A
Dissertation
On

Enhanced Threshold Sensitive Protocol in Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks are derived of hundreds to thousands of limited energy battery powered sensor nodes. The use and applicability of WSNs has increased in vivid areas like vehicular movement, weather monitoring, security and surveillance, industry applications etc. The limited powered nodes in WSNs sense the environment and send the desired information to a processing centre (base station) either directly or via a mechanism for optimization.

In this dissertation we developed CHATSEP, a clustering protocol for reactive networks with threshold sensitive heterogeneous sensor nodes. It includes an adaptive characteristic which helps the base station to be aware of the status of the nodes in situations when the nodes are idle from a long time and hence helping the base station to analyze the information network dynamically and efficiently. It also incorporates Critical Threshold which is any information of utmost importance in the network, and when such information is sensed it has to be sent to base station with highest priority. Our proposed protocol with adaptive nature and criticality of information is observed to perform better than the conventional clustering protocols like LEACH, SEP and TSEP in terms of stability period, network lifetime and throughput for a temperature sensing application.

We also developed Greedy Efficient Hop technique which is an energy efficient technique to increase the lifetime and stability period of the network. This technique balances the energy in the local clusters by introducing a phenomenon of distribution of the tasks of CH to the right candidate in its very own cluster. The GEH technique is simulated and it is observed to have increased the efficiency and performance of the conventional heterogeneous routing protocols.

Keywords: Network lifetime; Critical Threshold; Stability; Heterogeneity; Adaptive meter

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CERTIFICATE

This is to certify that the dissertation titled **"Enhanced Threshold Sensitive Protocol in Wireless Sensor Networks"** is a bonafide record of work done by **Arpan Jain, Roll No. 2K12/CSE/05** at **Delhi Technological University** for partial fulfilment of the requirements for the degree of Master of Technology in Computer Science & 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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List of Abbreviations

WSNs	Wireless Sensor Networks
BS	Base Station
WANETs	Wireless ad-hoc Networks
MMP	Mobile Management Plane
PMP	Power Management Plane
TMP	Task Management Plane
CHs	Cluster Heads
LEACH	Low Energy Adaptive Clustering Hierarchy
TEEN	Threshold sensitive Energy Efficient sensor Network Protocol
TSEP	Threshold sensitive Stable Election Protocol
ISO	International Organization for Standardization
SPIN	Sensor Protocols for Information via Negotiation
DD	Directed Diffusion
GAF	Geographic Adaptive Fidelity
GEAR	Geographic and Energy Aware Routing
E-LEACH	Energy- Low Energy Adaptive Clustering Hierarchy
TL-LEACH	Two Level-Low Energy Adaptive Clustering Hierarchy
LEACH-C	Low Energy Adaptive Clustering Hierarchy-Centralized
SEP	Stable Election Protocol
APTEEN	Adaptive Periodic Threshold sensitive Energy Efficient sensor Network Protocol
CHATSEP	Critical Heterogeneous Adaptive Threshold Sensitive Election Protocol
GEH	Greedy Efficient Hops
FSPM	Free Space Propagation Model
TRPM	Two-Ray Propagation Model

GEH-E	Greedy Efficient Hop- Energy
CT	Critical Threshold
AM	Adaptive Meter
SNR	Signal to Noise Ratio
SV	Sensed Value
CV	Current Value

CHAPTER 1

INTRODUCTION

Wireless Sensor Networks are composed of many limited battery powered sensor nodes with non rechargeable batteries. These sensor nodes are deployed randomly or with a static strategy in the desired remote territory to collectively fulfill the requirements of WSNs. All the sensor nodes form a network amongst themselves using different optimal mechanism(s) to establish a communication infrastructure which helps in transmission of the desired information like environmental and physical conditions as temperature, pressure, motion, sound, etc to a central authority efficiently. The central authority is referred to as sink or base-station (BS) and has ample power supply unlike constrained power of sensor nodes. With advances in the technology the sensor nodes now are small in size, cost effective and deployable with no fixed topology in the desired environment [2]. This has increased use and applicability of WSNs with unattended sensors in vivid areas like vehicular movement, weather monitoring, security-surveillance, industry applications, health monitoring etc [4, 8]. Some restrictions with the Sensor nodes used in WSNs other than limited power battery are limited processing capability, low bandwidth for communication and less memory space. Sensor nodes communicate over short distances using radio frequency channel to transmit the sensed information. Although each sensor has the capability of limited processing but collaborative efforts have the ability to analyze the desired environment in great details.

Wide applicability and recent advances in the technology have made study on WSNs a research area with lots of active research happening in the wireless domain. Major research is done to increase the network lifetime of the WSNs which is achieved by making efficient use of energy of the sensor nodes and by reducing the number and amount of transmissions by the nodes. Various routing protocols have been proposed to increase the energy efficiency of the WSNs based on the communication architecture between the nodes to transmit the information.

Some of the routing protocols transmit only the non redundant information with the sensor nodes processing all the data it has sensed and forwarding only the non repetitive data using the techniques of data aggregation [5] which saves a lot of transmission energy and increases the efficiency of the network. Data compression is a technique in which data packets received from different sensor nodes are processed and is reduced to fewer numbers of data packets to reduce the communication cost in the networks. The sensor nodes carry out some simple low energy local computations and transmit only the required and optimized information along the path to the BS. Data compression technique is employed by many routing protocols over the sensor nodes to further reduce the amount of transmissions and increasing the efficiency in the network [3].

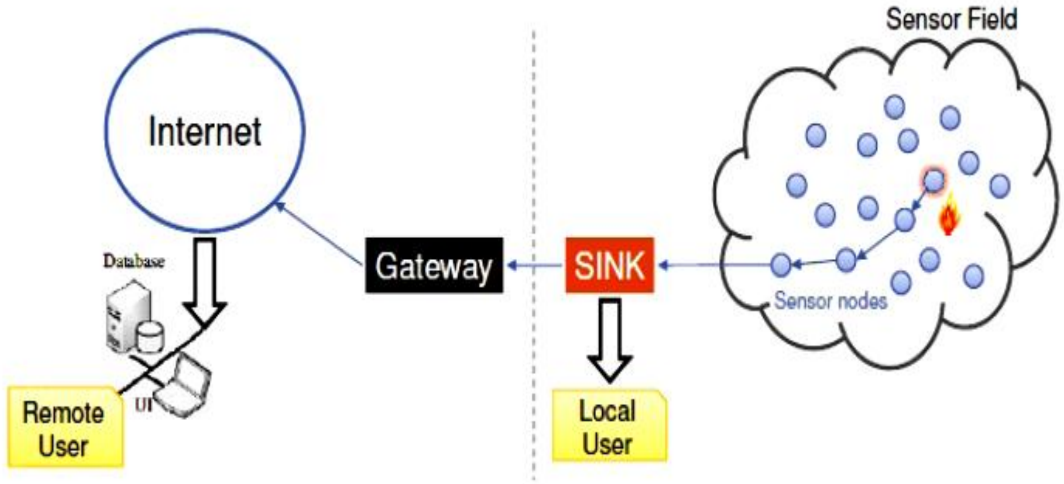

Figure 1.1: Wireless Sensor Network

Figure 1.1 presents the basic structure of a WSN. The sensor nodes are deployed densely in the desired environment. Depending upon the routing protocol of the WSN the sensors senses the environment continuously or after every fixed quantum. Then the sensor node transmits the sensed information either periodically or on the occurrence of some event to the BS. The transmission of information to the sensor nodes to the BS can be done in a variety of ways as proposed by many routing protocols to increase the efficiency of the network. Traditional way of transmitting the information directly from the sensor node to BS is very energy consuming and inefficient.

Thus many protocols are proposed which decreases the transmission from the sensor nodes as one depicted in Figure 1.1. It uses multi-hop transmissions to transmit the information to the BS which distributes the energy expended amongst many nodes and hence prolongs the lifetime of whole of the network. Use of such mechanisms and development of energy efficient routing protocol is a need for the proficient use of WSNs.

One other class of routing protocols in which lot of research has been done is clustered routing protocols. Clustered routing protocols are used in many WSN applications and is proved efficient than the traditional routing models. These protocols are very different from protocols used for wireless ad-hoc networks (WANETs) because of the differences amongst them which can be listed as:

- Network Density: The density of sensor nodes in WSNs is very high and the nodes are close to each other as compared to WANETs. Also the size of the nodes in WSNs may be even smaller than coins whereas for WANET nodes are large like laptops, cellular phones etc.
- Network Size: Number of nodes in WSNs can vary from hundreds to thousands but for WANETs number of nodes is lesser and can be up to few hundred at max.
- Frequency of Topology Change: Topology changes quite often in WSNs because of node failures, addition of new nodes, node movements and environmental interference. Topology may change as fast as in milliseconds in WSNs and network has to adapt with the change in the topology. While in WANETs nodes will join the network after request and can leave the network after some time and usually topology change is after a larger period of time as compared to WSNs.
- Failure of Nodes: In WSNs nodes are employed in remote areas which are sometimes isolated and from the human involvements like in disaster areas. The nodes once deployed cannot be replaced or recharged by the changing requirements and can be damaged from the environmental interferences. But in WANETs node can have rechargeable batteries and they are not imposed to difficult conditions as sensor nodes in WSNs.
- Communication Paradigm: In WANETs point to point communication is done in order establish communication between nodes whereas in WSNs, nodes broadcast in order to communicate with each other.
- Limited Resources: Memory storage of sensor nodes in WSNs is few kilobytes and for WANETs nodes can have gigabytes of storage. Power as mentioned is very limited in WSNs while WANETs can have rechargeable batteries for the nodes.
- Identification of Node: In WSNs it is very difficult to maintain a global identifier for the identification of the nodes because of high number of sensor nodes in a network. Also the nodes in WSNs are deployed in remote areas and hence can be damaged or

moved outside network area frequently. The nodes of WANETs consists of unique identifier like IP (Internet Protocol) addresses.

1.1. Sensor Node Architecture

Sensor nodes are the outcome of the recent advances in low power highly integrated digital electronics and micro-electro-mechanical systems. The sensing circuitry is capable of measuring ambient conditions related to surroundings of the sensor which is then transformed into an electric signal.

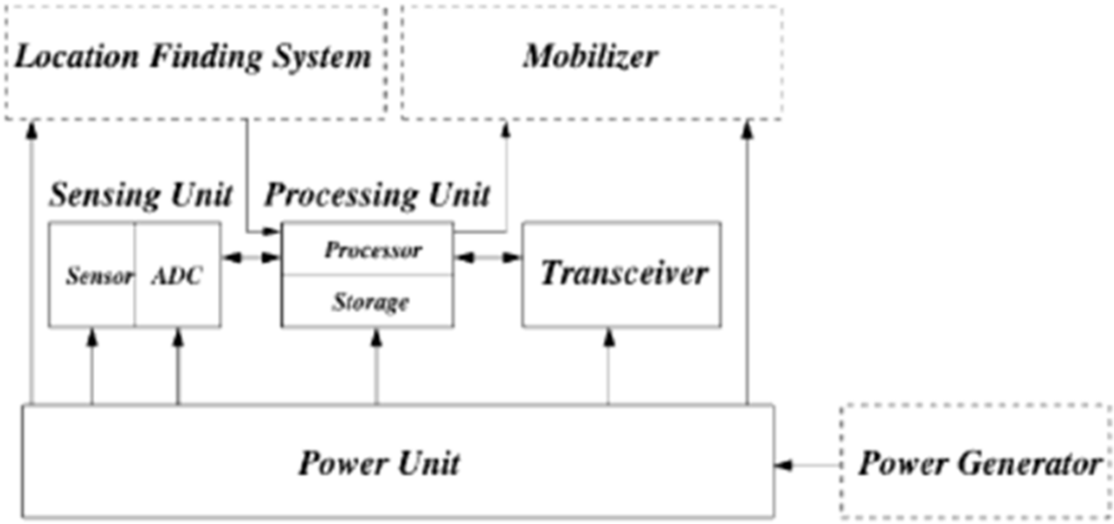

Figure 1.2: Components of a sensor node

Figure 1.2 represents the basic component structure of a sensor node. Sensors are generally composed of four basic components; a sensing unit, processing unit, transceiver unit and power unit [4]. Some of the additional components which can be found in the sensor depending on the applications are mobilizer, location finding system and power generator. The sensing unit is usually comprised of two subunits as can be seen in the figure. The two units are sensors and ADC (Analog to Digital Convertors). Sensors produces the analog signals based on the desired phenomenon and then those sensed analog signals are converted in to digital signals by ADC. The converted digital signals are then given as an input to the processing unit which is associated with a small storage unit and handles the collaboration of the sensor nodes with other nodes to accomplish desired sensing tasks. Transceiver is used to connect the node to the network. The most essential unit of a sensor node is the power unit as it derives all the other units to accomplish their respective tasks. Although in WSNs nodes have limited power and are not rechargeable there are some application dependent sources which can assist the power unit like solar cells. Location finding system is another optional but essential unit in sensor nodes as location of the respective node is generally required time to time to accomplish the routing efficiently. Thus because of limited transmission and power capabilities major research is done to reduce the number of transmission without sacrificing the essential information and efficient use of power unit to prolong the lifetime of the nodes and hence the network.

1.2. Sensor Network Protocol Stack

The sensor network protocol stack is different from the standard TCP/IP and along with the layers used in traditional protocols it has additional planes to handle the issues in the sensor nodes.

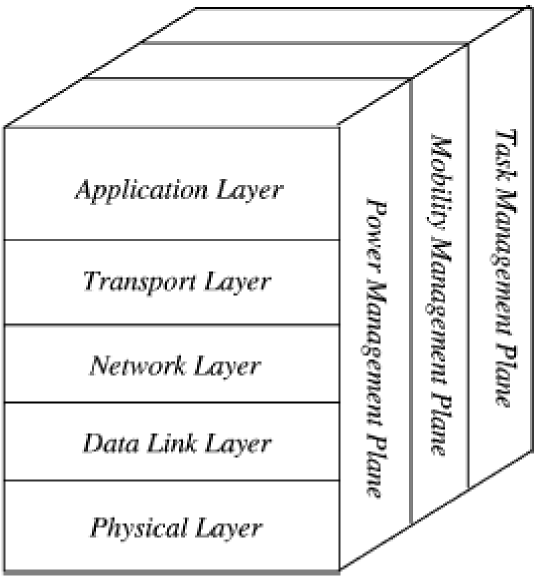

Figure 1.3: Sensor Network Protocol Stack

The front plane in the Figure 1.3 has five layers which work as traditional protocols. The application layer is involved in usage and development of application software(s) based on the specified sensing tasks. The flow of data in sensor networks is managed by transport layer of the protocol stack. The transport layer provides the data to the network layer and it is the responsibility of the network layer to route the data as desired. Data link layer handles the noise and mobility of the nodes in the network and are power aware. Data link layer is also responsible for reducing the collision with the neighbors' broadcast. Transmission, modulation and receiving techniques are handled by physical layer of the protocol stack. The additional planes of power, mobility and task management are specially created to cater the needs of sensor node related to battery, movement and task distribution. Main objective of these planes is to carry out the collaborative sensing task as desired with least power consumption. The power management plane (PMP) has the responsibility to decide how a node will use its power like when it has to switch on their sensors and when they have to switch off them. Power management plane also takes care of when to transmit the information and when not to. Mobility management plane (MMP) is responsible to know the route back to the BS in case of movement of the sensor nodes from their initial positions and inform neighbors about the newly moved sensor node. With the updated knowledge of neighbors now they can contribute and use the power of the nodes efficiently. Task management plane (TMP) performs the balancing of sensing tasks amongst the sensor nodes. It is not necessary that all the sensor nodes in the vicinity should sense and transmit the information. Thus TMP takes such decisions as per the application used in WSNs. So the additional planes are very essential for the objective of WSNs as without them a node will have no capability and will act as an individual transmitting the unwanted information and wasting the constrained power of the sensor node. These planes are essential for simple computations at the sensor nodes as per the changes in power, mobility and required tasks efficiently by the sensor nodes.

1.3. WSN Characteristics

In a WSN, sensor nodes are scattered randomly or with a static strategy in the network field varying from hundreds to thousands in number. There are many operational characteristics of WSNs, few can be listed as:

- Self Configuration: The topology of WSNs is not static and is supposedly changed with no traceable patterns. So the sensor nodes of the network have to be adaptable to such changes while keeping the power efficiency intact. Self configuration also has to handle the situations like node failures and node additions to the network or any other obstacles.

