensing the critical information transmit their data to the sink node via multi hop or single hop. In short, the data transfer between the CH node and BS, Non-CH node and CH node and critical node and BS takes place through multi hop but if not possible then through single hop.We give the detailed description of the proposed protocol "ATEEM" in the following section:

4.3.2.1. Features

The proposed solution has some key features which are given below:

- The concept of “Minimum Communication Energy” (MCE) is used in cluster formation phase.
- The Gateway node is used to balance the load of CH node.
- The selection of Gateway node is done on the basis of residual energy of the node.
- The Helper node is used by the critical node to transmit the information efficiently to the BS.
- Another Helper node is used by the Non-CH node to transmit the data efficiently to the CH node when the remaining energy of the Non-CH node is less than 0.25J.
- The election of Helper node depends upon the concept of neighboring node and MCE.
- The whole network is divided into four grids of equal area by the BS logically.
- The BS stores the information about every node in the network. The information is related to, number of times the node sense the critical information throughout its lifetime.
- A mechanism is developed, which uses this stored information to find the critical region in the network.

4.3.2.2. Cluster Head Selection Phase

In the ATEEM routing protocol local cluster is formed by the nodes in the network. Each cluster has one CH node and some Non-CH node associated with that CH node. The CHs nodes, thus elected have to perform lots of tasks such as aggregating data from all its associated Non-CH nodes on the occurrence of desired events and performing compression technique if needed on the aggregated data. In this protocol the associated Non-CH nodes transmit their remaining energy along with the data to their cluster head. The CH node has to perform an additional task of computing the transmitted data to find the node with the maximum remaining energy among the associated Non-CH node. This maximum remaining energy node is named as a Gateway node for that cluster and helps the CH in balancing the load during the data transfer phase. This node removes the overhead incurred by the CH node in data transmission to the BS.

In our protocol the CH selection mechanism remains same as described in the previous work. It is based on the probability model with some key factors taken into consideration. The CH election is based on the formula as described in the equation (4.4) which is given below.

$$T(n) = \begin{cases} \frac{P_{opt}}{1 - P_{opt}\,(r\, mod(\frac{1}{P_{opt}}))} \; X \frac{E_{rem}}{E_{avg}} X \frac{dis_{toCHavg}}{S_{distoNBRavg}\;(n)} X \frac{|dis_{max} - dis(n\,,\;\; BS)|}{dis_{toBSavg}} & n \in G \\ 0 & otherwise \end{cases}$$

This equation is used in every round for the selection of cluster head. It takes into account the factors like remaining energy of the node, average distance from all the neighboring nodes and the distance of the node from the sink node. The values of the variable described in the above equation are given in the formulas described in the previous protocol.

4.3.2.3. Cluster Formation Phase

After the cluster head election phase, the Non-CH nodes have to select one of the CH as their head and become the member of that cluster. In conventional protocols the Non-CH nodes select the CH on the basis of the strength of the signal which they receive from the CHs.

Here we introduce the concept of MCE for the formation of clusters. The CHs nodes transmit the remaining energy of the associated nodes and itself along with the data it aggregated to the BS. Due to this BS gets the information about the remaining energy of every node in the network. In each round the BS broadcasts these remaining energies.

According to MCE, the Non-CH node computes the energy required to transfer data to each CH node generated in the particular round. The Non-CH node joins that CH for which the transmission energy required for the transfer of data to the CH is minimized. We use the First Order Radio Energy Model [26, 27, 28, 29, 30] to compute the transmission energy required in transfer of data to CH.

4.3.2.4.Data Transmission Phase

In this section we provide the flow diagram to explain the working of multi hop routing in our proposed protocol “ATEEM”.

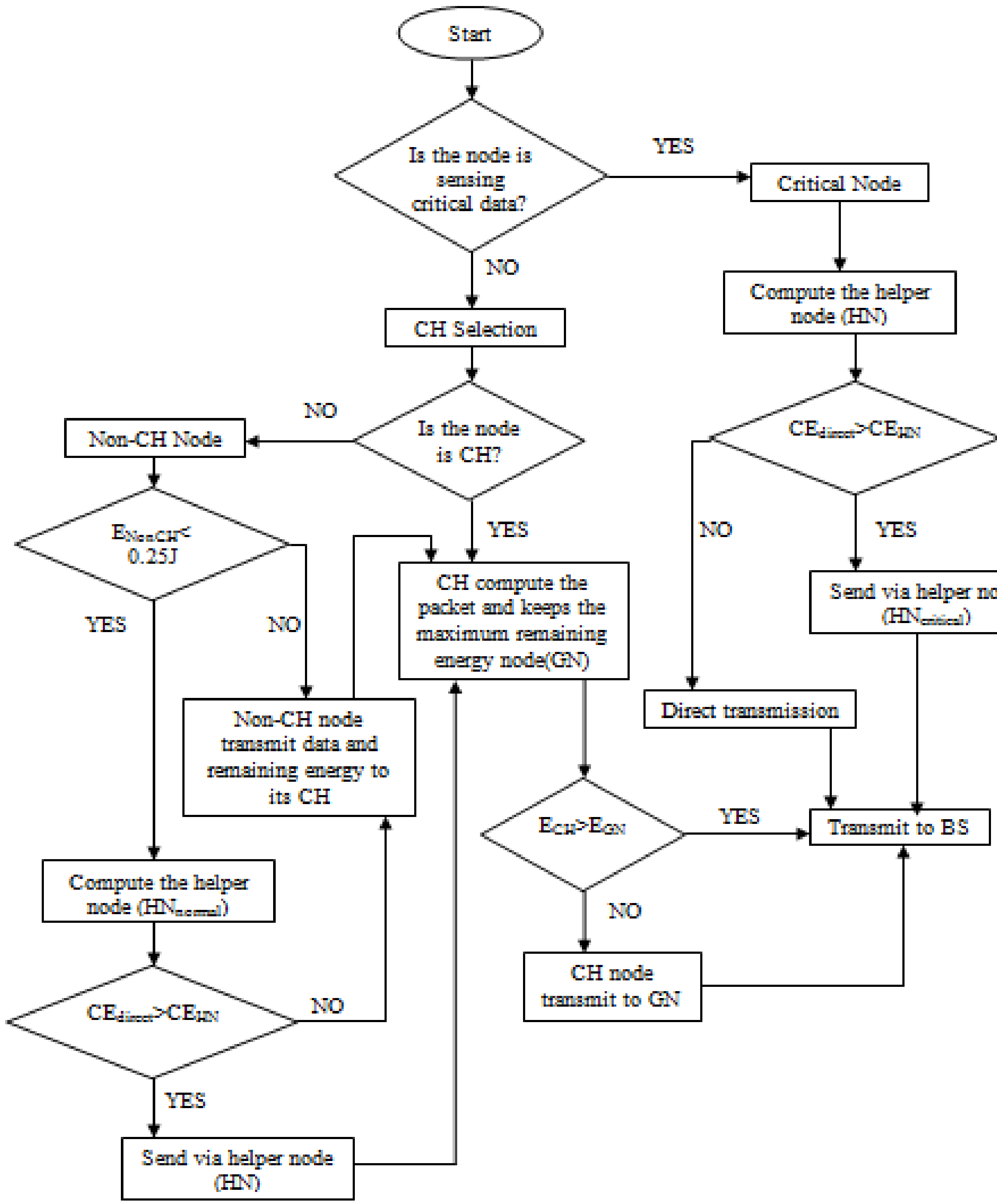

Figure 4.5: Data transmission phase of ATEEM routing protocol

In data transmission phase, BS broadcasts all the parameters related to the threshold values. The BS also broadcasts the remaining energy of all the nodes in the network. In the earlier proposed protocol "EECHR" the nodes which are sensing critical information does not take part in the CH selection process and send their information directly to BS. This results in more energy consumption during the transmission of data from these nodes. To reduce this consumption, we have introduced the helper node (HN). The HN is one of the neighboring nodes of the critical node which require MCE to transmit data to BS among all the other neighboring nodes. Concept of neighboring node is described in the previous proposed protocol "EECHR". After the selection of the HN, the critical node compares its communication energy required to transmit directly to BS with the communication energy required to transmit via HN to BS. If via HN it requires less communication energy then it is sent via helper node otherwise sent directly to BS.