- Efficient Energy Usage: Power is very critical issue in increasing the performance of the network. So energy in a WSN should be expended in optimal manner like sensor nodes can switch off their sensors for a particular period of time and can switch on their transmitters only when any event occurs or after every frame time.
- Single Hop Communication: Traditional WSN protocol used single hop mechanism to send the information to the BS. In this mode of communication all the sensor senses the information and then transmits all the information it has sensed to the BS directly without the involvement of other sensor nodes on its own. This mode of communication is very inefficient and power consuming with lots of redundant information to the BS. Thus modern protocols rely on the multi hop mode of communication for better efficiency.
- Multi Hop Communication: In case of larger networks where the distance of the BS from the node is greater than the transmission range of the sensor node. The single hop communication fails. Multi hop communication uses packet forwarding to increase the efficiency of the network. The nodes send the information to the sink with the help of other intermediate sensor nodes which receives the information from the node and transfers the information to other node along the path of the BS or to BS itself. Multi hop communication saves transmission energy and is proved to be useful for energy efficiency and network lifetime.
- Automatic Load Balancing: Nodes in the network must decide who will be the parent node to transmit the information based on the hop count to the respective node, signal strength, link quality and present load quantity of the parent node. Automatic load balancing is dynamic in nature as the number of nodes in the network can run out of power anytime in between the network lifetime.

1.4. Motivation

In hierarchical routing protocols the sensors coordinate among themselves to form a communication network such as multi-hop network or a hierarchical organization with several clusters and cluster heads (CHs) [1]. Cluster formation increases the performances of the WSNs by making efficient use of energy of sensor nodes [10, 13, 14]. The CH selection is done on the basis of probability of nodes to become the CH or on the basis of remaining energy of the nodes. After CH selection nodes near to CH are associated with CH and transmit data to CH instead of base station (BS) to reduce transmission energy.

CH then transmits only non-redundant necessary information to the BS which increases the network lifetime of the network [5]. WSNs can be classified into two types based on the type of application [7].

- Proactive Networks: Sensor nodes transmit the data periodically in such networks. After a fixed time interval called frame time, nodes switch on their sensors which sense the environment and transmit the data to the CH or BS at regular intervals. They are suitable and used when information required is to be monitored periodically.
- Reactive Networks: They are application specific protocols where nodes keep sensing the environment continuously and transmit the information to the CH or BS only when it observes a drastic change in the environment as per the defined threshold parameters. It reduces the transmission by not sending the data periodically and hence is efficient for time critical applications.

The reactive networks are of great importance if the networks are to be application specific. The sensor nodes in reactive networks do not have uniform periodic transmissions of the data and hence reduces the transmission power of the nodes. This reduction in transmission power increases the lifetime of the network. Homogeneous networks with all the sensor nodes having same initial energy have many clustering protocols for efficient use of the energy of the nodes. LEACH proposed in [13] is a clustered protocol where the nodes elect their CH and transmit the packets to the CH which than performs computations and forwards the non redundant information to the BS. LEACH was then used as the base protocol for hierarchical clustering and family of protocols were proposed as improvements over LEACH. First reactive protocol for homogeneous network, TEEN as proposed in [7] improved the performance of WSNs for time critical applications. Heterogeneity was introduced in WSNs with the implementation of SEP as proposed in [14]. [10] Proposed TSEP, a reactive protocol for the heterogeneous WSNs. TSEP improved the network lifetime and throughput of the network but has some drawbacks which are the same as with other threshold sensitive networks.

Thus lots of active research is done in the area of reactive networks. Although reactive network provide great flexibility and efficiency but there are some shortcomings associated with these networks. Some of the application specific networks do not rely on reactive network because of its drawbacks in terms of status of the network and priority in information. We in this dissertation have worked on addressing these drawbacks of the reactive protocols in WSNs to increase the use and applicability of such networks and making it more efficient and reliable for time critical applications.

1.5. Research Objective

With the motivation explained in the previous section, the objective of our research work can be identified as:

- Development of a mechanism to keep the BS aware of the status of the network dynamically in situations when the network is idle. This will assist the BS to analyze and use the network structure efficiently.
- To improvise the transmission of critical information(s) to BS with highest priority, almost instantaneously.
- To transmit the information using greedy hops instead of regular hops to increase the lifetime of the network.
- To give control to the user to monitor the introduced features after each round of CH selection so that the user can decide which information is critical to the network and optimally evaluate the degree of awareness needed by the BS.
- Compare our protocol which takes into consideration all the above characteristics with the conventional routing protocols in terms of energy efficiency and performance metrics.

1.6. Thesis Organization

We start this dissertation with introduction in chapter 1. A detailed description of background is presented in chapter 2 which includes applications, issues and characteristics of WSNs. Chapter 3 describes the routing protocols in detail which are related to our research problem. Chapter 4 gives a brief about the network model we have used. Chapter 4 also explains in detail about our proposed protocol CHATSEP and proposed technique GEH. The description of the proposed work is explained in phases of cluster head selection, cluster formation and data transmission phase in chapter 4. We evaluate the performance of the proposed routing protocol and technique with conventional routing protocols in chapter 5. We conclude about the work done and observations in chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 WSNs Classification

Sensor networks can be employed to benefit a variety of applications in diverse environments. To benefit the applications, sensor nodes differ greatly in technical requirements for these various applications. Such networks require specific application oriented sensors to be developed and deployed. Although there are many specific properties of the sensors but some of the properties are common in these networks even for some very discrete applications. Like one group of application uses randomness for node distribution as the network area may be remote and isolated from human involvement and the remaining group of applications may use strategic static deployment. Hence a network can be classified based on the deployment strategy. Such common properties classify the WSNs. Some of the most prominent can be listed as [6, 7, 10, 11].

2.1.1 Aggregating and non-aggregating networks

This classification is based upon the aggregating capability of the nodes. Aggregating networks do not transmit the information directly to the BS but use packet forwarding and uses intermediate sensor nodes to reach to BS. In large sensor network it is preferred to perform aggregation rather than using traditional technique of non aggregating networks where the transmission of all the information is done directly to the BS. Aggregating network is very useful when the node density is high which is usually common in WSNs. It is also efficient when the network area is larger than the range of the nodes as in such cases it is not possible to use non-aggregating network for the transmission of information. Aggregating networks also improves performance of the network when the data count is high as such network only transmits the compact non-redundant information to BS. Aggregating network reduces a lot of network traffic by balancing the amount of data and reducing the number of transmissions to the BS. The network load traffic is proportional to the size and density of the network and as the size of the network increase preference for aggregating networks also increase over non aggregating networks for a better efficiency of the limited energy of the sensor nodes.

2.1.2 Single-hop and multi-hop networks

Depending upon the hop count of the sensor nodes during transmission of data to the BS networks can be divided into single hop network or multi hop network. In single hop sensed data is transmitted directly to the BS without the involvement of any other node while in multi hop network many intermediate nodes are involved in transmission of the data to the BS. Let's assume we have five nodes in the network A, B, C, D, E and BS. As shown in the figure 2.1, in single hop network every node will send the information they have sensed to the BS independently. And in multi-hop communication nodes A and C send their sensed information to BS via an intermediate node B and node E sends the information to the BS with the help of node D. It can be seen if some simple computation responsibility is given to the senor nodes then we can reduce in the network traffic and increase the efficiency with multi hop networks.

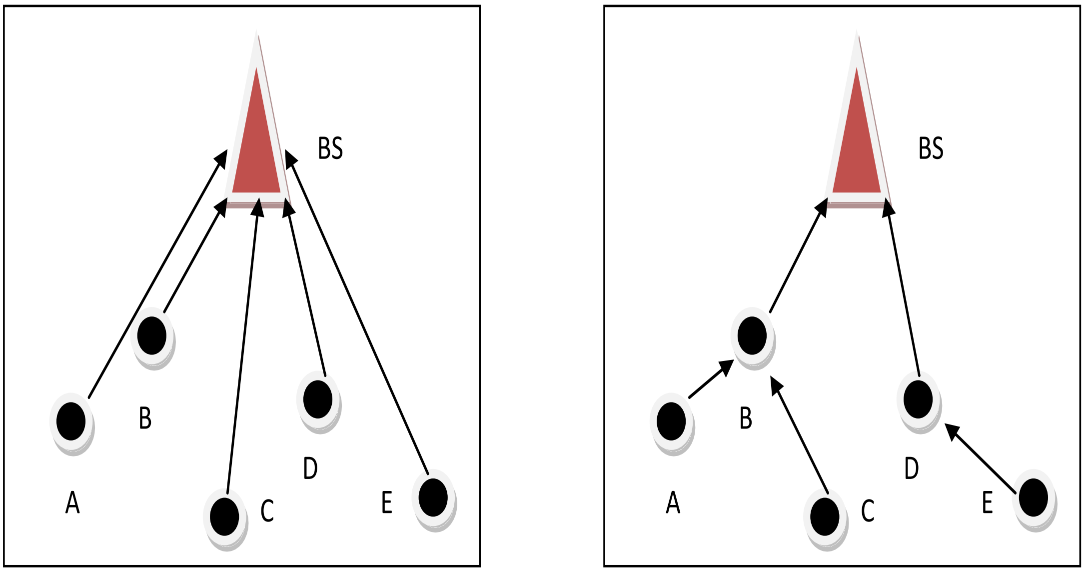

Figure 2.1: Single and multi hop networks

2.1.3 Deterministic and dynamic networks

Spatial distribution of the nodes in the network derives this classification of WSNs. Node deployment is an essential element for the working and efficiency of any WSN. The nodes can be deployed in any area of interest which can be in a vivid variety of environment. In most of the cases there are no strategies for the distribution of the nodes as the area of interest may be places of disaster, a place where human interference is not possible, water bodies, thick forests etc. Thus in such network areas only random deployment of the nodes is feasible. Thus dynamic scheme is when the nodes deployment is not strategic and the location of the node is not known to the central authority while in deterministic schemes the position of the nodes is preplanned or known in the network. Topologies of deterministic networks are static generally and inflexible. In dynamic network topology is not stable and such implementations are more stable and flexible to changes.

2.1.4 Proactive and reactive networks

This classification can be derived from the type of target application. In the applications where periodic data is required by the BS to analyze the desired task proactive networks are employed. In proactive network the working of sensor is periodic. After every fixed time interval called frame time each sensor switches on their transmitter and senses the environment and transmits the sensed information to the intermediate node or BS. Thus the amount of energy dissipated in such network in each round is calculative and the life time of the network can be estimated. In some applications which are time critical or event driven periodic transmission of information is not necessary and hence using periodic networks in such situation is waste of resources. In such cases reactive network are used. In reactive networks the sensors continuously sense the environment and transmit the information only when any specified event occurs like certain changes in temperature, pressure etc. Thus as transmission requires most of the energy of the sensor nodes, reactive network are more efficient than proactive in terms of network lifetime, throughput and energy efficiency and are used actively for specific event driven applications.

2.1.5 Self-configurable and non-self-configurable networks

Control scheme of the network derives this classification in WSNs. Most of the WSNs work on the self-configurable schemes only so as to handle the complicated tasks for the correct working of the network. As the topology of network is not pre-planned, self – configuration is the only way a network can handle such a dynamic changes in topology. Addition and deletion of nodes in a WSN is quite often and self-configuration is needed to manage changes in the number of nodes in the network. Non-self-configurable networks are not used quite often but can be employed in small-scale networks with usually a static deployment of the sensor nodes.

2.2 WSNs Application Areas

With the increase in growth and feasibility of WSNs, there are numbers of fields of applications which now use WSNs. Wide varieties of sensors are used for such applications. The sensors used can be thermal, visual, infrared, radar, seismic, low sampling rate magnetic and these sensors are capable of monitoring variety of diversified environmental conditions like temperature, pressure, soil makeup, vehicular movement, noise levels. Sensors are also used to detect the presence or absence of certain objects, to measure the mechanical stress levels on attached objects and to measure some of the dynamics characteristics like speed of the target object along with its direction and size [12]. As the numbers of applications of WSNs are enormous, one cannot list an exhaustive list of the application areas but can be briefly categorize in military, health, home, environment and commercial applications.

2.2.1 Military applications

Most extensive use of WSNs is done in military applications right from the inception of WSN. The category of military applications can be in computing, intelligence, surveillance, military command, control etc [15]. The characteristics of WSNs like rapid deployment, cheap sensors, self-configuration and fault tolerance makes WSNs the most suitable option in military operations as in the battlefield there is a need to quick deployment of the nodes so as to setup a network as fast as possible in high tension areas. The number of nodes may be subject to change frequently due to intrusions in the field and hence self-configuration is necessary to keep the network working. Cheap cost of sensors in WSN is another factor which is of importance to military applications as the sensors once deployed may be destroyed and can be subjected to redeployment quite frequently.

Few military operations involving WSNs are targeting, battlefield surveillance, battle damage assessment, monitoring friendly forces, equipment and ammunition etc. Sensor networks are used in the guidance systems of intelligent ammunition. Battle damage assessment is done with the help of WSNs in the areas which are not in the home range. For the battlefield surveillance military install WSNs on the critical terrains and the areas far from the home range and can closely track the activities of the opposing forces. Other than these military can always use WSNs for monitoring of the troops of the friendly forces to keep a close watch on them. WSNs are also used in managing the information related to the availability and conditions of the equipments used in the battlefield before and after the battles.

2.2.2 Health applications

Health industry has adopted the use of WSNs for variety of applications right from the simple diagnostics to providing interfaces for the disabled. Some other applications which are employing WSNs are patient monitoring, administration of drugs, monitoring the movements of internal processes for animals of interest, tele-monitoring of the physiological human data and also tracking of the doctors in the hospital [12].

In tele-monitoring of the physiological human data sensors give more freedom to the humans. It can retain the information from the sensed behavior of the individual which can be stored for long and can be used for exploration. Also, use of WSNs in tele-monitoring provides greater flexibility and comfort to the patient. WSNs used to track the doctors and patient is done by attaching sensor nodes to them. The sensor nodes attached has specific tasks which may be checking heart beat, blood pressure etc.

2.2.3 Environmental applications

WSNs play a major role in environmental applications specially related to natural calamities and disasters. Some of the other applications using WSNs are monitoring environmental conditions which can affect the growth of crops, tracking the movements of small animals, insects and birds, monitoring in soil, marine and other atmospheric contexts, bio-complexity and pollution studies [17].

Precision in agriculture can be maintained by WSNs as it can monitor the level of soil erosion, the level of pesticides in water and the amount of air pollution [19]. Flood detection is another area where WSNs are used and one of the examples of such sensors is ALERT which is used by US. Several sensors like weather, water level and rainfall sensors are deployed and send's the data packets to central authority. The central authority then monitors the values and takes appropriate actions and keeps the data for later purposes. Another critical area of environmental applications where WSNs are used is forest fire detection. There are situations when forest fire can broke large and can cause a lot of disaster. Thus to avoid such incidents sensor nodes are deployed either statically or dynamically of the stretch of the forest with high density. In case of early stages of fire in forest the sensor node communicate the exact location of the origin of fire and thus necessary action can be taken to stop it from spreading. If the fire has expanded and is beyond controls the information from the sensors helps in evacuating the place and thus saves any human losses.

2.2.4 Commercial applications

Many commercial applications use WSNs for better flexibility and versatility. Some of the commercial applications which use WSNs are monitoring quality of the products, construction of smart office places, robot control, automation and control in factories, machine transportation. WSNs are deployed in security services also like monitoring and detecting thefts, tracking of vehicles. Various factory applications are modeled using WSNs like factory instrumentation, local control of actuators, instrumentation of semiconductor processing chambers, rotating machinery, wind tunnels, and anechoic chambers.

Environmental control in the office buildings is widely handled using WSNs. As the heat and air conditioning of most of the buildings is centrally controlled there are places with differences in temperature. One place in the room may be cooler than the other as the central control does not distribute the energy evenly. Thus distributed WSNs are deployed in such building to control the temperature and air flow in different parts of the building. Detection and monitoring of vehicle thefts is another commercial application which uses WSNs. Sensors are spread within a geographical region and with the help of internet these changes reach the users in the remote areas. Also the location in case of the theft can be directly sent to the BS and theft vehicle can be recovered. In inventory control each item is attached to a sensor node which can tell the location of the item. Thus in the inventory the user can locate each and every item and can keep a count of items. Remote user can also track the exact position of the items and can be ensured of the count of the items.