Now to balance the load of CH node we have introduced a new node called Gateway node (GN). Among the members of a particular cluster one node is selected as a GN. Each Non-CH node transmits its remaining energy along with the data to the CH node. The CH node on receiving this information computes the node with maximum remaining energy and stores the information of that node in the name of GN. Now CH node compares its energy with the GN, if the CH node has more energy then it will transmit to BS directly else transmit via GN.The **figure 4.6** explains the scenario.

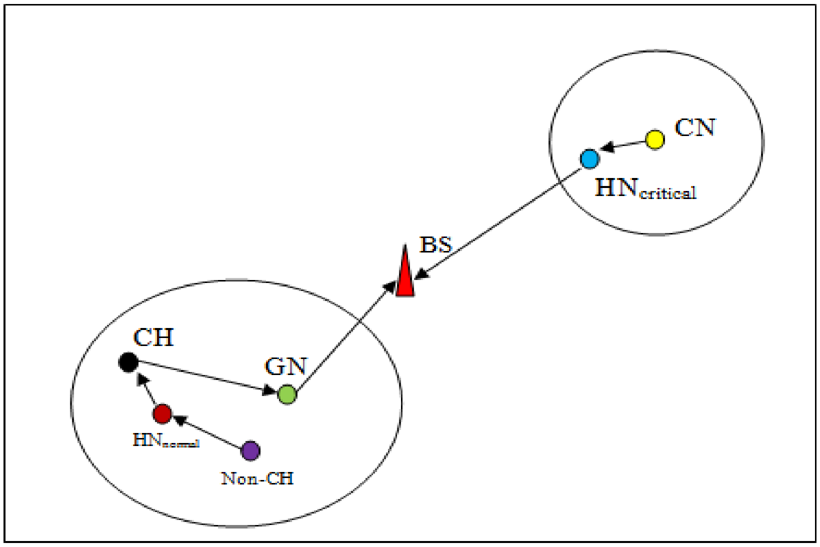

Figure 4.6: An example of Multi hop routing in ATEEM routing protocol

To increase the lifetime of the network each Non-CH node which has its remaining energy less than 0.25J has an option to send either directly to CH node or via HN related to the Non-CH node. The selection procedure of the HN for Non-CH node is similar to that of the HN for critical node, but here the transmission is limited to CH node and not to the BS. Depending on the communication energy, the Non-CH node transmits data either directly or via HN to CH node.

4.3.2.5. Critical Region

According to BS, the network is divided logically into four grids of equal area. All the nodes which sense the critical information sends their id, remaining energy along the critical information to the BS. The BS stores all this information and utilizes this information for finding critical region. When the network is divided into four grids, the number of nodes in each grid is not same. Here we describe the pseudo code for finding the critical region.

```
Label 1: For each round                                         // 1 to R_max
        Increment round R_i = i +1
        Label 2: For each node                                  // 1 to n
                Increment Node N_j = j +1
          If(N_j-CSV>= CV)
                 N_j-count =N_j-count + 1
          If( Node Index j <= Total number of nodes 'n')
    GoTo: Label 2
                If (Round R_i != Last Round R_max)
                 GoTo: Label 1
```

Label 3: For each node

Increment Node $N_i = i + 1$

If($N_{i\text{-gridno}} == 1$)

$Avg_1 = Avg_1 + N_{j\text{-count}}$

Else if ($N_{i\text{-gridno}} == 2$)

$Avg_2 = Avg_2 + N_{j\text{-count}}$

Else if ($N_{i\text{-gridno}} == 3$)

$Avg_3 = Avg_3 + N_{j\text{-count}}$

Else

$Avg_4 = Avg_4 + N_{j\text{-count}}$

If(Node Index i <= Total number of nodes ‘n’)

GoTo : Label 3

$Avg_1 = Avg_1$ / Number of nodes in grid 1

$Avg_2 = Avg_2$ / Number of nodes in grid 2

$Avg_3 = Avg_3$ / Number of nodes in grid 3

$Avg_4 = Avg_4$ / Number of nodes in grid 4

Critical grid Index = max(Avg_1, Avg_2, Avg_3, Avg_4)

STOP

The variable Critical grid Index will provide the grid number which is considered as a “critical region”.

CHAPTER 5

SIMULATION RESULTS & ANALYSIS

Simulation is the representation of the real world system in the form of the model. This model represents the basic characteristics or functions of the system. Here we simulate the models of our proposed work under the various environmental conditions to evaluate their performance. To evaluate the performance of our proposed protocols we have compared them with the conventional protocols in term of network's lifetime, throughput and energy efficiency.

5.1. Simulation Setup

To simulate the proposed work we have used the simulation tool**MATLAB**. We have compared our work with LEACH [20], E-LEACH [21], I-LEACH [18], M-LEACH [21] and TEEN [23] protocols, to evaluate its performance in terms of energy efficiency, lifetime of network and throughput.

The simulated environment is given in the **figure 5.1**. There are 200 homogeneous nodes deployed randomly over the network field of 200m * 200m area. The BS is positioned at the point (100,100). It has very high processing capabilities and unlimited resources. All the nodes deployed in the network are sensing the temperature value which ranges between [50^o, 200^o]. The length of the data packet transmitted to the BS by CHs or by Non-CH node to the CH node is 4000 bits for all the protocols compared in evaluation. The Simulation environment in terms of number of nodes, area of network and position of the BS is same for all the conventional protocols with which our work is comparable. The values of the parameters used in the simulation are given in the **table 5.1**.

Parameters	Value
A * A	200m *200m
N	200
E_o	0.5 J
E_{elec}	50 nJ/bit
E_{DA}	5 nJ/bit/message
ϵ_{fs}	10 pJ/bit/m^2
ϵ_{amp}	0.0013 pJ/bit/m^4
M	4000 bits
Cv	180^o