2.2.5 Characteristics

Most of the applications of WSNs share many common characteristics. Some of the similarities based on the interaction(s) between sources and BS are:

- Periodic monitoring: sensor can be made to periodically measure the values in the environment and send the measured values to the user.
- Event detection: Specific events can be detected by the sensor nodes. Such sensor are also applied to addresses the event of natural calamities. Some of the applications

with event detection are grass fires, forest fires, volcanic eruptions etc. Classification of events is necessary in case of a sensor network used for more than one event detection.

- Location driven: Most of the applications work on the changes in the position of the sensors. Applications theft detection, inventory management, detection of behaviour of humans are monitored based upon the changes in the position of the sensors.
- Tracking: Some applications sense the data even after continuous change in position. In cases of surveillance if any threat is on the move the sensor nodes communicate the source to the BS along with the speed and direction. This helps to estimate the present position of the targets.

2.3 Design metrics

In the early days of WSNs, majority of its implementation was done for military applications. With the advances in technology and increase in WSNs scope now they are used in a variety of applications. To address these vivid classes of applications some of the essential design issues a sensor network must possess are [18, 20];

- Scalability: As the numbers of nodes in a WSN are dense from hundreds to thousands, scalability is an important issue. Thus the schemes in the sensor nodes should be scalable enough to respond to certain events.
- Fault tolerance: There are many situations which can cause sensor nodes to be failed or blocked from the network. Situations like lack of power, environmental interference and physical damages can often arise of the sensor nodes. Thus the network should be fault tolerant to such scenarios and the working of network should not be affected even after reduction of the sensor nodes. Thus fault tolerance is the ability of the network to work as expected even after node failures.
- Production costs: The production costs of sensor nodes should be low as the numbers of sensor nodes in the network is very high and most of the network is defined by the sensor nodes only. Thus lesser prices of sensor nodes lead to feasible networks.
- Power consumption: The transmission of information in WSNs is very energy consuming, proportional to the square of the distance or even four times in some cases when the distance between the source and target nodes is greater than a particular distance. Multi-hoping is used to reduce the energy consumption. But multi-hops introduce complexity for the medium access control and topology management plane.

Thus trade-off should be considered about which mode of communication should be used. If the nodes are in close vicinity of BS then direct communication should be preferred over multi hop communication.

- Operating environment: Sensor networks can be setup almost anywhere any possible place in the environment like bottom of a ocean, around battle field beyond enemy lines, in a chemically contaminated field, inside large buildings or home, can be attached to humans or animals, can be installed in high speed vehicles, can spread out in forest to prevent disasters etc.
- Data delivery models: These models decide when the node has to transmit the information it has sensed to the BS. Some of the models which are used depending upon the applications are event-driven, continuous, query-driven and hybrid. Event-driven models transmit the information when any desired event has occurred. Transmission is done periodically in case of continuous data delivery model. A query-driven model transmits after receiving a particular query from the BS. Hybrid models are used by some of the applications which combine the approaches of continuous, event-driven and query-driven.
- Data fusion: As the sensor nodes are deployed with high density in the area of interest it is very likely that a group of these sensors will sense the same information. Such redundant information from the sensors can be aggregated to reduce the transmission. Data aggregation is the technique used for such purposes in which data from more than one sensor is combined with the help of functions like min, max, average or elimination of duplicates. For large networks, data aggregation introduces a little computation capability in the sensor nodes but still saves lot of energy by reducing the amount of transmissions. Thus varieties of routing protocols use data aggregation for traffic optimization and energy efficiency of the sensor networks.
- Network setup: Setting up the network is dependent on the application and also plays are role in the performance of the network. Deployment of nodes can be either deterministic or random. In deterministic scenarios the nodes are deployed to the pre determined locations. Such situations are possible only in the areas with human involvements like inside a building. In random deployment of the sensor nodes distribution of the nodes is not uniform. In such cases when clustering is done position of CH is a critical issue to retain the energy efficiency of the network.

- Overhead and data latency: Data latency can be introduced by data aggregation and/or multi-hop communication. Complex algorithms of some routing protocols can sometime create excess overheads which may not be suited for network energy high energy constraints.
- Quality of service: Quality of service is determined by the application. It may be data reliability, energy efficiency, location awareness, synchronised processing etc. These factors decide which routing protocol should be used for particular application. Some applications like military applications are focused on secure and periodic information from the sensor networks and hence the selection of routing protocol for such an application is continuous routing with cryptographic schemes

2.4 Network Layer Routing Protocol

According to ISO model routing protocols are defined as network layer protocol [21]. Each layer of ISO model has pre defined responsibilities. When any information is to be transmitted between two network-hosts, need arises for protocols which can define a mechanism of sending and receiving the correct information across the network hosts. Routing is understood as the process of selection of path between the source and destination which are used for the successful transmission of information. It is a set of formal rules describing how to transmit across a network. It decides how routers will communicate with each other, enabling the usage of multi hop routes between any two nodes for the transmission of information on a communication network.

2.4.1 Routing protocols in WSNs

Sensor nodes have limited capabilities with limited energy, restricted communication bandwidth and computational ability. These are some of the feature of WSN which distinguishes it from wireless ad-hoc networks and traditional networks. Almost all the applications of WSNs require the information to be sensed from multiple sensors and send to a particular sink [22]. Thus this many-to-one transmission model of WSN is different from one-to-one and many-to-many model which are implemented in wireless and wireless ad-hoc networks. Another characteristic of WSNs is that many nodes are deployed in the same vicinity and they share a high probability that they will sense the redundant values. This redundant value increases a lot of traffic in the network [1, 5]. Increase in traffic for redundant information causes inefficiency in the network. Therefore there is a need to implement data aggregation in protocols of WSNs. Energy constraint is the biggest challenge to create a routing protocol in WSN. Also it is unrealistic and impossible to recharge or replace the batteries of a sensor node. Thus we cannot use traditional routing protocols available to address the needs of a WSN.

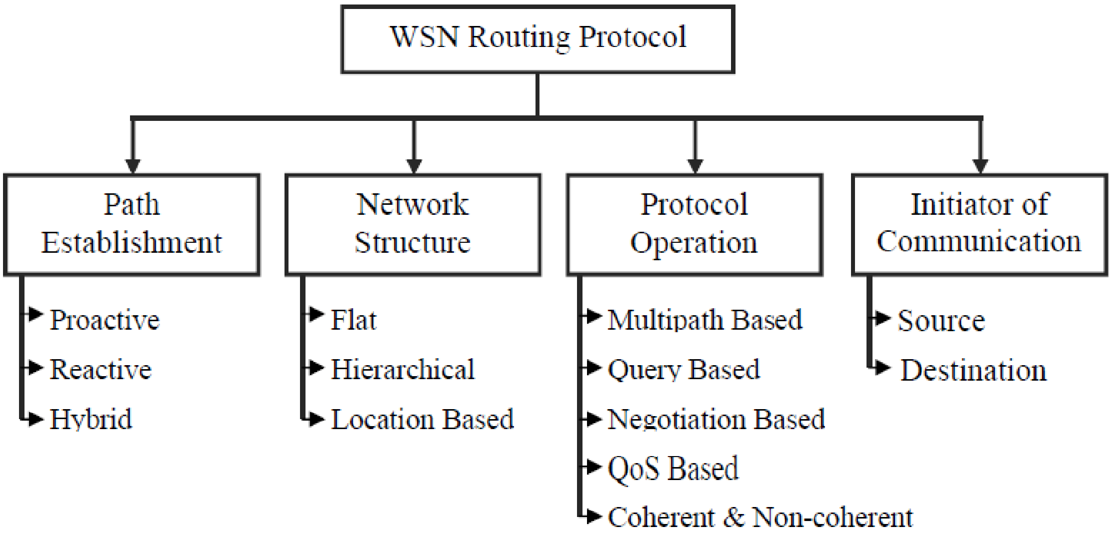

Figure 2.2: Classification of WSNs

Figure 2.2 presents a brief classification of WSNs based on various design criteria's. We have already discussed protocols based on path establishment. Underlying structure in the routing protocol plays a major role in the operation of routing protocol of WSNs. Thus network structure based protocols like flat, hierarchical and location based are employed depending on the applications so as to increase the performance of the protocols. Some of the standard protocols are discussed in the following sections.

2.4.1 Flat-based routing protocol

In flat networks, every node plays an identical role and all the sensor nodes coordinate to execute the desired sensing task. Due to very high number of sensor nodes and random deployment it is almost impossible to attach a global identifier for each sensor node. Absence of global identifier in the sensor node makes it unrealistic for BS to query a set of specific nodes. Thus it has led to data centric routing, in which the BS sends query not a particular node but to a region of interest and waits for the sensor nodes from that regions to send the sensed information to the BS. Thus even after absence of global identifier, the BS can monitor the network depending on the result of the queries. SPIN

[23] and DD [24] are two data centric protocols which performs data negotiation between the nodes to save energy by eliminating the redundant data.

SPIN proposed in [23] is an adaptive data centric protocol which exchanges meta-data among the nodes which is a data advertisement mechanism. The data advertisement is done before the transmission of data. When a node receives new data from other nodes it transmits the data to the neighbors. If any of the neighbors is interested in data it will retrieve the data by sending a request message to the node from which it has received the meta-data message.

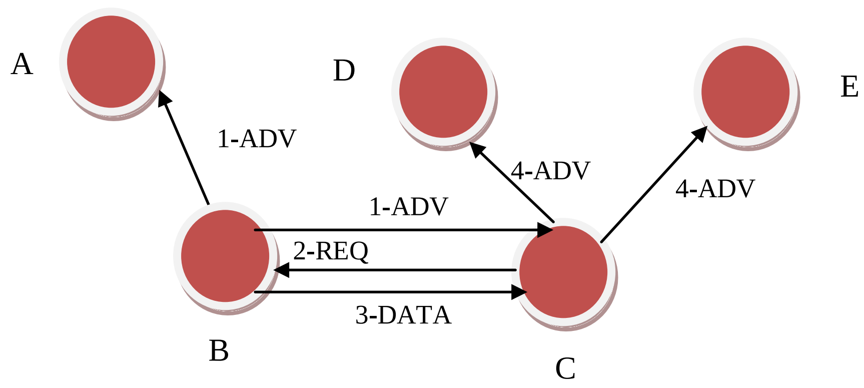

Figure 2.3: SPIN Protocol

SPIN is a 3 stage protocol with messages as ADV, REQ and DATA. Figure 2.3 gives an overview of SPIN protocol. When node B receives data packet, it sends the ADV message to its neighbors with the meta-data. Then interested neighbor (C) sends a REQ message to node B. After receiving request for the data it transmits the DATA to the interested node C. Now as C has received data it sends ADV messages to its neighbors (D and E) with the meta-data. Thus SPIN localizes the topological changes as the nodes are required to know only single hop neighbors. One disadvantage of SPIN is that if some node which is far is interested in the data but the neighbors of the node which has sent the ADV messages are not interested in the data. Then that node will never receive the data even if it was interested in it.

Directed Diffusion, proposed in [24] is a data centric protocol with application awareness which uses name scheme for the data to introduce data diffusion among the sensors. To create a query, an interest is defined using the list of attribute-value pairs such as interval and the name of the object. Then the interest is broadcasted by the sink via its neighbors. When the nodes receive interest from the BS they perform catching. Then the interests in the catches are used to compare the received data with the values in the interest received by the BS. The interests also contain gradients which contains back link to the neighbor from which the interests were received. Gradients are characterized by time stamp of the interest, data rate and duration. Hence with the help of interests and the gradient path between the node and the BS can be derived. Thus then the sink can send the original interest message through the selected pat with smaller time interval to get the data packets of interest frequently. The main objective of DD is to combine the data it receives from the various nodes using in-network data aggregation based on the list of attributes of the form attribute-value pairs. DD differs from SPIN in terms of the on demand data querying mechanism. In DD the sink will query the sensor node only if a particular data of interest is available while in SPIN it advertises the availability of data to the sensor nodes.

Some advantages of DD are that the nodes are capability of data aggregation and caching which is a great plus to save the energy of the nodes. No need to maintain global identity of the nodes and it is an on demand protocol so is highly energy efficient. However it should not be used in the situation where continuous monitoring of the data is required like environmental monitoring as it a query driven protocol.

2.4.2 Hierarchical based routing protocol

In the scenario when large number of sensor nodes are deployed in large fields it is not possible for the nodes to transmit information directly to the BS. The single gateway architecture is not efficient in larger set of nodes. Thus clustering in the network is performed to address this issue in variety of protocols [25, 26, 27]. In the hierarchical or clustering protocol the process is divided into two phases. First phase is the selection of the cluster and cluster head for the cluster. Selection of cluster head is done on the basis of remaining energy of the nodes. The hierarchical protocol works on probabilistic models or residual energy based models for the selection of the CH. Even the frequency of selection of the cluster head is dependent on the protocols. The second phase is the routing phase, where the data packets are sensed and transmitted to the BS.

The transmission phase varies according to the protocol. It may use single hop for the communication of data packets or multiple hops can be used with any number of levels deepening on the area and density of the network. Different computational capabilities can be assigned to the sensor nodes or the CHs in the hierarchical networks like data aggregation, data compression to achieve optimality as per the needs of the applications.

These techniques can reduce significant size of the data packets to reduce the network traffic. Thus hierarchical protocol increases the overall system lifetime, scalability and energy efficiency. Various routing protocols like LEACH, PEAGIS, SEP etc uses hierarchical clustering. Each such protocol has some unique characteristics which makes them suitable for the desired environments. We have focused our work in the hierarchical clustering protocols. Reactive clustering is the main area of focus for our work and hence we will discuss clustering protocols in greater detail in later sections.

2.4.3 Location based routing protocol

Location based routing protocols are used in the situations when the location of the nodes is needed. In such routing protocols the sensor nodes are referred by their positions in the network. They approximate the distance between two nodes based on the incoming signal strength. Then relative coordinates between the two nodes can be measured by exchanging the information between them. They can also use satellites to get the location of the nodes by using Global Positioning System services if the sensor nodes have a low power GPS receiver [28, 29]. Some of the location based routing protocol uses the locations of the nodes to transmit the data packets in energy efficient way. Like if we know the region and location of the sensors, it will be efficient to diffuse any query as now the query will be diffused only to that specific region.

GAF proposed in [28] is one of the energy aware location based routing protocol which was developed for the mobile ad-hoc networks but works for sensor networks too. It aims at conservation of energy by switching off unnecessary nodes keeping the routing fidelity intact. In GAF, the sensor nodes are divided in fixed regions/zones and form a virtual grid. In each of the zones nodes synchronize and take different roles. Every node uses its GPS based location and associate itself with a point in the virtual grid. Nodes which are associated with the same point the grid are considered equivalent in terms of packet routing cost. This equivalence is used to keep some nodes in the sleeping state to save the energy.

The states defined in GAF are *discovery, active* and *sleep*. The discovery state determines the neighbors in the grid. Active state represents the participation of the node in the transmission and sleep state refers to the nodes which have their transmitter switched off to save energy. To handle the routing fidelity, sleeping time of nodes is broadcasted to the neighbors. The neighbors in the sleeping state adjust their sleeping time so that before the active nodes go to sleep, the nodes that are in the sleeping state should wake up. Although it is location based protocol, it also uses clustering as it breaks the sensor nodes into clusters/grids based on the location. In each grid there is a leader node however in GAF no data aggregation or data compression is performed.

GEAR is another location based energy aware routing protocol proposed in [29]. To route a data packet to a particular destination GEAR uses heuristic based neighbor selection and energy awareness. The main objective of GEAR is to reduce the number of interests in the diffusion by sending the interest message only to specific nodes along the path in the desired region rather than broadcasting the interest message. Each node in GEAR knows an estimation cost and learned cost. Estimated cost is based on the remaining energy of the node and the distance towards the destination. Learned cost is the more accurate version of the estimated cost which takes into account the holes in the network to reach the destinations. Hole is the situation when there is no neighbor closer to the target node in the region than itself. If there are no holes in the path to the destination the learned cost is same as the estimated cost.