Table 5.1: Networks Parameters

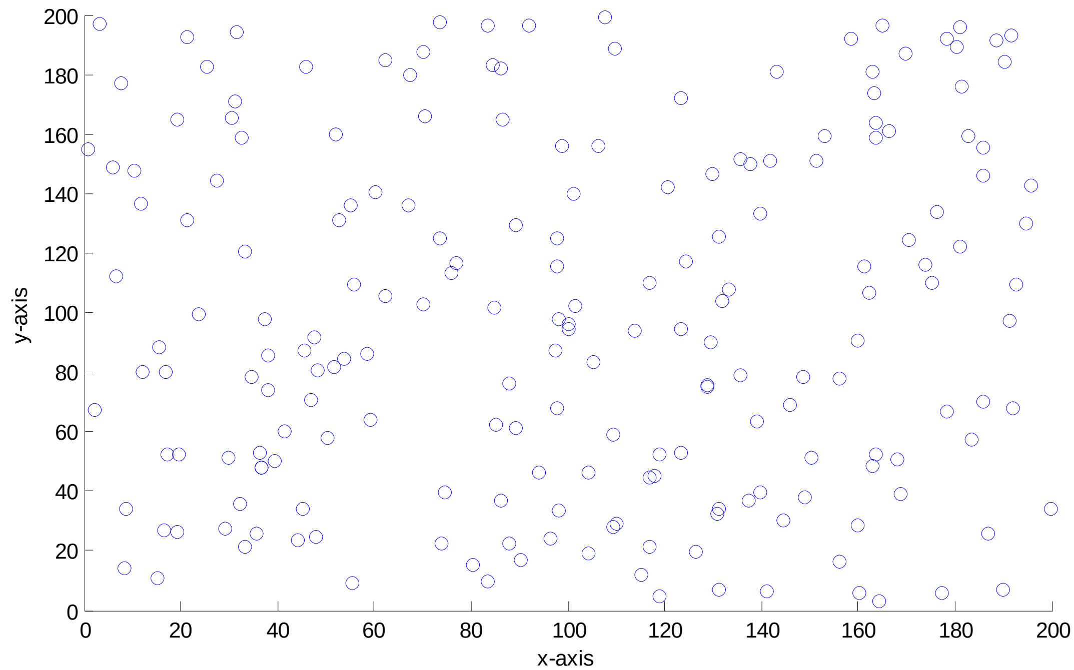

Figure 5.1: Initial Simulated Network

5.2. Performance Evaluation-EECHR Protocol

In this section we have presented the performance evaluation of the EECHR protocol by comparing it with LEACH [20], E-LEACH [21], I-LEACH [18] protocols using MATLAB as a simulation tool. We have implemented all these protocols as per the given simulating environment. The simulation runs for 4000 rounds. We have compared EECHR protocol with other protocols on the basis of the given performance metrics.

5.2.1. Performance Metrics

1. *Alive Nodes:* The number of nodes alive per round.
2. *Throughput:* The number of packets sent to BS by CHs per round.
3. *Average Remaining Energy:* Average Remaining energy of the network per round.
4. *FND:* Round after which First Node Die.
5. *MND:* Round after which Middle Node Die.
6. *LND:* Round after which Last Node Die.

5.2.2. Simulation Result

In this section, we have presented the simulation results of EECHR protocol on the basis of above given performance metrics in comparison to LEACH [20], E-LEACH [21] and I-LEACH [18] protocol. The LEACH protocol is basic of the clustering protocol. All the above protocols with which EECHR protocol is compared are homogeneous in nature. We provide the simulation result on the basis of the performance metrics explained above in the section 5.2.1. The results of simulation are given in the **figure 5.2** to **figure 5.5**. The result shows that EECHR outperform the other three protocols with which it is compared in all the given performance metrics. After this section we provide the analysis in detail in the next section.

The simulation result for EECHR protocol is given below:

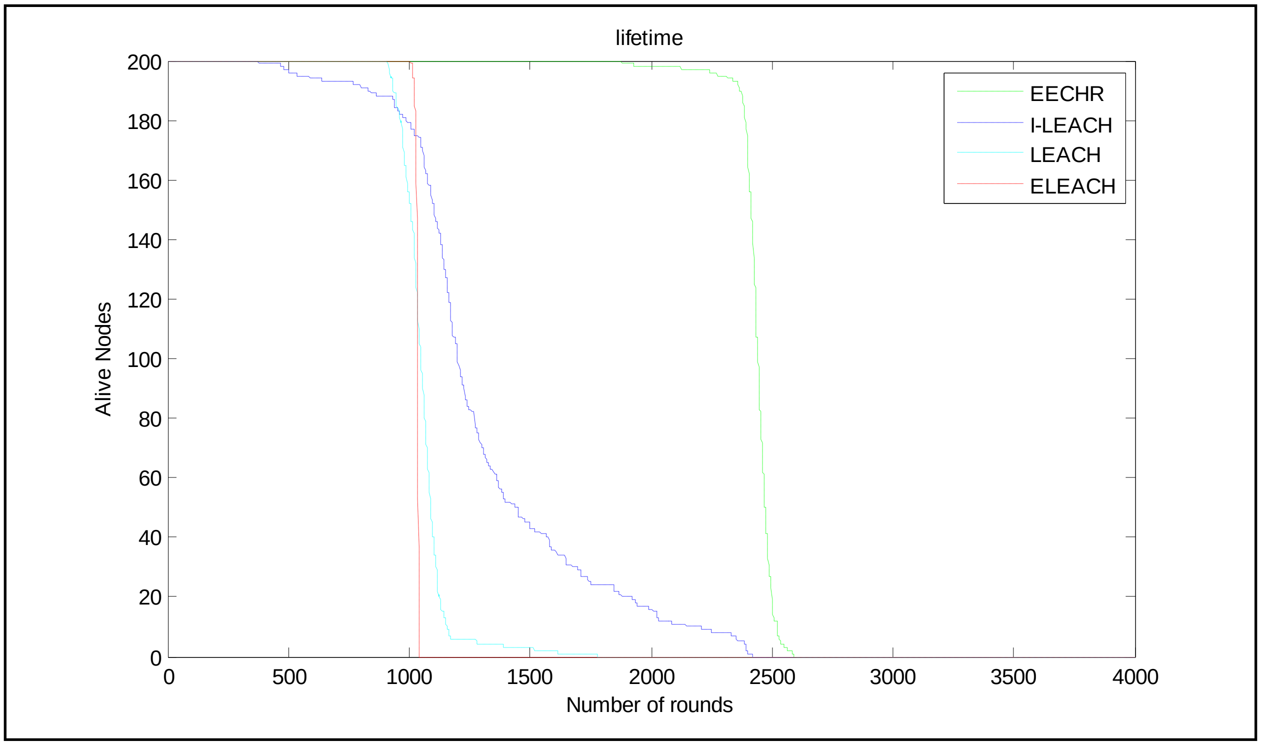

Figure 5.2: Number of Alive Nodes per round

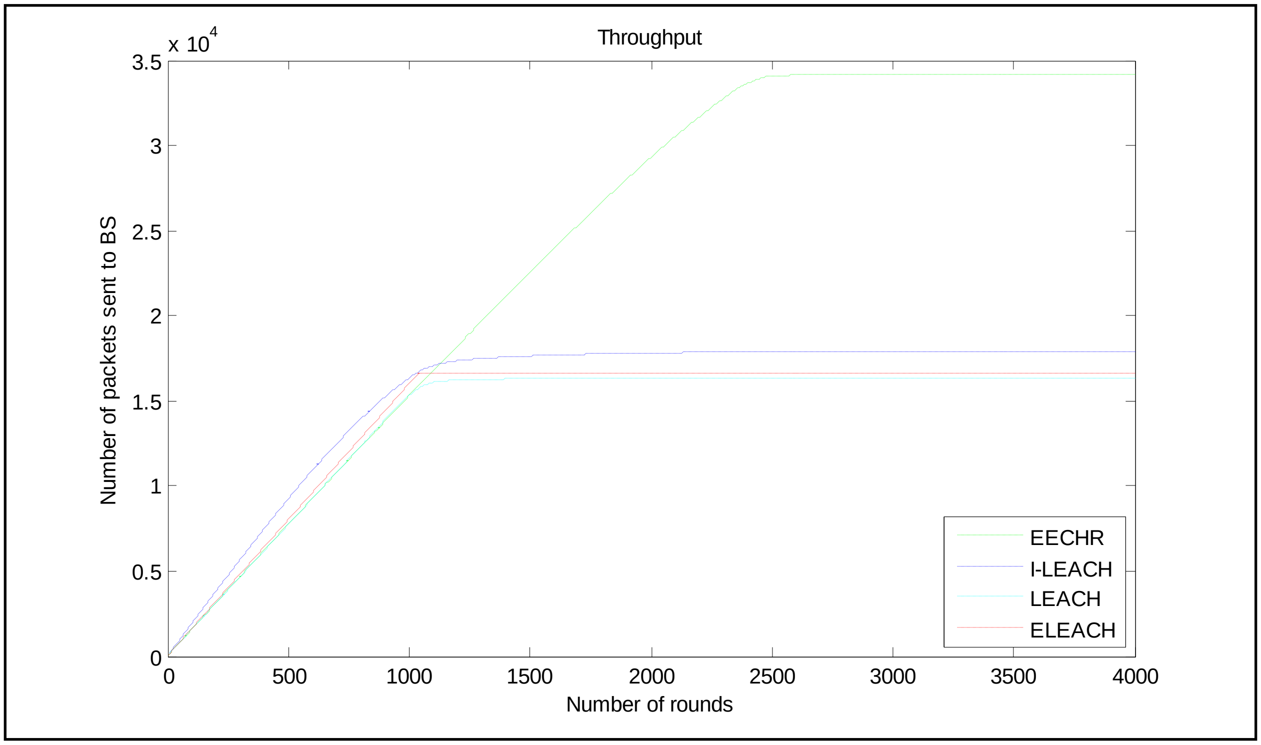

Figure 5.3: Number of Packets sent to BS by CHs

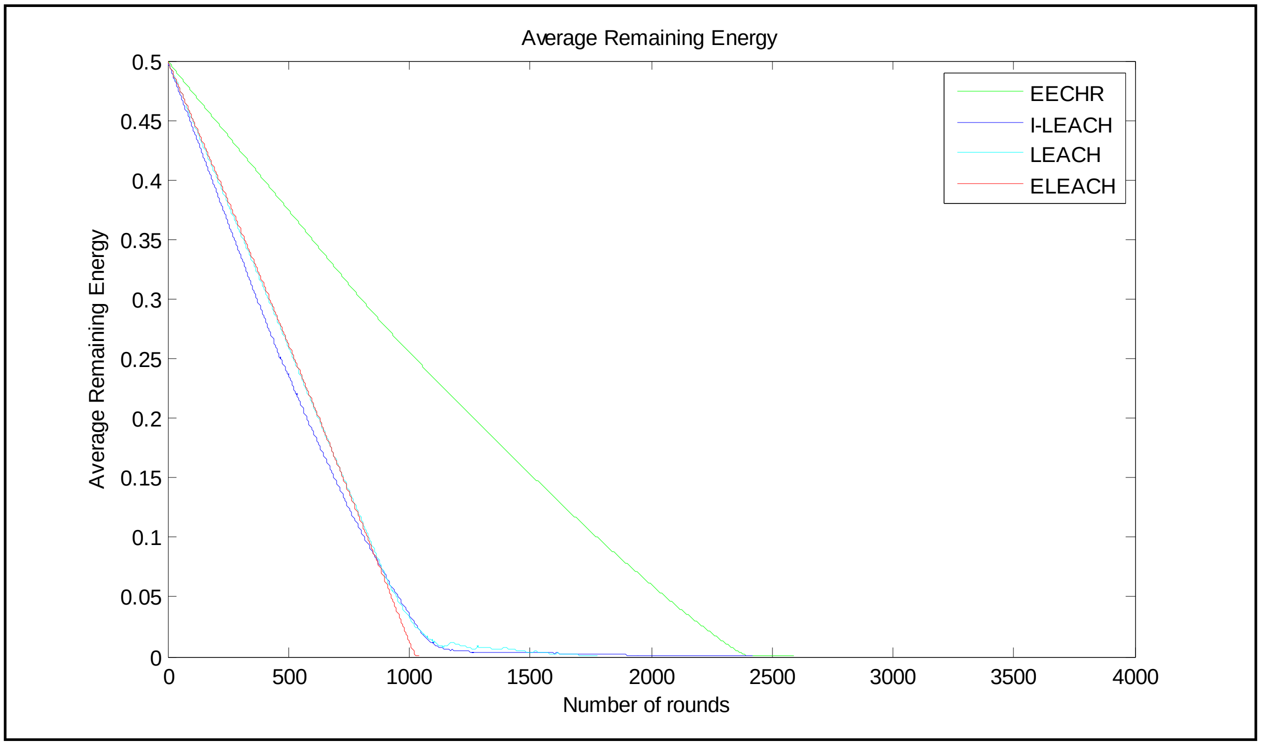

Figure 5.4: Average Remaining Energy of the Network per round

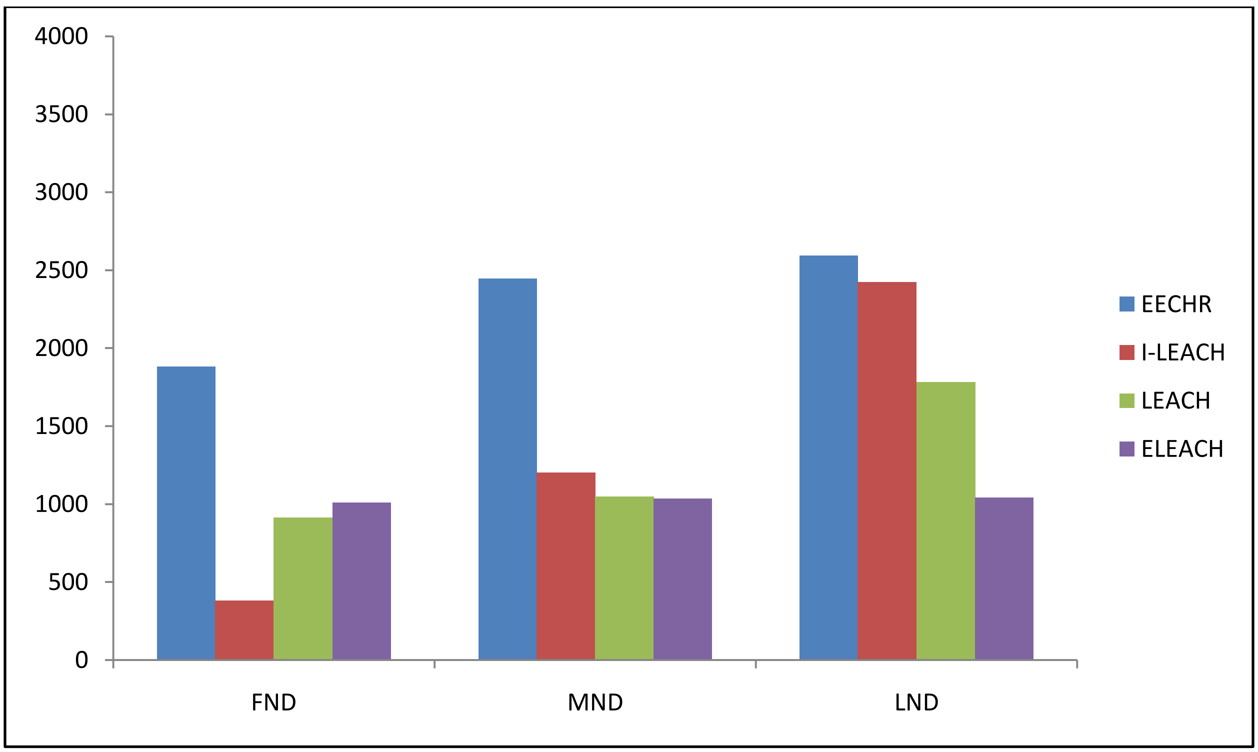

Figure 5.5: Rounds after which first, middle and last node die

5.2.3. Analysis

From the above given simulation results we have reached to the conclusion given in the **table 5.2**.

Protocols	Stability Period (rounds)	Lifetime (rounds)	Throughput (packets)
LEACH	913	1781	1.63×10^4
E-LEACH	1010	1041	1.66×10^4
I-LEACH	380	2420	1.66×10^4
EECHR	1882	2591	3.41×10^4

Table 5.2: EECHR Analysis

Thus we have observed the increase in stability, network lifetime, throughput and remaining energy of the network. Our protocol EECHR is a reactive protocol, but makes the BS aware of the status of network from time to time. It can be seen from the **figure 5.2** and **table 5.2** that our proposed protocol EECHR has outperformed the other three protocols in terms of stability and network's lifetime. In comparison to LEACH protocol the network's lifetime of EECHR protocol has been increased from 1781 rounds to 2591 rounds similarly in comparison to I-LEACH protocol it has been increasedfrom 2420 rounds to 2591 rounds.