GEAR works in two phases. First is forwarding data packets towards the target region and the second is to forward the data packet within the region. In the first phase, node with the data packet/interest checks if there is any node which is closer to the target region than itself. If there are many nodes which are closer to the target region then the closest neighbor is selected as the next hop to reach the target region. In situation when no neighbor is close to the target region than itself, one of the neighbors is selected based on the learning cost to transmit the data/interest to the target region. In the second phase the interest has reached in the target region. The packet can be diffused in the region using restrictive flooding or recursive geographic flooding. In sparse deployment restrictive flooding is better and in densely deployed networks recursive geographic flooding performs better.

2.4.4 Operation based routing protocols

Some of the routing protocols incorporate additional computation capabilities in order to access variety of issues. Some adds certain feature to an existing protocol to improve the design issues and enhance the performance. Some of such operation based protocols are discussed:

- Multipath routing protocols: These protocols ensure stability of the network. Multipath protocols maintains alternate path between the nodes and the BS. There can be multiple paths between the source and the destination. It depends on the application and trade-off between energy efficiency and fault tolerance on how many paths are to be stored by the protocol. The alternate paths are cross checked and kept alive by transmission of periodic messages. It increases the network traffic in the network and costs energy too. Although multi path protocols increases the reliability of a network but are inefficient in terms of lifetime of the network.

- Query based: We have discussed query based protocols like DD in the previous sections. In such protocol destination raises a query in the network. This query reaches the desired node or the region of interest with the help of a particular mechanism like broadcasting, communication in neighbors, location based etc. Then particular group of nodes which matches the area of interest of the query senses the information and sends it back to the destination via a path which is established when the query has reached from destination to source. The queries can be sent in normal or encoded forms.
- Negotiation based: Negotiation based routing protocol reduce the redundancy of data by the usage of data advertisements which are high-level data descriptors containing meta-data. One such routing protocol SPIN we have discussed. The three stats in these protocols are used to broadcast the data only to those neighbors which are interested for that particular data. As the node receives some data ADV message is sent to all the neighbors which then checks if they need this data or not. If they need the data it sends a REQ message to the node. The node after receiving the REQ message sends the data only those nodes which are interested and hence avoids higher network traffic. One pitfall of such protocols is that suppose a node X is interest in the data but is not in the neighbor of the node Y which has data. Then this node X may or may not receive the data depending on the neighbors of the node Y. If none of the neighbors of Y are interested in the data then X will not receive the ADV message for the data even if it is interested. The nodes in such protocols are capable of little computations like data aggregation which reduces the redundancy of the data. The usage of flooding to send the query of interest is better than broadcasting the data packet even to those nodes who are not interested in it.
- Quality of service based: These protocols are created to address the QoS of network as per the application using WSN. Some of the factors which fall under QoS can be delay in sending the data to the BS. It may be data reliability, location awareness, synchronised processing etc. These factors decide which routing protocol should be

used for particular application. Energy is another factor which is kept under consideration while implementing QoS based protocols.

- Coherent and non-coherent processing based: Data processing is an essential element amongst all the operations of WSNs. Data processing is a compulsory as the whole WSN depends on the sensing of sensor nodes and transmission of sensed information of the central authority. Thus vivid techniques of processing of data are developed in different routing protocols addressing large set of applications. Broadly we can divide data processing in coherent data processing and non coherent data processing. In non-coherent data processing the sensor nodes perform a local processing of the raw data before sending for further processing to other nodes. The nodes which perform further processing of data are known as aggregators. In coherent data processing, nodes after sensing the data performs only minimal processing and send the data to aggregator nodes for further processing of the data. The least processing which the node does are some very essential tasks like time stamping, duplicate suppression etc. In direct transmission traditional techniques there used to only one aggregator i.e. BS. But this causes a lot of redundancy and traffic in the network. This is improved by limiting the number of sources and having optimal number of aggregator nodes.

CHAPTER 3

RELATED PROTOCOLS

In this chapter we discuss some of the routing protocols which introduced clustering for efficient routing. These protocols have paved a way for intelligent and energy efficient transmission of data. Clustering protocols also employ a variety of specific techniques to increase the efficiency of the protocols. Data fusion is one of the techniques used by clustering protocols for reducing the network traffic and increasing the performance of the network. It increases the performance of the network by addition of some low power computation capabilities to the nodes. Communication mode of transmission in clustering protocols is multi-hop in almost all routing protocols. With the wide applicability and usage of clustering protocols lot of research is done in this area. Some researches proposed routing protocols with various improvements over variety of traditional clustering protocols in terms of energy, lifetime, throughput and other application specific requirements. LEACH proposed in [13] forms the base for many routing protocols. After LEACH was introduced, many protocols were proposed which imposed some improvement over LEACH and are generally termed as LEACH family of protocols. E-LEACH, TL-LEACH, M-LEACH, V-LEACH and LEACH-C are some of the protocols from LEACH family of protocols [31]. E-LEACH was LEACH with consideration of residual energy in the selection of CH. TL-LEACH is introduction of two hops in the LEACH protocol in consideration of reduction in the network traffic. M-LEACH was introduction of multiple hops in the LEACH protocol which can be more energy efficient in cases of large networks. V-LEACH proposed in [33] handled the cases of failure of CHs by electing a vice-CH to handle the failures. LEACH-C proposed in [32] introduced centralized algorithm of selection of the CHs to aim at better uniform distribution of the CHs throughout the network to balance the network traffic and energy in the network and hence increases the performance of the network but needs the BS to be aware of the position and energy of the nodes to decide the respective CH. Many other routing protocols were developed other than LEACH family to entertain a certain class of applications. TEEN was developed for time critical applications and was the first protocol in the class of reactive clustered networks. TEEN [7] was not a periodic protocol like LEACH but threshold sensitive protocol where the transmission of data is dependent upon the occurrence of drastic change in the environment as desired. Thus TEEN proved to be an improvement over LEACH for time critical application where periodic information is not a requirement. Some protocols like APTEEN [34] were developed over TEEN as improvements in situational scenarios. Later a new feature was introduced in clustering protocols was heterogeneity. Heterogeneity means different energy sensor nodes deployed in the network rather than all the nodes with same initial energy. SEP [14] was proposed with two level of heterogeneity and proved to efficient than other clustering protocols with little complexity of heterogeneity. TSEP [9] was introduced as threshold sensitive clustering protocol with three levels of heterogeneity.

We have focused our work on the clustering protocols in WSN. We in this dissertation have worked on addressing the drawbacks of the reactive heterogeneous clustering protocols. The issue of lack of network information availability to the BS at any instant of time is addressed. The issue of delay in the high priority information is addressed. Hop communication is changed to add deterministic quantification in probability based CH selection. Thus we give a brief about the related routing protocols to have a better understanding of the proposed work.

3.1 LEACH

It is a self organising homogeneous proactive clustering protocol proposed in [13]. Sensor nodes with equal limited initial energy are used for randomized distribution of load in the network. The nodes are organised into local clusters with one CH. Nodes transmit data to their associated CH which then aggregates the data and sends only the required irredundant data to the BS optimising the energy. LEACH is categorized in two phases; cluster setup phase and steady state phase. To minimize the overhead, duration of steady state phase is higher than cluster setup phase.

In the setup phase, a probabilistic threshold T(n) is used to decide if the node can become a CH. Sensor node chooses a random number between 0 and 1 and if number is less than T(n) the node can become the CH. T(n) can be obtained as

$$\mathrm{T(n)} = \begin{cases} \dfrac{P}{1 - P * (\mathrm{r} \bmod \frac{1}{P})} & \text{If } \mathrm{n} \in \mathrm{G} \\ 0 & \end{cases} \tag{3.1}$$

With P is the optimal percentage of CHs, G is group of nodes which have not become CH in 1/P rounds and r is the current round. CH is decided in a way that only once a node can become a CH in an epoch of 1/P rounds. Cluster formation is done by CHs advertising to other nodes which then associate themselves to nearest CH based on the signal strength of the advertisement. After local clusters are formed CH informs all the nodes in its cluster about when to send the information based on a TDMA schedule.

Then in steady state phase, nodes switch on their sensors and transmit the data to CH periodically as per the parameters assigned by CH. CH aggregates the data and send it to BS. Steady state continues for certain period of time and then network goes to setup phase again with CH selection and local cluster formation followed by steady state. LEACH serves many advantages to the data gathering applications of WSNs. Hierarchical data structure of LEACH and capability of data aggregation reduces the amount of data and saves a significant amount of energy to the network. Rotation among the nodes for the responsibility of the CH balances the energy of the nodes and helps in elongating the stability period of the network. But LEACH protocol has high energy constraint with homogeneous nodes and is less efficient in large areas. Also LEACH does not guarantee proper placement of the CHs in the networks. Proactive nature of LEACH decreases its efficiency in terms of energy and is not suitable for time critical applications.

3.2 TEEN

TEEN is a reactive protocol proposed in [7]. It is a homogeneous protocol with all the nodes having same initial energy. TEEN suits best for those applications which works on drastic changes in the relevant parameters of interest. The amount of transmission in TEEN is very less as compared to periodic hierarchical protocols. Reason of reduction in the network traffic is event/query based transmission of data rather than periodic transmissions of clustering protocols. The objective of TEEN to address the issues of time criticality of applications. TEEN also aims at providing flexibility to end user in controlling the trade-off between response time, energy efficiency and accuracy dynamically. Being a hierarchical clustering protocol, all the nodes in TEEN send their sensed data to immediate CH only saving energy. Not the nodes but only the cluster head performs additional computations like data fusion etc. CHs have to transmit to larger distances as the BS/other CHs may be far from the node thus they drain up energy quickly. Thus to keep a balance of the energy in the nodes all the nodes take responsibility of becoming CH for a time period T which is called cluster period.

In TEEN, there are two phases cluster setup phase and steady state phase as in LEACH. But in TEEN at every cluster setup phase/ cluster change time along with the attributes there are additional parameters broadcasted which are hard threshold and soft threshold. Hard threshold is an absolute value which can trigger the transmission of the nodes. If the sensed value of the cluster node becomes equal to or greater then hard threshold it will switch on the transmitter and will send the sensed information to the associated CH. Soft threshold can be defined as the small component of the thresholds which can also trigger a nodes transmission. If difference between sensed value and current value is equal to or greater then soft threshold the node will switch on its transmitter and transmit the information to the CH. The nodes in the clusters sense the environment continuously. Nodes transmit the information to the CH only when the sensed value is either greater than the hard threshold or from the second time onwards it is greater than the hard threshold and also the difference between the current sensed value and previously sensed value is greater than soft threshold. Thus the transmission is threshold dependent and hence reduces the number of transmissions. Some of the main features of TEEN protocol are:

- The data sensed and satisfying the threshold criteria reaches the BS with very low time lag and hence it is well suited for time critical applications.
- Transmission of data packets takes more energy than sensing the data and thus it is energy efficient to keep sensing the environment and transmitting less frequently rather than having periodic transmissions with switching on and off the transmitters.
- The broadcast parameters are flexible to the changed after steady state phase which gives control to the user to sense the environment as per the desired requirements.
- Smaller the value of parameters, higher will the accuracy and transmission and lower will be the energy of the nodes. Thus to control the energy efficiency and accuracy the values of the thresholds should be decided by the user.

Thus TEEN is suitable for time critical applications and served efficient for them. Drawback of TEEN is that if the desired threshold is not met the BS will not know about the status of the network. This increases the loss in the communication infrastructure of the network and will cause BS to be confused about the status of the network if it is dead or the nodes are not transmitting the information because of thresholds.

3.3 SEP

SEP is a heterogeneous proactive protocol proposed in [14] with two levels of heterogeneity. It improves the stable region of the clustering process using the parameters of heterogeneity, which are fraction of advanced nodes (m) and additional energy factor (α) between advanced and normal nodes. SEP maintains the balanced constraint energy of the network by assigning high probability for advanced nodes to become CH which is equal to the fairness constraint on energy consumption of the nodes. Heterogeneous setup has no change in spatial density of the network and thus optimal probability of a node to become CH, *Popt* is not affected. Weighted election probabilities of the normal and advance nodes, *Pnrm* and *Padv* can be calculated as:

$$Pnrm = \frac{Popt}{1+\alpha.m} \tag{3.2}$$

$$Padv = \frac{Popt}{1+\alpha.m}(1+\alpha) \tag{3.3}$$

Cluster election in SEP is done randomly using weighted probabilities of the normal nodes and advanced nodes similar to [13]. After clusters are formed all the members of the cluster send data to CH which then processes the data and sends only the required data to the BS after processing the data. The two phase cycle of cluster head selection and transmission is then continued for the rotation of responsibility to become the cluster head. Introduction of heterogeneity paved a way for lot of research in the terms of energy levels of sensor nodes. Many protocols are developed addressing the trade-offs between efficiency and heterogeneity. Different levels of energy in the nodes helped to balance the tasks of extra computations like data fusion, routing selected path etc. In clustered routing protocols different energy of the nodes helped to take up the responsibility of becoming the CH frequently. Now there are more number of high energy nodes and these nodes are selected more often to become CHs rather than low energy nodes. This further increases the load balancing and gives more life-time to the networks. SEP performs better in terms of network lifetime and stability period when compared to family to LEACH protocols and uses the heterogeneity efficiently. However SEP is not suited for time critical applications because of its periodic nature of transmission of the information sensed by the sensor nodes.

3.4 TSEP

As described in [9] TSEP is a reactive protocol with three levels of heterogeneity. In TSEP transmission is done only when there is severe change in the environment which is controlled by the thresholds decided by the BS as per the application. The values of the thresholds are variable depending on the applications for which it is used and can be monitored by the user after every cycle to keep a balance between the energy efficiency and requirements of the application. Threshold Sensitive Environment reduces the transmissions to the base station which saves a lot of energy of the nodes. The nodes are categorised as normal nodes, intermediate nodes and advanced nodes based on the energy of the nodes. These nodes are categorised as the fraction of total number of nodes in the network and the density of this categorisation can vary as per the needs of the environment in which these different energy nodes are to be deployed. Energy of intermediate node lies between normal nodes and advanced nodes. The nodes are grouped into clusters and the CH election is done based on the weighted election probabilities of the nodes. Election probabilities are decided so as to maintain stable energy constraint in the network and hence increase the energy efficiency. Election probabilities are derived from [13] where there were only uniform energy nodes. With the introduction of heterogeneity the election probabilities are also derived depending upon the energy of the nodes. In the early rounds of the network the election probabilities of advanced nodes will be the highest followed by intermediate nodes and then normal nodes. Reason is the energy differences between the nodes. Thus in the initial epochs there is high probability for advanced nodes to become cluster heads which is realistic too as they have high energy which can be used for the additional computations of the CHs. It is based on two thresholds for transmitting the information to the CH, hard threshold and soft threshold. After CH selection and cluster formation is done, the nodes in the cluster keep on sensing the environment and when sensed value (SV) becomes equal to or greater then hard threshold, nodes switch on their transmitters and sends the data to their associated CH. After that they transmit the data to the CH only when the difference between the current sensed and previously SV is greater than or equal to the soft threshold. Thus heterogeneity and thresholds optimizes the energy and increases the performance of the protocol.

This chapter presented a brief about the proposed routing protocols of our concern which are required to be understood to have a clear understanding of the proposed protocol. In LEACH, parameters cannot be changed at cluster selection time which can be done in SEP and TSEP. SEP improves the performance of WSNs but heterogeneity increases throughput which affects the efficiency of the network. TSEP is threshold sensitive protocol which reduces the transmission to increase the performance but it does not take care of critical information. Also TSEP has a drawback that if the SV of nodes is not meeting the hard and soft thresholds criteria, nodes will not transmit and BS will not get the information whether one or all nodes are alive or dead. Our proposed protocol provides a solution by taking into consideration the importance of critical information and introducing adaptive nature in all the nodes of the network to help the BS analyse and utilize the information network efficiently.

CHAPTER 4

PROPOSED WORK

This chapter gives the understanding of the proposed work along with the details of the new features introduced. Our work is divided in two parts, part one is Critical Heterogeneous Adaptive Threshold Sensitive Election Protocol. This protocol is developed as an improvement to make heterogeneous threshold sensitive protocol usable to more number of applications with the introduction of new features. *CHATSEP* introduces two key features to threshold sensitive election protocols which keeps the network aware of the communication infrastructure to analyze and utilize the network with great ease and control. CHATSEP also prioritizes the information packets sensed by sensor nodes. This prioritization helps instant transmission of critical information as per the requirements of the user. In the second part of our work we present *greedy efficient hops* communication mechanism for efficient transmission of data packets from CHs to higher levels in hierarchy or BS. It considers the remaining energy of the nodes in the cluster as a parameter to take decision on transmission of the information. It results in better network life time as it introduces residual energy in the probability based clustering protocols which increases the balance in the load distribution. We also explain the system model used and assumptions for a better understanding of the work done. In later sections we analyze the performance of our proposed protocol i.e. CHATSEP with conventional protocols. Then we make a comparison of CHATSEP with GEH technique and without GEH technique to show the increase in the network life-time and performance in similar simulation environment.

4.1 System Model

We describe the network model and energy model taken for the proposed protocols and mechanism in this section. Network model describes the operations of the networking environment with characteristics and capabilities of the sensor nodes used in the networks. Energy model deals with the energy usage of the sensor node when used for variety of responsibilities like sensing the information, transmission of information, receiving of information etc.

4.1.1 Network model

For the proposed protocol, the network consists of N nodes and one BS for which the network model is operational. Deployment of the nodes is done randomly in D X D area with BS located in the centre of the area. The sensor nodes continuously sense the environment and transmit only after the occurrence of any desired event, decided by thresholds. The BS has the responsibility to receive the data packets from the network and perform analysis of data packets received to present the end-user with the desired reports of the network environment. The energy of all the nodes is not same. There are three levels of energy for the nodes. The energy of the nodes is limited and cannot be replaced or recharged. Capabilities in regards to sensing, communication and processing of data packets are same for all the nodes in the network. The transmission range of all the nodes is variable and dependent on the remaining energy of the nodes. After the random deployment of the nodes, they are immobile. The BS is fixed at the centre of the network D X D area and has no energy constraint. As most of the WSN routing protocols the nodes are left unattended after the deployment in the network area. This is the network model which is taken into consideration for the development of the proposed protocol.

4.1.2 Energy Model

To measure the energy dissipation we have used the first order radio energy dissipation model proposed in [3]. It has three main components; the power amplifier, the transmitter and the receiver. The transmitter uses the energy in order to run the transmitter circuitry, power amplifier in transmitting the data packets and the receiver module uses energy to run the receiver circuitry for receiving of the data packets.

The free space and two-ray ground propagation models [3, 35] are considered. The propagation models differ according to the line-of-sight paths between the sender node and the receiver node. Free space propagation model says that there is a direct line-of-sight communication path between the transmitter and the receiver. In two-ray ground propagation model there is no direct line-of-sight communication path between the transmitter and the receiver thus the data packet will arrive at the receiver via different paths at different times. The propagation loss in transmitting power in FSPM is modeled as inversely proportional to the square distance between transmitter and receiver whereas the propagation loss in transmitting power in TRPM is modeled as inversely proportional to the distance between transmitter and receiver powered to four.

Power amplifier can be used for the amplification of the transmitting power for compensating the propagation loss during the transmission. Energy consumed by the radio sensor for transmission of *k* bit information to a node at distance *d* with acceptable signal to noise ratio (SNR) is given by

$$\mathrm{ETx(k, d)} = \begin{cases} Eelect * k + \varepsilon amp * k * d^2 & \text{if } d \le d_0 \\ Eelect * k + \varepsilon amp * k * d^4 & \text{otherwise} \end{cases} \qquad (4.1)$$

Where *ETx* is the energy dissipation in the source nodes transmitter, *Eelect* is the energy dissipated per bit to run the transmitter or receiver circuit, ε_{fs} is the amplifier parameter of the free space propagation model, ε_{amp} is the amplifier parameter of two-ray propagation model. Values of ε_{amp} and ε_{fs} are decided base upon the amplifier model. Optimal cross-over distance d_0 can be obtained as

$$d_0 = \sqrt{\frac{\varepsilon fs}{\varepsilon amp}} \qquad (4.2)$$

If the distance between the source and the target node is greater than d_0 then TRPM is applied and if the distance is less than d_0 then FSPM is implied to calculate the energy dissipation. To receive a k bit information energy expended by the node is given by

$$ERx(k) = Eelect*k \qquad (4.3)$$

4.2 Proposed Protocol- CHATSEP

Threshold sensitive routing protocols are energy efficient for time critical applications when compared to periodic clustering routing protocols. But applicability of these routing protocols is restricted because of certain limitations of such protocols. We have dedicated our work for finding some limitations of such protocols and addressing a solution for the respective problems. In this section we describe our new protocol CHATSEP (Critical Hybrid Adaptive Threshold Sensitive Election Protocol) with two main features. "*Criticality aware threshold*" which gives utmost priority to any sensed information that is specified important by the network and "*Adaptive nature*" which dynamically keeps the BS aware of the status of the network in case if there is no transmission for long time due to reactive nature of the network. It helps BS to efficiently monitor the network with great ease and flexibility.

4.2.1 Problem Statement

We have focused our work on the reactive protocols for clustered hierarchical network. The network model followed is as explained. Thus problem we addressed from our work is

Development of an efficient threshold sensitive protocol for heterogeneous networks which can prioritize the information transmission and keep the BS updated about the communication infrastructure of the network even in the situations of idle periods with provision to monitor the parameters dynamically.

The solution to the problem is our proposed protocol CHATSEP which addresses the drawbacks of the traditional threshold sensitive protocols keeping the energy constraints and other parameters constant. Some of the sub-problems we addressed were

- Introduction of criticality aware threshold, CT to prioritize the information transmission in the network along.
- Monitoring the newly introduced CT parameter at any point in time during the lifetime of the network to get flexibility in deciding what information should be of high priority.
- Adaptive Meter, AM is introduced which handles the BS awareness about the network structure and give control to BS in analyzing the network with ease and versatility.
- Give the control to the used to decide the value of AM during the network lifetime so as to get freedom in deciding how often BS would like to know about the information structure of the network and control the trade-off between efficiency and awareness about the network.

4.2.2 Proposed solution-CHATSEP

In this section we discuss in detail about the protocol we propose to address the problem statement. The protocol is a reactive protocol with heterogeneous nodes. There are three levels of heterogeneity amongst the nodes. CHATSEP belongs to hierarchical class of protocols with efficient clustering. Selection of cluster heads is done based on probabilistic model of cluster head selection. After the selection of CHs, clusters are formed based on the received signal strength from the cluster heads. Nodes in the cluster transmit the information to their CHs only in absence of high priority data packet. CHs are capable of variety of computational tasks to increase the efficiency of the network. All the nodes have same computational capabilities but only the CHs use their computation tasks rather than all the nodes of the network which saves a considerable amount of energy. In transmission phase, data packet transmission is event driven. The transmission phase is not periodic which operates and transmits the data packets after every frame time to the CH/BS and hence are less energy efficient than reactive protocols. We study CHATSEP in detail in the following sections.

4.2.2.1 Heterogeneity levels

CHATSEP uses three levels of heterogeneity. There are advanced, intermediate and normal nodes based on initial energy of the nodes. The energy of advanced nodes is highest among all the other nodes. Energy of intermediate nodes is between the normal nodes and the advanced. Normal nodes have lowest energy among all the nodes. Energy of normal nodes is represented by *Eo.* Initial energy of the advanced nodes can be given as:

$$Eadv = Eo.(1 + \alpha) \tag{4.4}$$

Where α is the fraction of higher energy of the advanced nodes from normal nodes. Energy of the intermediate nodes in the network can be calculated as:

$$Eint = Eo.(1 + \mu) \tag{4.5}$$

Where μ is the fraction of energy higher for the intermediate nodes as compared to normal nodes. For CHATSEP we take $\mu = \alpha/2$. Thus total energy of the network will be

$$Etot = Enrm + Eint + Eadv \tag{4.6}$$

We suppose that there are *n* numbers of nodes in the network. Thus the total energy of the network can be quantified as

$$Etot = n.Eo.(1 + b.\mu + m.\alpha) \tag{4.7}$$

Where b is the fraction of total number of nodes which are intermediate nodes and m is the fraction of the total number of nodes n which are advanced nodes.

Thus the energy of nodes can be varied as it depends on α and μ. Different energy of the nodes plays a major role in balancing the load on the network. Even though probabilistic algorithm is used for the cluster head but selection in heterogeneous networks is biased for high energy nodes. This biased feature is increasing the probability of a higher energy node to become CH. If a high energy node is selected as CH quite often it helps in balancing the load on the network and increasing the performance. The fraction of advanced nodes and intermediate nodes can be controlled as per the requirement of the application for which the routing protocol is to be used. Usage of heterogeneous nodes increases a little complexity but adds great increase in the flexibility and efficiency of the routing protocol.

4.2.2.2 Cluster head selection algorithm

In CHATSEP nodes are organized into local clusters. Every cluster has one CH and its associated members which are sensor nodes nearest to the respective CH. All the non-cluster nodes transmit the no priority data to the CH using single hop of communication when there is occurrence of any desired event. CH will receive the data from its member node and then perform aggregation techniques and process the data. After the data is processed it sends the optimized data to the BS. Thus CH has high responsibility and much energy is expended to play the CH role. Thus responsibility of becoming CH has to be rotated between the preferable candidates of the task. In WSNs with very limited energy constraint nodes, CH has to be selected efficiently.

In CHATSEP, CH selection is done based on the weighted election probabilities of the nodes. In our proposed network election probabilities are different based on the three levels of heterogeneity in the network. The probabilities of election of the CH for normal nodes, intermediate nodes and advanced nodes can be calculated as:

$$Pnrm = \frac{Popt}{1 + \alpha.m + b.\mu} \tag{4.8}$$

$$Pint = \frac{Popt.(1 + \mu)}{1 + \alpha.m + b.\mu} \tag{4.9}$$

$$Padv = \frac{Popt.(1+\alpha)}{1+\alpha.m+b.\mu} \quad (4.10)$$

Popt is the optimal number of CHs in the network. *Popt* is same as [13] as the optimal numbers of CHs do not change with the introduction of heterogeneity. CH selection is done based on the thresholds. Each node generates a random value between 0 and 1 and if this value is less than its particular threshold then the node can become the CH. Calculation of thresholds based on the probabilities of the nodes and can be obtained as

$$\text{Tnrm} = \begin{cases} \dfrac{Pnrm}{1 - Pnrm * (\text{r mod} \dfrac{1}{Pnrm})} & \text{If } n_{nrm} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (4.11)$$

$$\text{Tint} = \begin{cases} \dfrac{Pint}{1 - Pint * (\text{r mod} \dfrac{1}{Pint})} & \text{If } n_{int} \in G'' \\ 0 & \text{otherwise} \end{cases} \quad (4.12)$$

$$\text{Tadv} = \begin{cases} \dfrac{Padv}{1 - Padv * (\text{r mod} \dfrac{1}{Padv})} & \text{If } n_{adv} \in G''' \\ 0 & \text{otherwise} \end{cases} \quad (4.13)$$

Where G′ is the group of normal nodes which have not become CH in last *1/Pnrm* rounds, G′′ is the group of intermediate nodes that were not the CH in last *1/Pint* rounds and G′′′ are the group of advanced nodes that were not the CH in last *1/Padv* rounds. As compared to normal nodes there is high probability of intermediate nodes to become CH while the probability of advance node is higher than that of intermediate nodes which shows that the advanced nodes are more likely to become cluster heads when compared to intermediate and normal nodes. Average numbers of CH is same as that of the other clustering protocols like LEACH, SEP and TSEP. This difference in the value of election probabilities helps in balancing the load distribution of the network according to energy of the sensor nodes and hence increases the lifetime of the network.

4.2.2.3 Cluster Formation scheme

After the selection of the CH is done, clusters are formed. Those nodes which are not CHs are termed as ordinary nodes. In CHATSEP the newly elected CH sends an invitation to the ordinary nodes to join in as their cluster members. All the ordinary nodes decide their CH based on the signal strength of the signals received from the CHs. Higher the received signal strength closer the CH is from that node. Thus ordinary nodes associate themselves with the CH which is closest to them and hence the cluster is formed. After the clusters are formed in CHATSEP, the elected CHs first broadcast the following parameters.

1) *Attributes (A):* These are the physical parameters in which user or BS is interested in obtaining the information.
2) *Hard Threshold (H_T):* It is an absolute value which can trigger the transmission of the nodes. If the SV of the cluster node becomes equal to or greater then hard threshold it will switch on the transmitter and will send the sensed information to the associated CH.
3) *Soft Threshold (S_T):* It is the small component of the thresholds which can also trigger a nodes transmission. If difference between SV and current value is equal to or greater then soft threshold the node will switch on its transmitter and transmit the information to the CH.
4) *Critical Threshold (C_T):* This is a new parameter we have introduced in our proposed protocol to give highest priority to any information of importance in the network. For a temperature sensing application, priority of information can be decided by C_T. If SV of any node is equal to or greater than C_T, it checks if it has sufficient energy to send the information directly to the BS or not. If yes then it transmits directly to the BS else information goes to BS via CH. Thus it gives highest priority to critical information by responding instantly and decreasing the response time.
5) *Adaptive Meter (A_M):* It is another parameter we have introduced to keep the BS aware of the status of the network in case of lots of continuous rounds with no transmissions in the network. If a node has not transmitted data consecutively for A_M number of rounds then the node initiates a transmission irrespective of the thresholds and informs the base station about its existence. Optimal value of A_M depends on the application and by varying the values of A_M we can control the trade-off between efficiency and flexibility.

These parameters can be monitored after every cluster head selection. Changing the values of these parameters helps in controlling the trade-off between energy efficiency and requirements of the applications. Introduction of this dynamic change in the values of the parameter can assist the BS to have a greater control on how often it needs to know about the network structure to perform necessary operation. The two new features introduced in CHATSEP i.e. C_T and A_M are responsible for addressing the issues addressed in the conventional reactive protocols. C_T decides about the priority of the data packets sensed by the sensors of the sensor node. C_T keeps the important data on high priority and transfers the same to the BS before any other data packets depending upon the residual energy of the nodes sensing high priority information. A_M is the unique meter introduced which keeps the BS aware of the network infrastructure. Value of A_M can be changed during every cluster formation phase in case there is a need to. Increasing the value of A_M increases the efficiency of the network as the numbers of transmissions are reduced. This happens because there will be more number of nodes who are idle from X rounds then nodes which are idle from Y rounds given that X is greater than Y. Thus adaptive characteristics introduce a little increase in the network traffic but add great ease and flexibility by keeping the BS aware of the information structure of the network.

To handle the changing requirements of the network or the end user the parameters broadcasted are changed which can further affect the efficiency of the protocol. With the introduction of C_T and A_M now our proposed protocol can be used in more vivid applications than in other reactive protocols. Now the applications which have a need to prioritize the information in terms of high priority and no priority information can use our proposed protocol CHATSEP. The time critical application where it not necessary that network will transmit the data packets after certain rounds can now use CHATSEP which gives the flexibility to the user about how often BS will need the information even if the nodes are idle. The application which requires to be aware of the status of the nodes in the network can also use CHATSEP as it informs the BS about the dead/alive status of the network as per the requirements of the network and application which is using the network. We have demonstrated the applicability of CHATSEP for a temperature sensing application with emphasis on newly added features. The performance is observed good and addressed our objectives as expected. Thus CHATSEP serves as increasing the scope of the reactive network with heterogeneous sensor nodes. After these parameters are successfully broadcasted by all the CHs to their respective sensors transmission phase of the network begins.