The **figure 5.3** shows that the number of packets sent to BS by CHs. Our protocol EECHR has sent more number of packets than the other protocols by which it is compared. The number of packets transmitted in EECHR is almost double of the LEACH, E-LEACH and I-LEACH.

The **figure 5.4** shows the average remaining energy of the network per round. The EECHR has utilized the energy of the nodes in an efficient way than that of other three protocols.

The **figure 5.5** shows that the number of rounds after which the first, middle and last node dies in the network. Our protocol has more stability than other compared protocols.

5.3 Performance Evaluation- ATEEM Protocol

In this section we have presented the performance evaluation of the ATEEM protocol by comparing it with LEACH [20], M-LEACH [21], TEEN [23] protocols using MATLAB as a simulation tool. We have also compared the ATEEM protocol with the EECHR protocol. We have implemented all these protocols as per the given simulating environment. The simulation runs for 6000 rounds. We have compared ATEEM protocol with other protocols on the basis of the given performance metrics.

5.3.1. Performance Metrics

1. *Alive Nodes:* The number of nodes alive per round.
2. *Throughput:* The number of packets sent to BS by CHs per round.
3. *Average Remaining Energy:* Average Remaining energy of the network per round.
4. *FND:* Round after which First Node Die.
5. *MND:* Round after which Middle Node Die.
6. *LND:* Round after which Last Node Die.

5.3.2. Simulation Result

In this section, we have presented the simulation results of the ATEEM protocol on the basis of above given performance metrics in comparison to LEACH [20], M-LEACH [21] and TEEN [23] protocol. The ATEEM protocol is also compared with the EECHR protocol. All the above protocols with which ATEEM protocol is compared are homogeneous in nature. We provide the simulation result on the basis of the performance metrics explained above in the section 5.2.1. The results of simulation are given in the **figure 5.6** to **figure 5.13**. The result shows that ATEEM outperform the other three protocols as well as EECHR in all the given performance metrics. After this section we provide the analysis in detail in the next section.

The simulation result for the ATEEM protocol is given below:

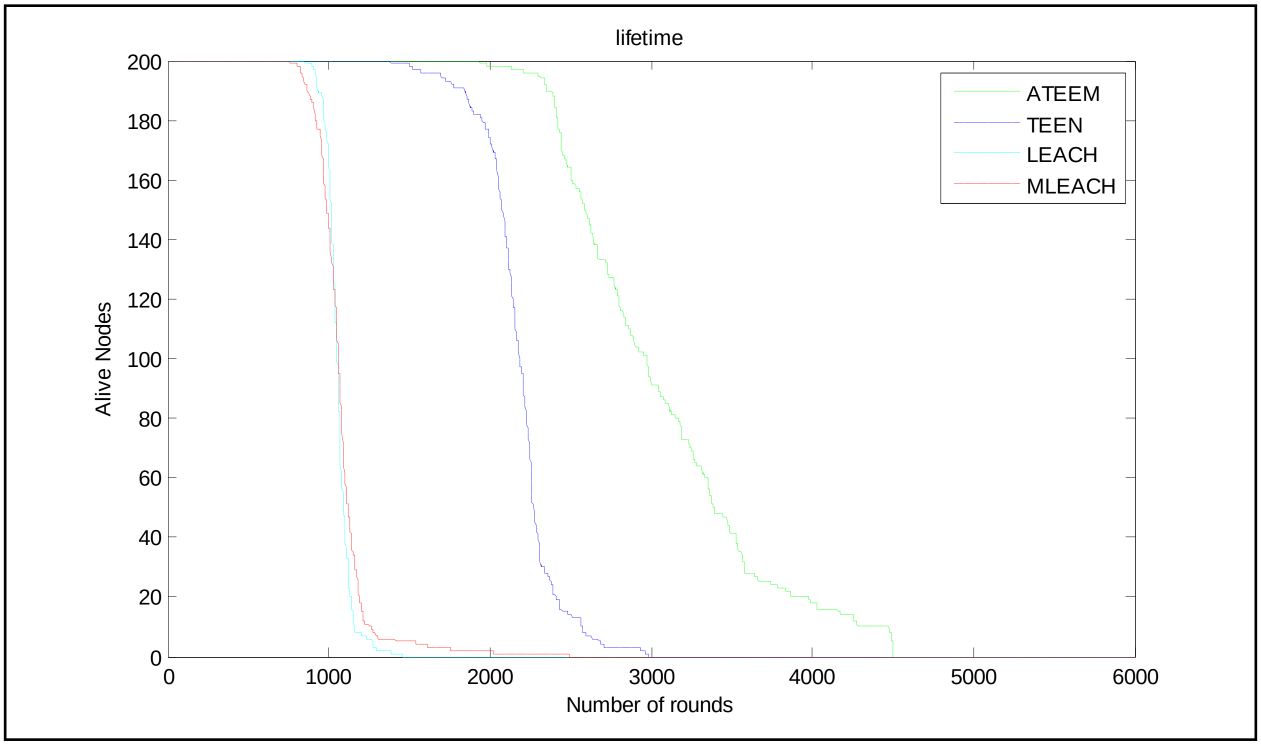

Figure 5.6: Number of Alive Nodes per round

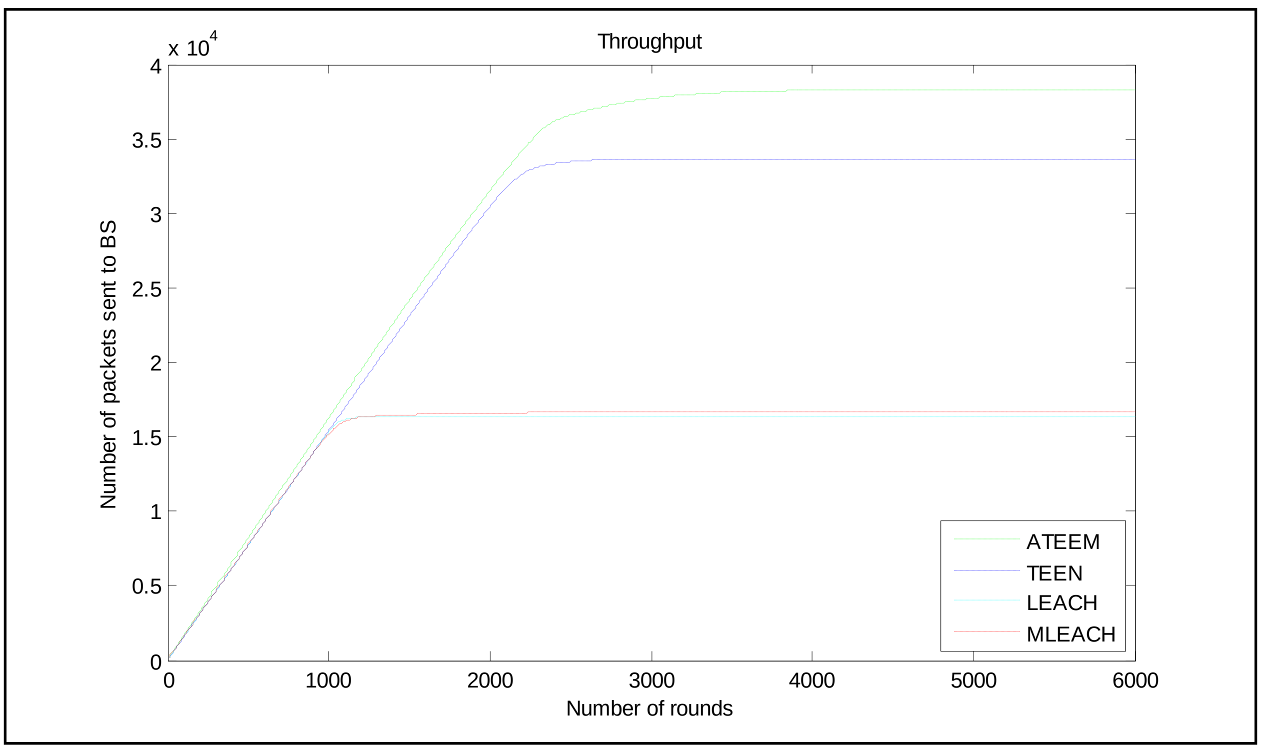

Figure 5.7: Number of Packets sent to BS by CHs

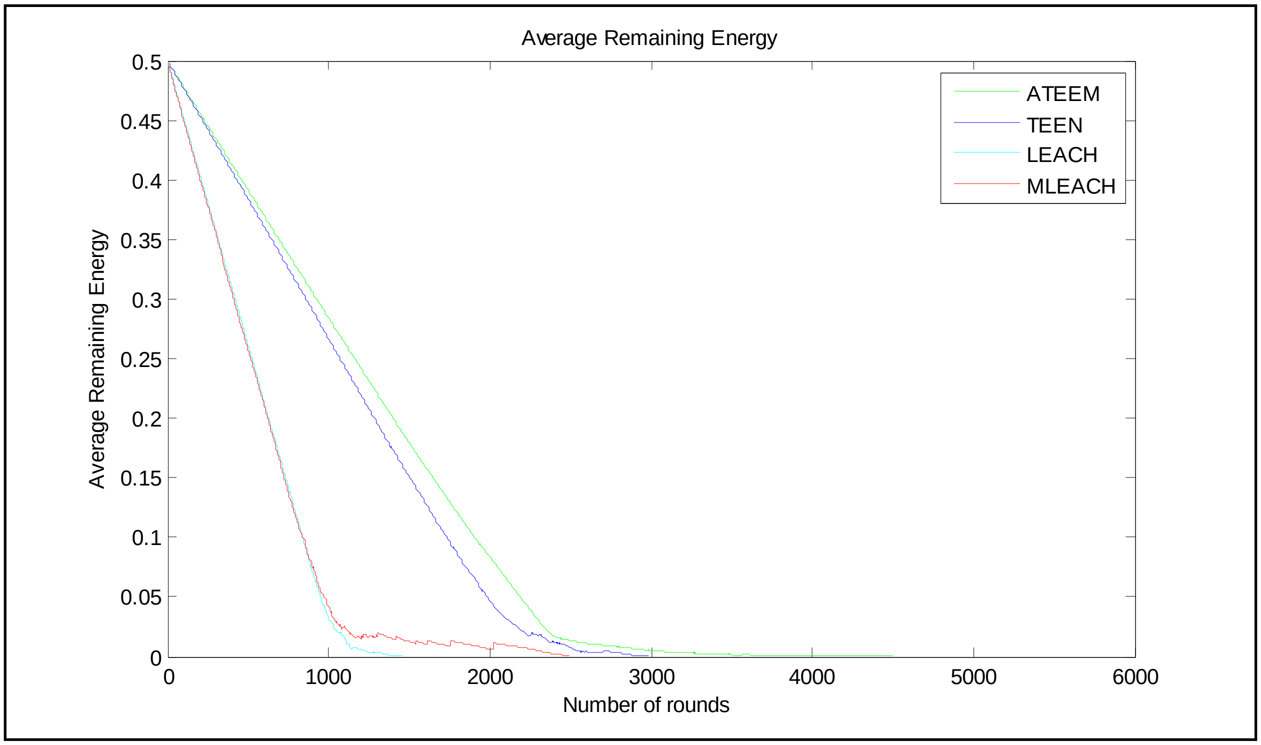

Figure 5.8: Average Remaining Energy of the Network per round

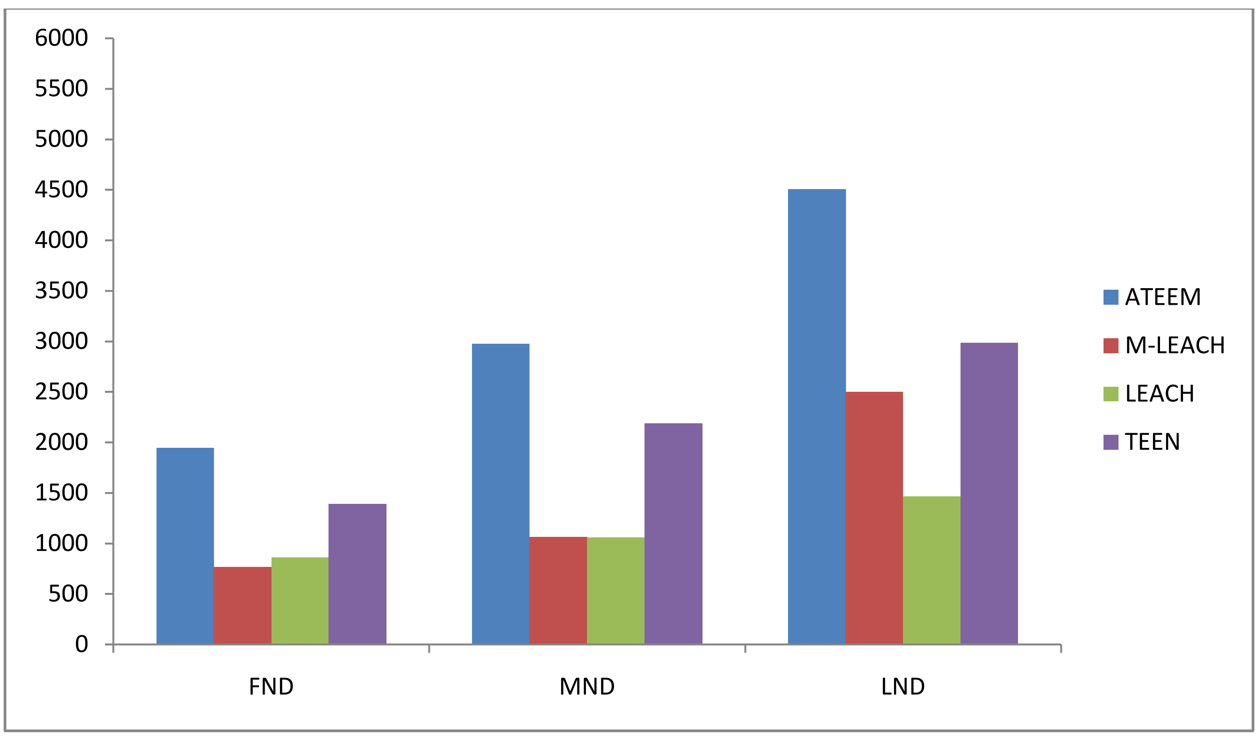

Figure 5.9: Rounds after which first, middle and last node die

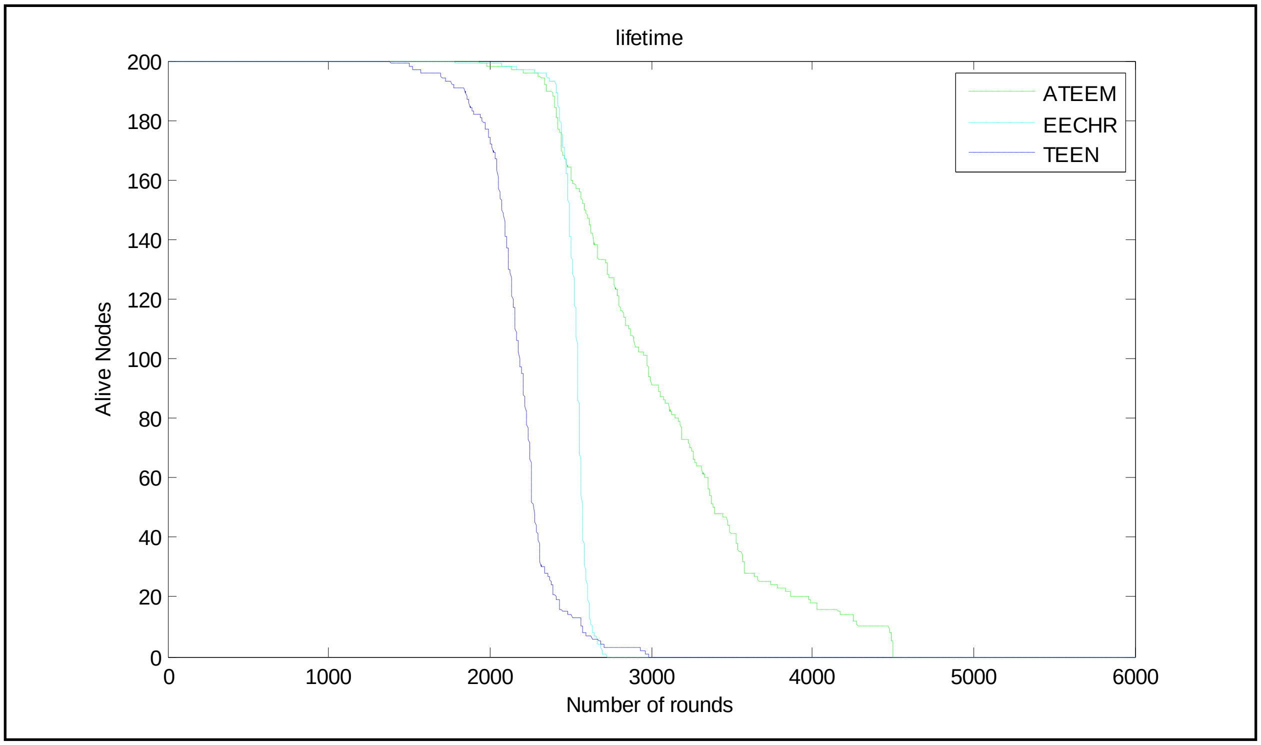

Figure 5.10: Number of Alive Nodes per round

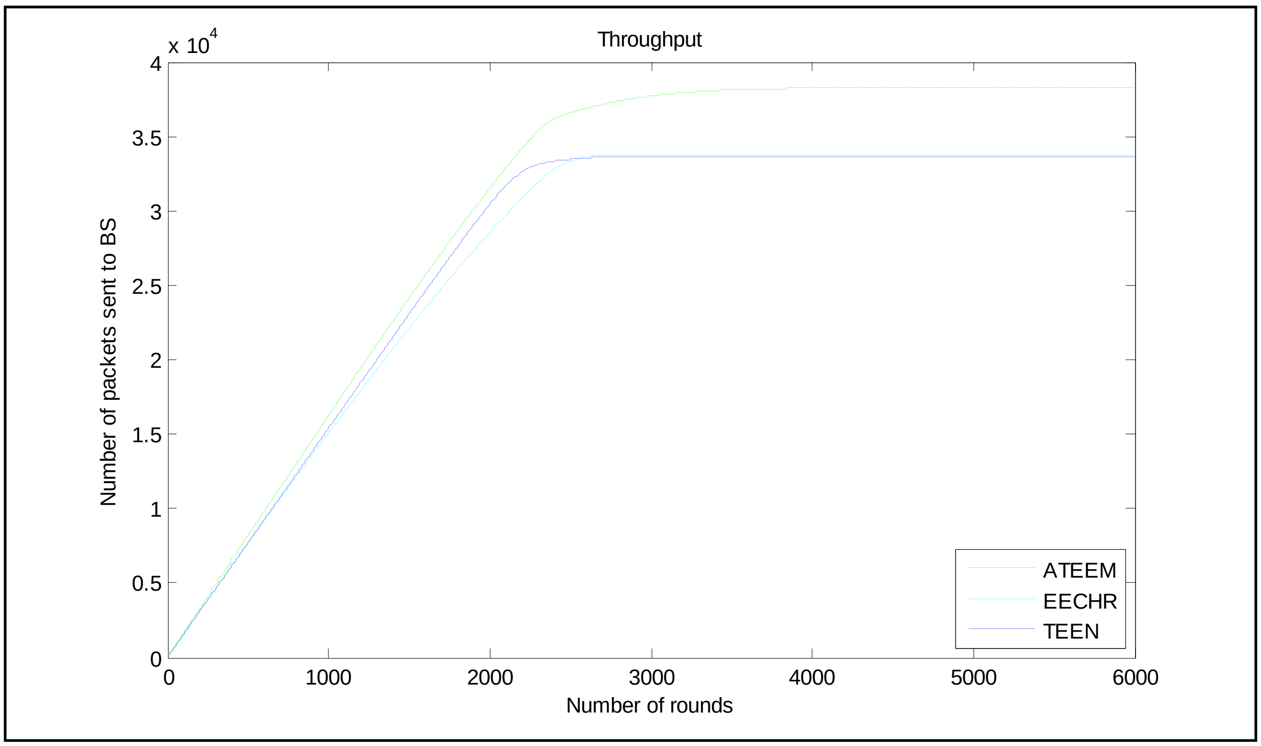

Figure 5.11: Number of Packets sent to BS by CHs

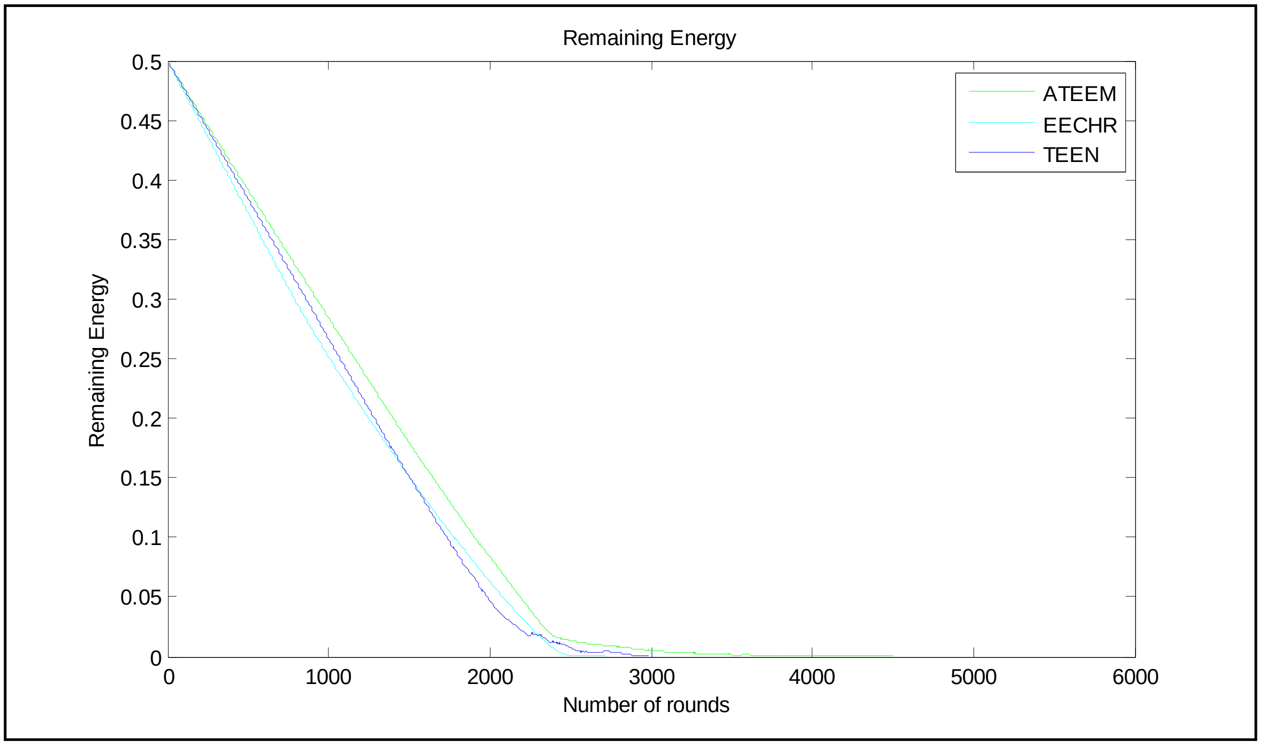

Figure 5.12: Average Remaining Energy of the Network per round

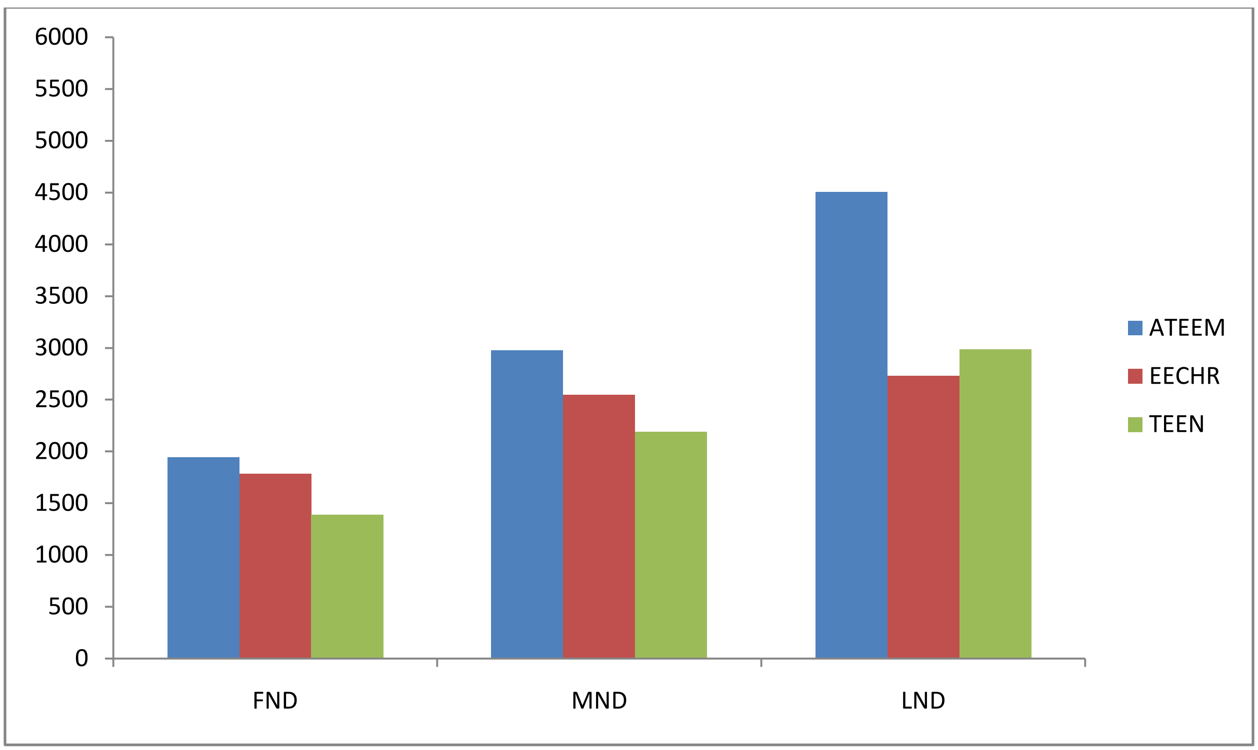

Figure 5.13: Rounds after which first, middle and last node die

5.3.3. Analysis

From the above given simulation results we have reached to the conclusion given in the **table 5.3** and **5.4**.

Protocols	Stability Period (rounds)	Lifetime (rounds)	Throughput (packets)
LEACH	857	1463	1.63×10^4
M-LEACH	764	2498	1.66×10^4
TEEN	1389	2984	3.36×10^4
ATEEM	1941	4503	3.83×10^4

Table 5.3: ATEEM Analysis

Protocols	Stability Period (rounds)	Lifetime (rounds)	Throughput (packets)
ATEEM	1941	4503	3.83×10^4
EECHR	1785	2724	3.37×10^4
TEEN	1389	2984	3.36×10^4

Table 5.4: EECHR & ATEEM Analysis

It can be seen from the **figure 5.6**, **figure 5.10**, **table 5.3** and **table 5.4** that our protocol ATEEM routing protocol has performed better than the other four protocols in terms of network's lifetime and stability. In comparison to LEACH protocol the network's lifetime of ATEEM protocol has been increased from 1463 rounds to 4503 rounds, similarly in comparison to TEEN protocol it has been increased from 2984 rounds to 4503 rounds. The network's lifetime of TEEN protocol and EECHR protocol is somewhat similar but the EECHR protocol is more stable than TEEN protocol.