4.2.2.4 Data Transmission phase

After these parameters are broadcasted by CH, transmission phase of our protocol can be understood with the help of the following flow diagram:

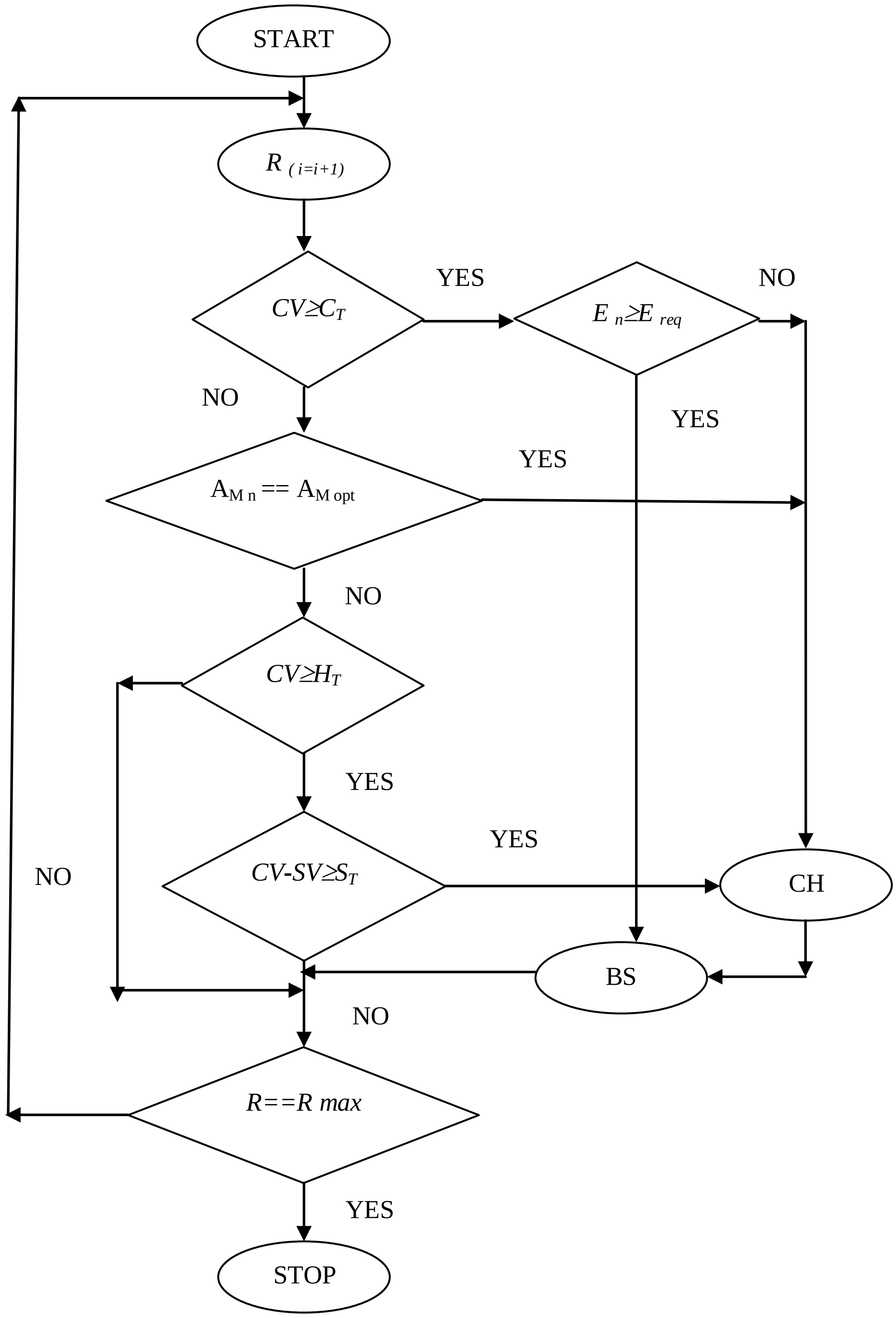

Figure 4.1: Data transmission phase of CHATSEP

The transmission phase of CHATSEP is very different from those traditional reactive networks as it adds more flexibility and versatility to the network. All the nodes keep sensing the environment continuously and reactive to the changes in the surrounding as per the desired threshold and other broadcasted parameters. The reaction to sudden changes in the environment is addressed by sending the information to their respective CHs. If the current sensed value is equal to or greater then C_T, nodes switch on their transmitter and send the data directly to the BS or CH based upon the remaining energy of the node. Thus gives highest priority to the critical information. Otherwise the member nodes check if they have not transmitted the data for contiguous $A_{M\ opt}$ rounds. The value of $A_{M\ opt}$ is broadcasted by the CHs and can be changed after every CH selection phased. If they have not transmitted the data for contiguous $A_{M\ opt}$ rounds then they initiate a transmission to the CH to make the BS aware of the status of the nodes. If both the aforementioned criteria's, critically aware threshold and adaptive characteristics are not satisfied then node transmits only when the SV is greater than H_T and the difference between the CV and previous SV is greater than S_T. Hence it not only reduces the transmissions using the thresholds but also maintains the information network intact for the BS and ensures to give highest priority to critical information. Thus the two additional parameters which are broadcasted by the CHs takes care of the problem of prioritization and network awareness and makes CHATSEP usable to more number of applications. The data transmission phase pseudo algorithm for our proposed protocol CHATSEP can be understood as

Label 1: For round // (1 to $Rmax$)

Increment round $R_i = i + 1$

Set node $j = 0$

Label 2: For node // (1 to n)

Increment node $N_j = j + 1$

If ($Current\ Value > Critical\ Threshold$)

If ($Energy\ of\ node > Energy\ in\ direct\ transmission$)

Transmit_data (BS)

Else

Transmit_data (CH)

Else If ($Adaptive\ Count >= Optimal\ Adaptive\ Count$)

Transmit_data (CH)

Else If ($Current\ Value > Hard\ Threshold$)

$Test\ value = Current\ value - Sensed\ value\ ;$

If ($Test\ Value > Soft\ Threshold$)

Transmit_data (CH)

Else

No Transmission

Else

No Transmission

If ($Node\ Index\ j \leq Total\ no.of\ nodes\ n$)

Continue: Label 2

Else if ($Round\ Ri\ != Last\ Round\ Rmax$)

Continue: Label 1

Else

$STOP$

This algorithm is used for the data transmission phase in CHATSEP. Thus as can be seen the data transmission is not periodic as it is a threshold sensitive protocol and hence the network traffic is not as high as that of proactive networks. The transmission is done based on the threshold parameters broadcasted along with the introduced parameters. The introduced parameters are observed to increase the awareness of the network in terms of network node status and the increases the probability of high priority information to reach BS instantly. Thus CHATSEP, a reactive protocol for heterogeneous network has addressed our problem by the introduction of critically aware threshold and adaptive meter to threshold sensitive protocol and made it usable to a wider scope of applications with more requirements.

4.2.2.5 Features

Some of the features of CHATSEP are:

- Critical information is communicated instantly to the BS.
- BS is always aware of the network structure and status of the nodes in the network dynamically.
- User can change the broadcasting parameters like A_M, C_T etc after each cluster set up phase as per the requirements and can enhance the lifetime of the network.

Although transmissions done based on A_M increases little complexity but this is a reasonable trade-off and provides additional versatility and flexibility for the network. C_T gives highest priority to important data. This prioritization decides how and when to transmit the data packets. In the network with BS at the centre, C_T based transmission is observed to be efficient than usual reactive transmission as when CH is not involved E_{Rx} and data aggregation energy at CH is saved which is more than required for transmission to BS in most cases and hence increases the performance of CHATSEP.

4.3 Proposed Technique- GEH

Conventional WSN protocol used single hop mechanism to send the information to the BS. In this mode of communication all the sensor senses the information and then transmits all the information it has sensed to the BS directly without the involvement of other sensor nodes on its own. This mode of communication is very inefficient and power consuming with lots of redundant information to the BS. Thus present protocols rely on the multi hop mode of communication for better efficiency. In case of larger networks, the distance of the BS from the node is greater than the transmission range of the sensor node. The single hop communication fails. Multi hop communication uses packet forwarding to increase the efficiency of the network. The nodes send the information to the sink with the help of other intermediate sensor nodes which receives the information from the node and transfers the information to other node along the path of the BS or to BS itself. Multi hop communication saves transmission energy and is proved to be useful for energy efficiency and network lifetime. In clustering protocol multi-hop communication is done. First the cluster members send their sensed information to their respective CHs. The CHs then performs several computations like data fusion to reduce the amount of data received and transmit only the required and non-redundant information. The CHs may transmit the data packets to the BS directly or via higher level CHs. This improves the efficiency of the network. But selection of CH is done based on the probabilistic models with election probabilities. Thus election probabilities cannot guarantee that right candidate is chosen as the CH and can affect the efficiency of the network. Thus in this section we present a novel technique which can enhance the performance of the network.

4.3.1 Problem Statement

We have focused our work on developing an efficient communication technique for clustered hierarchical network. The network model followed is as explained. Thus problem we addressed from our work is

Developing a hybrid communication technique for hierarchal clustered networks with probabilistic CH selection models which increases the lifetime of the network by consideration of residual energy of the nodes during data transmission phase

Our proposed technique GEH is the solution to the problem which uses remaining energy of the nodes to increase the efficiency in the network. The usage of the residual energy of the nodes is done during the transmission phase in the local clusters. Some of the sub problems we needed to explore to address the solution to the problem statement were:

- How to find the present energy of the nodes by the CHs at the time of data transmission.
- What responsibilities of the CHs should be distributed and how to distribute the tasks.
- How to efficiently utilize the data fusion techniques so that the load on the network is not increased.

These are the some of the sub-problems which we addressed in our work to increase the efficiency of the clustering protocols of WSNs. This technique introduces quantification in the probabilistic CH selection model and selects the best contender for the distribution of responsibilities of CH as the CH selected with the help of election probabilities may not be capable of carrying out all the responsibilities efficiently on its own. Thus CH has to take care of its own remaining energy also while performing the required tasks of a CH. Thus this decision to distribute the responsibility of CH if necessary can cause a sufficient increase in the performance of the WSN. In the following section we discuss the proposed technique in detail.

4.3.2 Proposed Solution- GEH

In this section we propose an energy efficient communication technique which we termed as Greedy Efficient Hops. GEH increases the efficiency in the clustered routing protocols with taking the residual energy of the nodes under local clusters into consideration. The system model we have assumed for the GEH technique is same as the system model for CHATSEP and is explained in previous sections. We have focused on heterogeneous networks as the election probabilities of such networks are different and are derived upon the initial energy of the nodes. Thus due to different probabilities the nodes also share different chances of becoming the CH. The epoch defined for transmission in heterogeneous sensor networks are also different for different energy sensor nodes. GEH modifies the data transmission phase keeping the other phases intact of the heterogeneous networks to enhance performance of the network.

The cluster setup phase is same and is based on probabilistic model. Selection of cluster head is done based on the elected probability of the node. Every cluster has a CH. Along with the CH it has its associated members which are sensor nodes nearest to the respective CH. All the non-cluster nodes transmit the data to the CH using single hop of communication when there is occurrence of any desired event if it is reactive network or periodically in case of proactive network. CH will receive the data from its member nodes and then perform aggregation techniques to process the data. After the data is processed it sends the optimized data to the BS. So CH has high responsibility and much energy is expended to play the CH role. Thus responsibility of becoming CH has to be rotated between the preferable candidates of the network. Still due to different election probabilities, selection of right candidate for CH is not observed to be optimal and hence we in GEH take the residual energy of the member nodes of the local clusters into consideration to distribute the operations of the CH to address the energy balance of the nodes. The distribution of the energy of the nodes is done after careful computations of whether the distribution is needed or not.

The cluster formation starts after the cluster head selection is done. The newly elected CH sends an invitation to the ordinary nodes to join in the cluster as their cluster members. Cluster formation may require broadcasting some parameters like attributes, thresholds in case of reactive networks or just form the cluster and start periodic transmission after every frame time in case of proactive networks. All the non-CH nodes decide their CH based on the signal strength of the signals received from the CHs in the network. Higher the received signal strength closer the CH is from that node. The ordinary nodes associate themselves with the CH which is closest to them and hence the cluster is formed. The ordinary nodes attach themselves to the nearest cluster head by sending acknowledgment to the cluster head. In GEH technique the nodes along with the acknowledgement message send their remaining energy to the CH with the help of which CH will be aware of the energies of the nodes in its very own local cluster. The CH need not remember the energies of all the nodes but the one with the highest residual energy which may be required to help the CH if it decides to distribute its task to balance the energy in the cluster and increase the efficiency of the network. After the clusters are formed, in conventional routing protocols transmission of data is done using CHs. In reactive networks nodes keep on sensing the data until they observe a drastic change in the environment which meets the desired threshold criteria of the network. If at any point in time the criteria are met, the nodes send the sensed information to their respective CHs. The CH after receiving the information performs some optimizing computation tasks like data aggregation and sends the required irredundant information to the BS or higher level CHs. The amount of load received by CH is low in case of reactive network as the transmission by the sensor nodes is done only when they meet the threshold requirements which are less. Due to reduction in the network traffic the reactive protocols are observed to be more energy efficient than proactive protocols. But in reactive protocol the user cannot monitor the environment continuously and hence are not suitable to such continuous monitoring applications. While in proactive networks after every fixed frame time the non CH sensor nodes switch on their sensors and send the sensed information to the CH. The ordinary sensor nodes then switch off their sensors for the fixed period of time called frame time. This way the sensor nodes save energy by switching on and off their sensors and transmitters. The flow diagram which explains the working of routing protocols with GEH technique can be seen as:

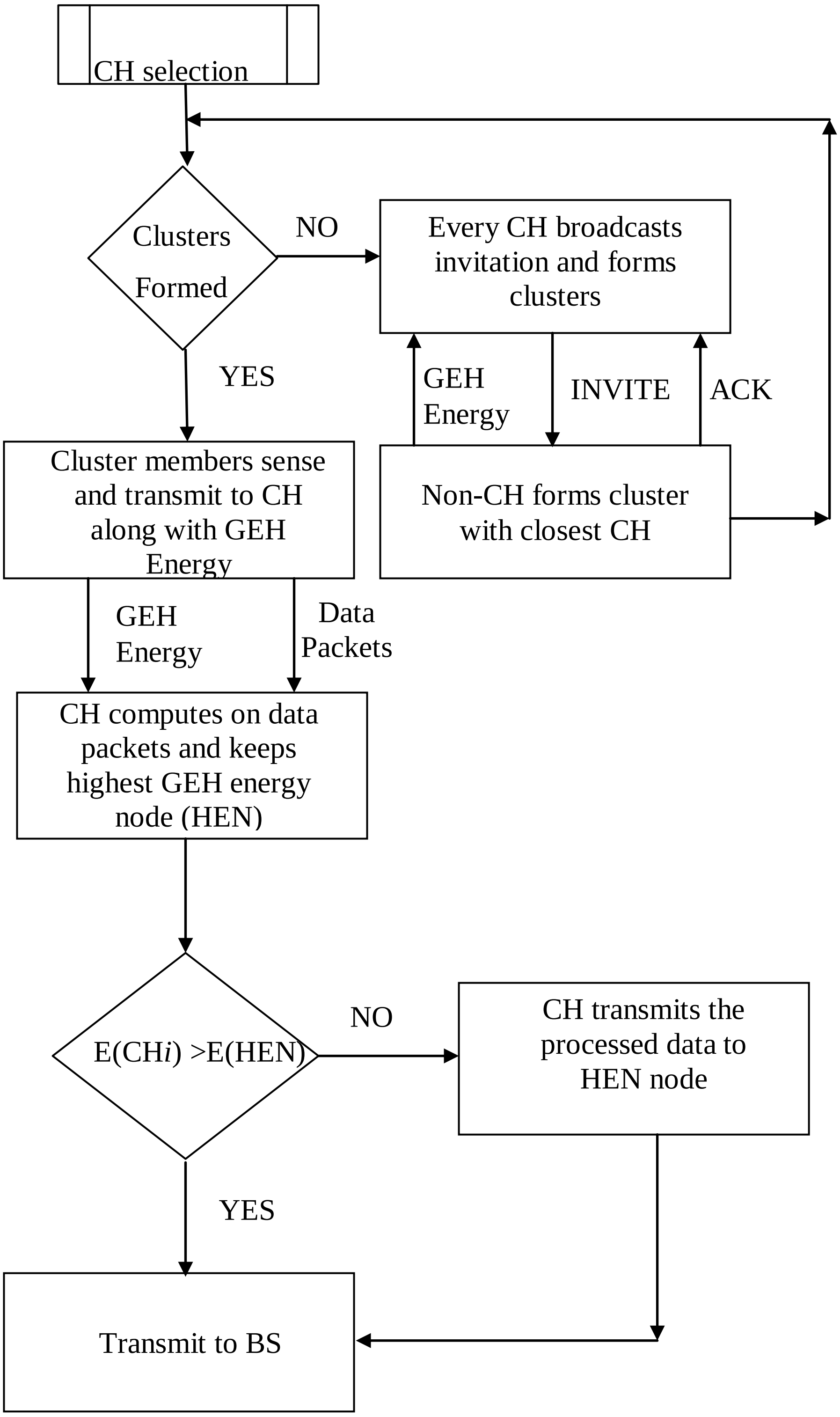

Figure 4.2: GEH Technique in Routing Protocol

The CH then receives the information from member nodes does some optimization via computation tasks like data aggregation and sends the required irredundant information to higher level CHs or the BS. The proposed GEH technique can be applied to both proactive and reactive protocols to increase the performance of the network. Whether it is a proactive network or reactive network the transmission is done via CH only and hence our GEH technique of deciding and distributing the load of the CH by including a parameter of certainty with the help of dynamic computation of energy of the nodes during the cluster formation and data transmission phase. The figure 4.2 represents the flow of a routing protocol implying GEH technique for efficient communication. The CH selection is done in the conventional way for the protocol using elected probabilities. We have focused on heterogeneous networks as in such networks we have different election probabilities which causes imbalance in the selection of right candidate for CH. Thus after CH selection when clusters are formed along with the acknowledgment to the CH the nodes send a new introduced parameter to the CH. This parameter is termed as *Greedy Efficient Hop Energy*.

The GEH energy is required to keep the CH aware of a capable member who can be used to distribute the tasks if required at any point of time during the transmission of data packets. Thus this how clusters are formed with GEH-Energy taken into consideration. After the CHs are formed, data transmission phase starts where the nodes sense the environment and transmit the data packets sensed to the CH periodically in frame time for proactive networks or based on thresholds for reactive networks. But in the protocols employing our GEH technique, every node which is transmitting to the BS sends GEH-Energy along with the data packets. GEH-Energy is the remaining energy of the nodes at that instant when they are transmitting the data packets. Thus now with the transmission of GEH-Energy the nodes are sending a token to the CH for their selection as the right candidate in the situations of low energy of the CHs.

The CH keeps on receiving the data from the nodes along with GEH-Energy. CH does not need to remember the GEH-Energy of all the nodes but the node with highest GEH-Energy. Storing only single GEH-Energy helps CH to optimize its memory. Thus then CH process the data packets received from the member nodes and performs data aggregation on the data packets to reduce the network traffic from the network. Now comes the time when GEH play its role in increasing the efficiency of the network. After the CH has processed the data, CH will need to transmit this information to the BS or higher level CH. In present protocols it is done by the CH itself. It is one of the responsibilities of CH to transmit the data to the BS after receiving from cluster members. But this causes a lot of load on the CH which is selected on the basis of election probabilities. Thus we give flexibility to CH to make a decision to take or distribute the transmission task based on the introduced GEH-Energy parameter.

In GEH implied protocol before transmitting the data to the BS/higher level CHs the CH checks it remaining energy and compares with the highest GEH-Energy node which is the member of its own cluster with highest remaining energy. If the energy of the CH is higher than GEH-Energy then the protocol will work in the traditional way with CH transmitting the aggregated data to the BS/higher level CHs. But if the energy of the CH is less than the GEH-Energy node then CH will not transmit the aggregated data to the BS/higher level CHs but it transmits the data to the GEH-Energy node. The transmission from CH to GEH-Energy node is very low energy consuming as the nodes are in the same cluster and hence are very close to each other. Also now there is no need to aggregate the data as the data packet received from the CH is already aggregated. The GEH-Energy node just has to transmit the data packet it received from the CH to the BS/higher level CHs as the CH would have done. GEH can be understood from the pseudo algorithm as:

Label 1: For each round // (1 to $Rmax$)

Increment round $R_i = i + 1$

Cluster Head Selection (probabilistic Model)

Label 2: For every Cluster // (1 to j)

Increment clusters $C_j = j + 1$

$C_{j-CH-GEH} = 0$

$While\ (!\, Cluster)$

C_j = Cluster Formation (C_{j-CH}, INVITE, ACK, GEH-E)

If ($C_{j-CH-GEH} < GEH\ Energy$)

$C_{j-CH-GEH} = GEH\ Energy$

$While\ (Members\ are\ transmitting\ to\ C_{j-CH})$

C_{j-CH} = Data Transmission (C_j, Data Packets, GEH-E)

$If(C_{j-CH-GEH} < GEH\ Energy)$

$C_{j-CH-GEH} = GEH\ Energy$

$C_{j-CH} = Process\_Aggregate\ (data\ packets\ recieved)$

$If(C_{j-CH}\ Enery > C_{j-CH-GEH})$

Transmit_data (C_j, BS)

Else

Transmit_data (C_j, GEH Node)

Transmit_data (GEH Node, BS)

$If\ (Round\ Ri\ != Last\ Round\ Rmax)$

Continue: Label 1

Else

STOP

Thus the algorithm presented describes the GEH technique for the heterogeneous routing protocols with probabilistic model for CH selection. GEH works well with proactive or reactive networks. Main objective of GEH is to increase the efficiency of the network by balancing the energy of the nodes. It does an optimal selection of right candidate to perform the responsibilities of the CH in case of a need. The major role played by GEH is in the data transmission phase of the clustering protocols. It is the data transmission phase only which decides how to transmit the aggregated data.

The decision to use the GEH-Energy node to transmit the processed information instead of CH is made only when it is observed that a wrong candidate is selected as the cluster head and it has higher energy nodes as members which would have been the right candidate for the CH because of their higher energy. Hence the data transmission energy of the CH is saved by CH just transmitting the data to the GEH Energy node and not the BS. After receiving the data from the CH, GEH Energy node does not require to again perform any computation as all computations are already performed by the CH. GEH Energy node just sends the received packet from the CH directly to the BS or higher CHs with any further processing. GEH introduces one extra hop as the data is now going to BS not via CH but like CH-GEH-BS. This extra hop costs energy but save a lot more by balancing the energy in the cluster and giving CH a chance to live longer in the network. Hence trade-off between energy saved and extra energy expended is in the favor of GEH technique.

4.3.2.1 Features

The GEH technique for efficient communication in the hierarchical clustered protocols addresses a solution to our problem whose features can be discussed as:

- GEH balances the energy of the local clusters.
- Increases the lifetime of the CHs by distributing its responsibilities if there is a need.
- Hops of communication are increased by one but keeps balance on the energy of the networks.
- Energy consumed in data transmission is the most and hence is given to the probable member node whether the node is a CH or GEH Energy node.

Thus the introduced GEH technique with the aforementioned features is observed to be efficient in terms of life time of the network. We have simulated GEH technique on some of the routing protocols and observed that it increase the lifetime and efficiency of the routing protocol. We also simulate our proposed protocol CHATSEP with GEH technique and observed the increase in the performance of the protocol.

CHAPTER 5

SIMULATION RESULTS & ANALYSIS

Simulation is considered as efficient and flexible tool to evaluate the performance of the protocol working under vivid environmental conditions. In this chapter, CHATSEP and GEH technique proposed in chapter 4 are evaluated on a simulation platform. The performance of the protocol is compared with other conventional protocols in terms of energy efficiency, lifetime and throughput. The proposed GEH technique is implemented on TSEP routing protocol and our proposed routing protocol and comparison is made on the performance of routing protocol with and without the proposed technique in terms of network life-time, energy efficiency and throughput.

5.1 Simulation Setup

Matlab is the tool we used for simulation and performance evaluation of CHATSEP and GEH technique. Our aim with the simulation is to compare LEACH, SEP, TSEP with our CHATSEP protocol in respect to energy and network lifetime and check for the performance of GEH technique in some conventional routing protocols.

There are 100 nodes in the network. The dimension of the network field is 100*100. All the100 nodes are deployed randomly in the 100*100 field dimension network. The BS is located at the centre of the network. The field has a varying temperature in different regions. The temperature range is [50^0, 200^0] with optimal values of the broadcasting parameters. Standard protocol is used for the simulation as of the conventional protocols. First order radio model is used as the energy model as described in the previous sections. The number of rounds used for the simulation is 8000 rounds. Length of the data packet is assumed to be 4000 bits for every evaluated protocol with capability of perfect data fusion by the CHs. Every protocol is made to run for 8000 rounds to get a better idea of the performance metrics. The values of the parameters used in the simulation are explained in the table 5.1

Parameters	Value
E_{elect}	50nJ/bit
E_{DA}	5nJ/bit/message
ε_{fs}	10pJ/bit/m^2
ε_{amp}	0.0013pJ/bit/m^4
Eo	0.5J
K	4000
N	100
P_{opt}	0.1
A	1
M	0.1
A_M	10,15
C_T	170,175

Table 5.1: Parameter Setting

5.2 Performance Evaluation-CHATSEP

In this section we present the simulation of CHATSEP into Matlab environment and compare with three conventional routing protocols LEACH [13], SEP [14] and TSEP [9]. We have also implemented the concerned protocols in the same simulation environment for the purpose of comparison. LEACH is the homogeneous hierarchical clustering protocol with rotation of responsibilities of cluster formations. Selection of cluster head is probability based with optimal number of CHs fixed for the network. SEP is heterogeneous WSN protocol with two level of heterogeneity. CH selection in SEP is also probability based with different election probabilities as per the levels of heterogeneity. TSEP is another clustering protocol which is a threshold sensitive protocol with three levels of heterogeneity with normal, intermediate and advanced nodes. It is a reactive protocol in which transmission is triggered based on drastic changes in the environment and is monitored by the hard and soft thresholds. We compare the performance of CHATSEP with aforementioned protocols. CHATSEP is threshold sensitive protocol with three levels of heterogeneity along with two additional features of prioritizing the information and keeping the BS aware of the status of the network by the additional of two broadcasting parameters Criticality aware threshold and adaptive meter. The introduced parameters are flexible to be changed in every round of the simulation to add flexibility to the user to control the trade-off between energy and awareness as per the requirements of the protocol.

5.2.1 Performance metrics

Performance metrics we used for analysis of the protocols are

- *Alive Nodes:* No. of alive nodes per round.
- *Throughput:* No. of packets sent to BS from CH.
- *A_M Index:* No. of adaptive transmissions initiated to keep the BS informed.
- *C_T Scale:* No. of nodes sensing critical information per round.
- *Network Lifetime:* It is the time till the last node of the network is not dead.

5.2.2 Simulation results

In this section we present simulation results of CHATSEP with the performance metrics in consideration compared to LEACH, SEP and TSEP in similar simulating environment of 100 nodes in 100*100 network area for 8000 rounds. We have performed simulations for different values of C_T and A_M while keeping the energy parameters (α, μ) and fraction of nodes (*m*, *b*) constant to observe the change in the network lifetime, C_T frequency and A_M based transmissions for different values of C_T and A_M .

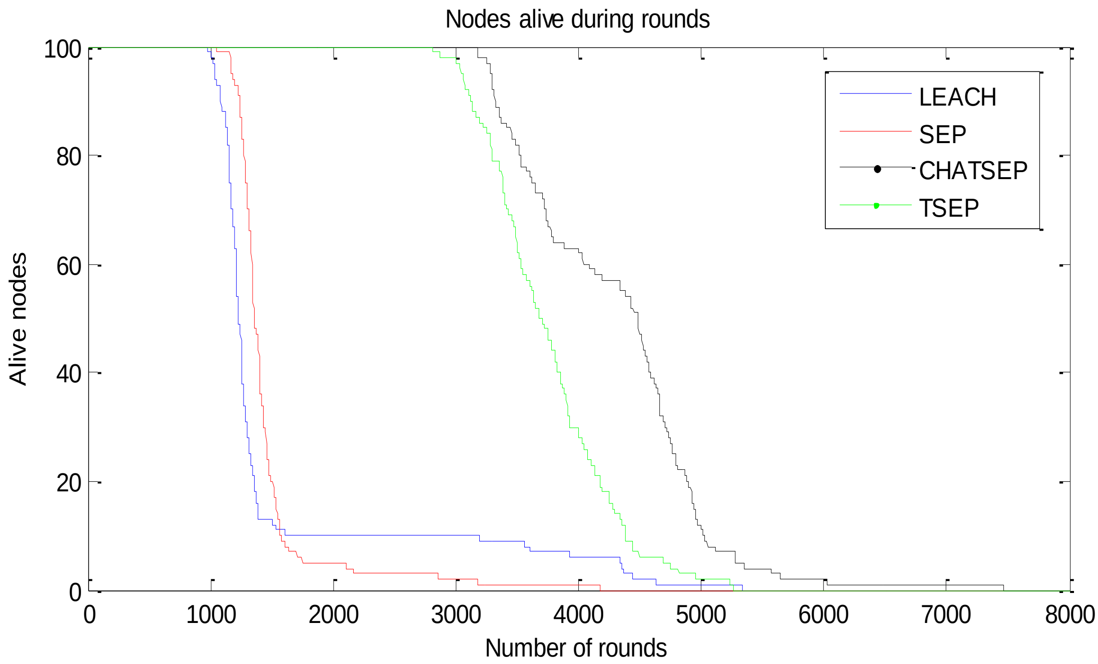

Figure 5.1: No. of alive nodes per rounds (170, 10)

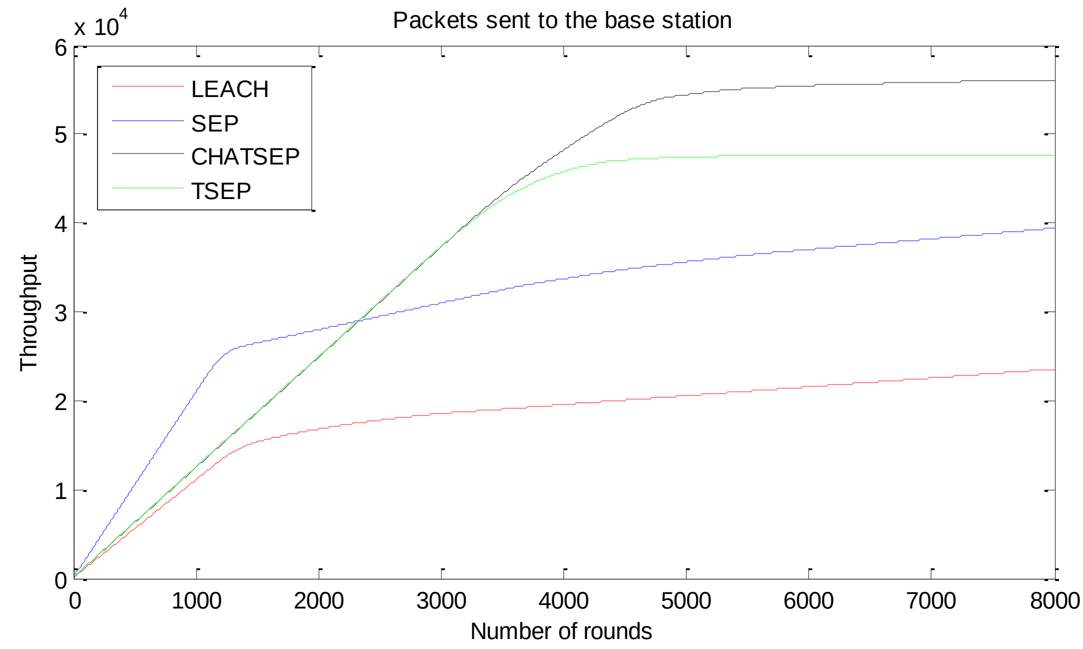

Figure 5.2: No. of packets sent to BS from CHs (170, 10)