The **figure 5.7** and **figure 5.11** shows the number of packets sent to BS by the CHs. Our protocol ATEEM has sent more number of packets than the other protocols by which it is compared.

The **figure 5.8** and **figure 5.12** shows the average remaining energy of the network per round. As the ATEEM protocol use multi hop routing at various levels, hence it utilizes the energy in a better manner than that of the other protocols with which it is compared.

The **figure 5.9** and **figure 5.13** shows that the number of rounds after which the first, middle and last node die in the network. Our protocol has more stability than other compared protocols.

Critical Region: We have implemented the concept of critical region in the ATEEM protocol. The BS divides the whole network area logically into 4 equal grids. Each grid consists of unequal numbers of sensor nodes. After the simulation of ATEEM protocol we are able to locate the critical region in terms of grid number '4' having coordinates {(0,100), (100,100), (100,200), (0,200)}. Thus, in our simulation this region is considered as critical.

CHAPTER 6

CONCLUSION & FUTURE WORK

We dedicate our work on finding the solution to the existing problems in the threshold sensitive protocol for homogeneous networks. We develop the EECHR protocol, a threshold sensitive protocol for homogeneous networks with some features introduced in various phases of the protocol. It includes an energy efficient mechanism for the CH selection procedure. It provides an effective technique for cluster formation phase. As it is a threshold sensitive protocol, it provides high priority to critical information and also makes the BS aware of the status of the nodes in the network which remains idle for a long duration. The threshold parameters are broadcasted by the BS. Hence these values can be changed from time to time. Most of the applications are event or query driven and also requires the critical information should be conveyed on time, our protocol EECHR is suitable for these applications. Future scope in this direction would be implementation of secure data transmission in EECHR. Simulation results show that EECHR has higher stability period and higher lifetime than LEACH, I-LEACH, E-LEACH.

We also proposed a multi hop routing protocol, ATEEM for homogeneous reactive networks. It aims at balancing the cluster energy and increases the network efficiency by finding the appropriate candidate to distribute the task of CH. It also provides an energy efficient data transfer mechanism which is used by critical nodes to transfer data to BS and by Non-CH nodes to CH nodes. It also includes an energy efficient cluster formation technique. We also develop a mechanism to find the critical region in the given area on the basis of the information stored at BS. Simulation results show that our protocol performs better than TEEN and EECHR protocol. And we are able to find the critical region. Future work can be done by extending this routing technique for heterogeneous reactive networks to increase their performance.

Thus both the proposed protocol EECHR and ATEEM successfully address the solution to the problem(s) we undertook as a part of this research work.

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