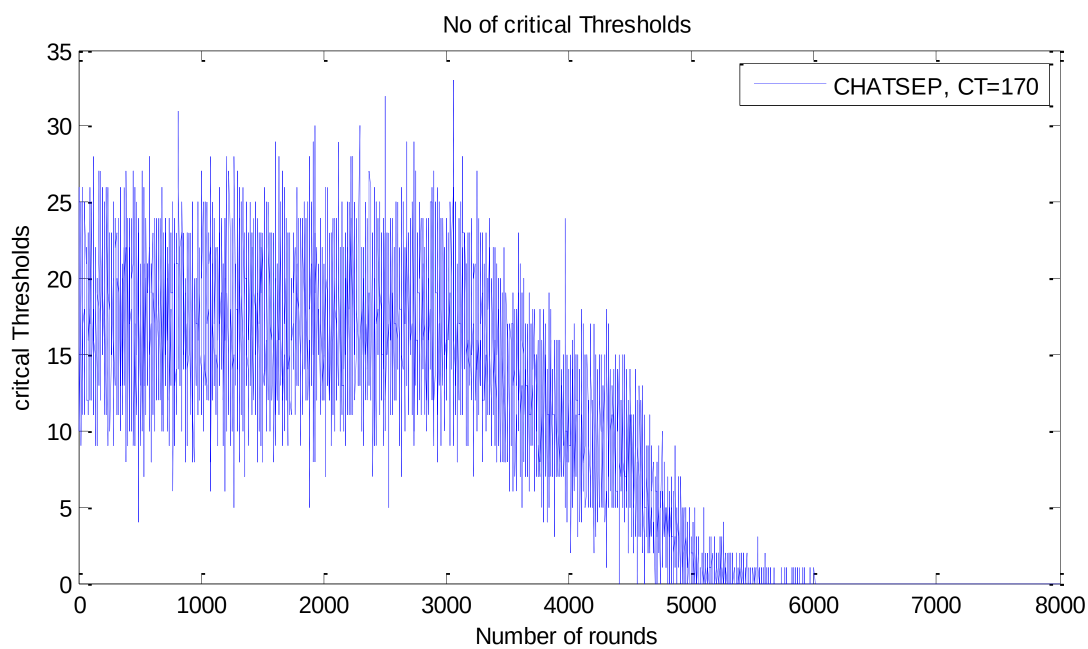

Figure 5.3: No. of critical transmissions per round (170, 10)

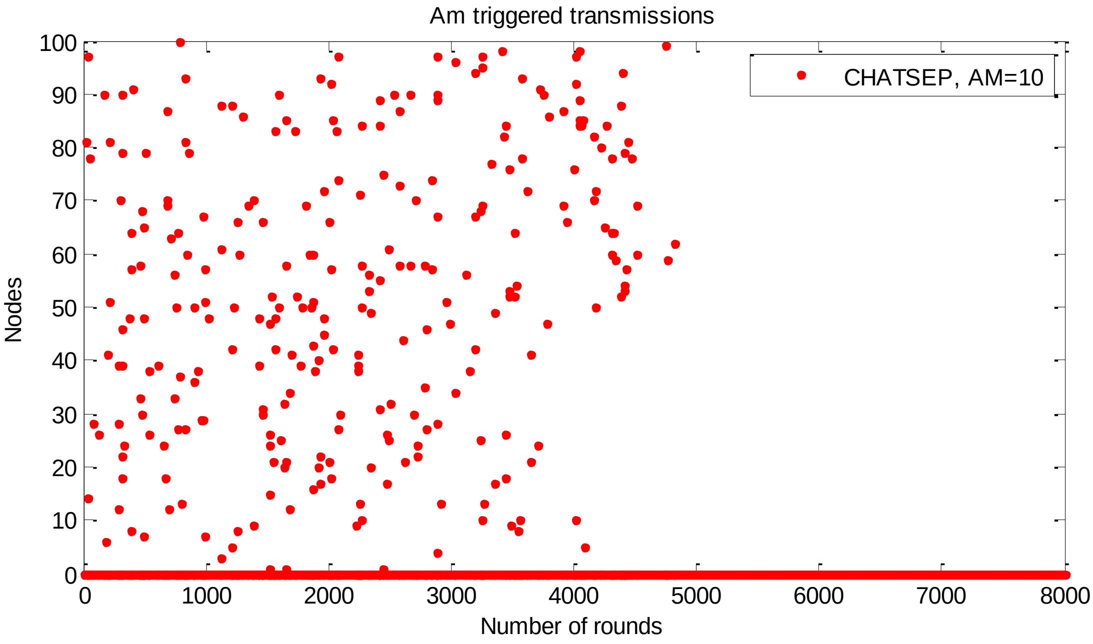

Figure 5.4: A_M based adaptive transmissions (170, 10)

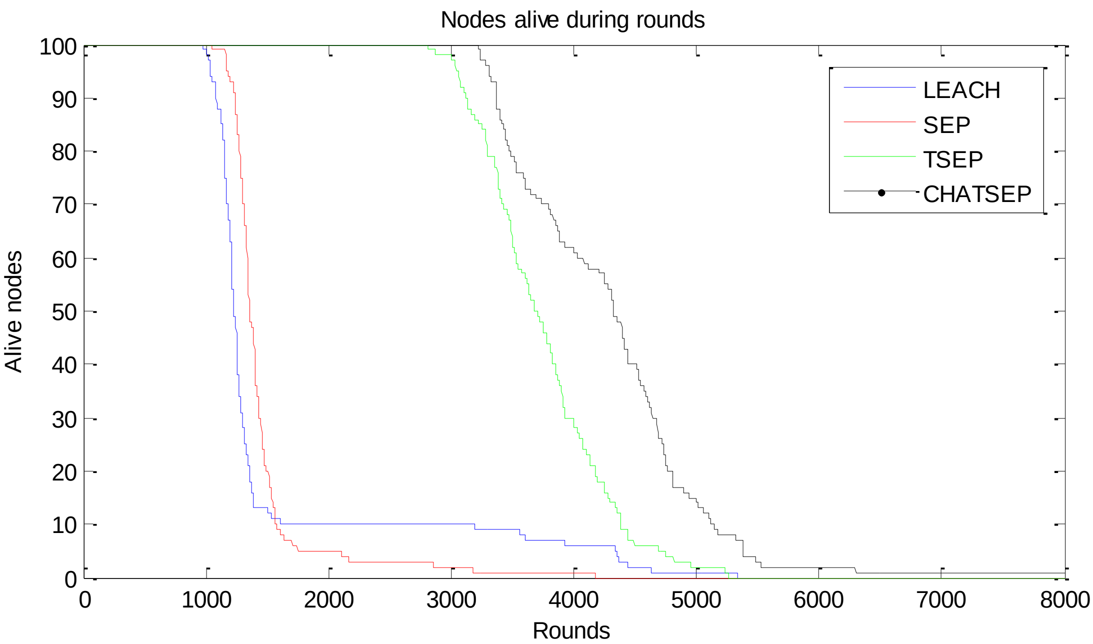

Figure 5.5: No. of alive nodes per round (175, 15)

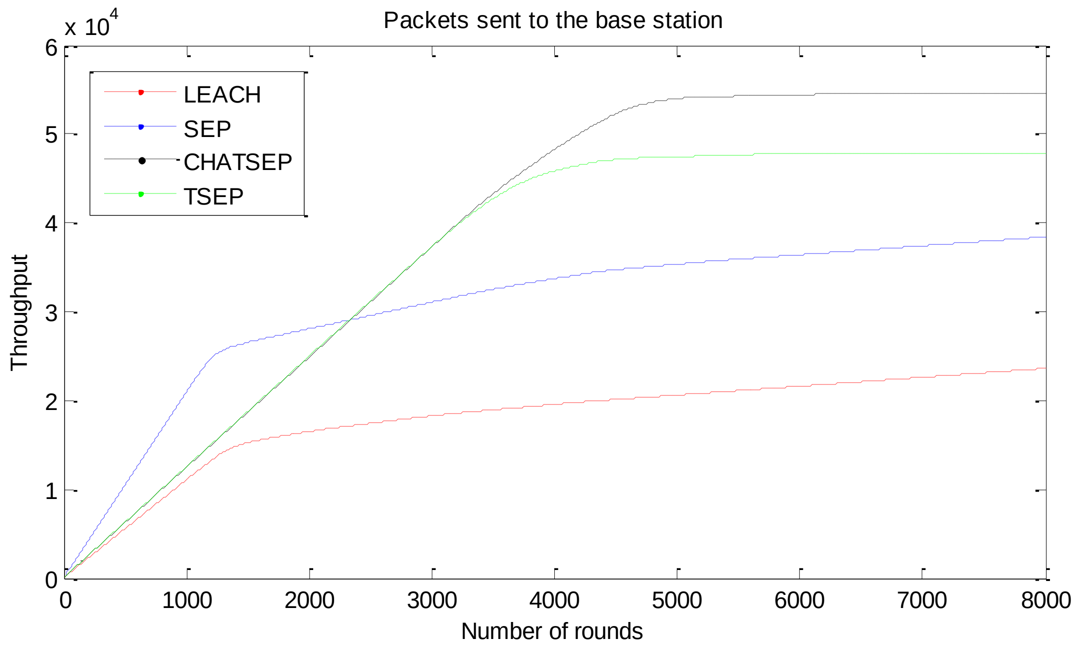

Figure 5.6: No. of packets sent to BS from CHs (175, 15)

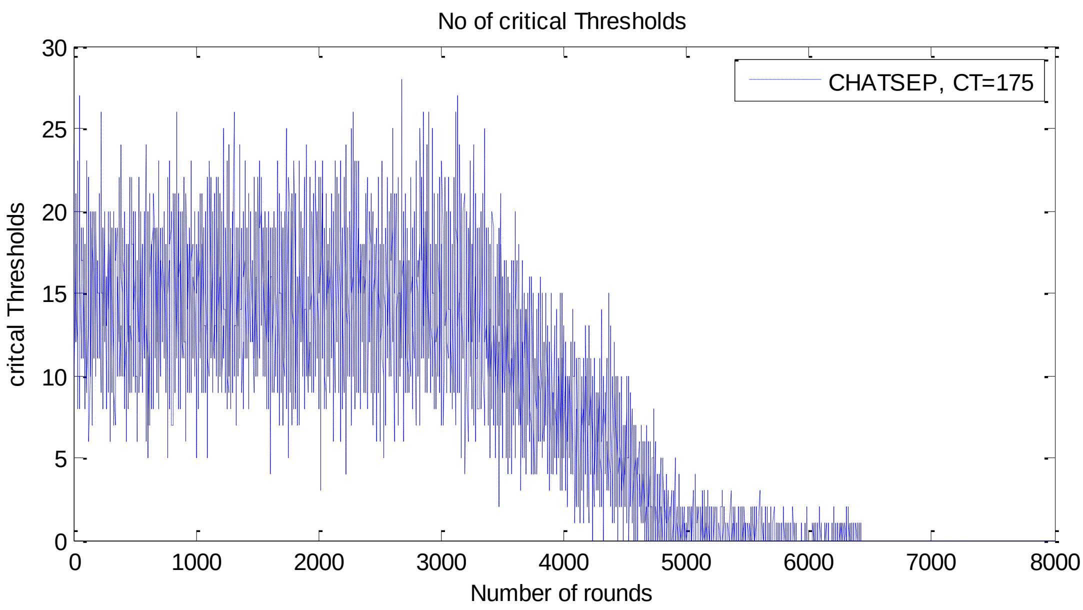

Figure 5.7: No. of critical transmissions per round (175, 15)

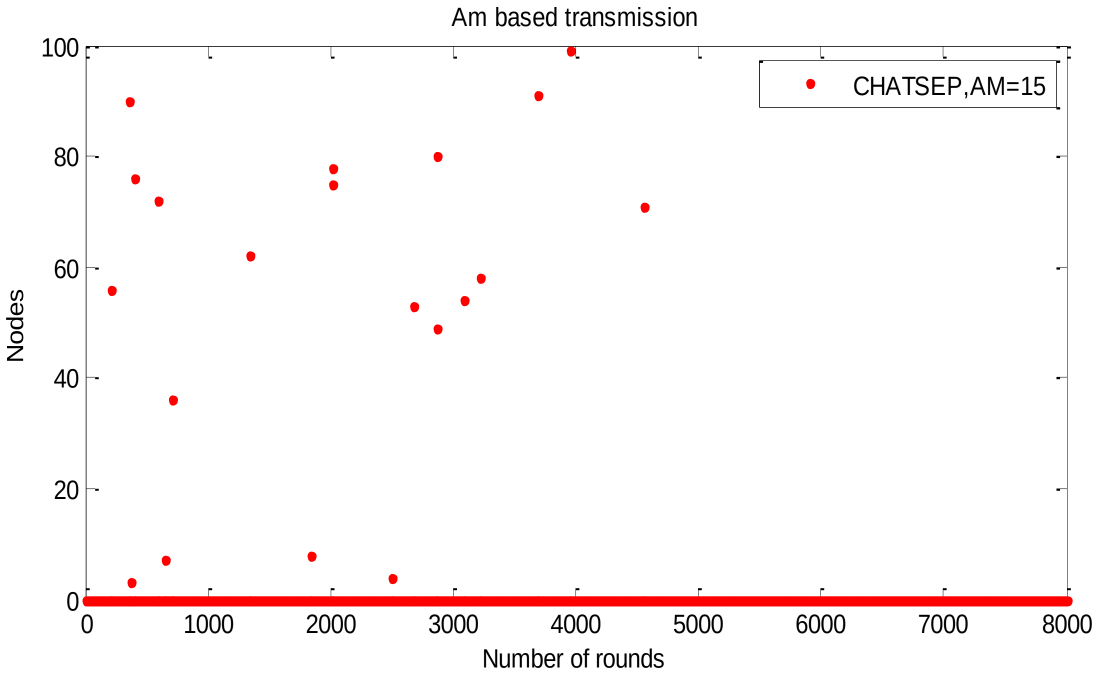

Figure 5.8: A_M based adaptive transmissions (175, 15)

5.2.3 Analysis

From the simulation performed the observations can be quantified in the table 5.2.

Protocol	**Stability Period (rounds)**	**Lifetime (rounds)**	**Throughput (packets)**
LEACH	980	4175	2.35×10^4
SEP	1040	5340	3.94×10^4
TSEP	2815	5265	4.77×10^4
CHATSEP (170, 10)	3175	6030	5.95×10^4
CHATSEP (175, 15)	3220	6300	5.45×10^4

Table 5.2: CHATSEP Analysis

Thus we observe an increase of the stability period and lifetime of the WSN. Even CHATSEP can be monitored to control the trade-off between the efficiency and network requirements. For first case (fig.5.1-fig. 5.4) we have taken (C_T =170, A_M =10) and for second case (fig. 5.5-fig. 5.8) we have taken (C_T = 175, A_M =15). As *Popt*=0.1, the weighted election probabilities are taken from (4.8), (4.9) and (4.10) whereas thresholds for CH selection are based on (4.11), (4.12) and (4.13).

Figure 5.1 and figure 5.5 shows comparison between LEACH, SEP, TSEP and CHATSEP based on the number of alive nodes in the network and the network lifetime. Simulation is performed for 8000 cycles. SEP and LEACH with heterogeneous behaviour results in close stability period. If homogeneous LEACH and SEP are compared, SEP has much higher stability period. TSEP is observed to perform better than LEACH and SEP as it is threshold driven protocol with three levels of heterogeneity. CHATSEP with C_T, A_M is observed to perform better than aforementioned protocols because of its threshold sensitive mode of transmission which decreases the frequency of transmissions and C_T based transmissions which are observed to more efficient in a network with BS at the centre when CHs are not involved. Three levels of heterogeneity also contribute in enhancing the performance of CHATSEP when compared to LEACH and SEP. By varying the values of C_T (170 to 175) and A_M (10 to 15) it can be seen that as A_M increases stability period also increases (3175 to 3220) because the number of transmissions are reduced. Optimal values of C_T and A_M are based on the application and user's efficiency requirements.

Figure 5.2 and figure 5.6 represents throughput of the network, the number of packets sent to the BS by the CHs. Throughput of CHATSEP and TSEP is higher than LEACH and SEP because of three levels of heterogeneity. Throughput of CHATSEP is more than TSEP because although both protocols are threshold sensitive and has three levels of heterogeneity but introduction of C_T and A_M increases the communication for achieving dynamic behaviour in knowing about the status of idle nodes. Also as the network lifetime increases the throughput also increases. By varying the values of C_T (170 to 175) and A_M (10 to 15) we observe a decrease in the throughput (5.95×10^4 to5.45×10^4) because of reduce in the overall transmissions.

Figure 5.3 and figure 5.7 shows the occurrences of critical information in each round. We have observed that there are instances when some information is of great importance to the BS and our protocol sends such information to the BS with highest priority which enhances the communication network. We observed a decrease in C_T transmissions from C_T =170 to C_T =175 and all such sensed information is sent to the BS with utmost priority.

Figure 5.4 and figure 5.8 show the adaptive characteristic of CHATSEP with A_M =10 and A_M =15 and it can be seen that number of adaptive transmissions decrease as the value of A_M increases because there are more idle nodes those who have not transmitted from 10 consecutive rounds as compared to those with 15 consecutive rounds. Increase in the value of A_M increases the network lifetime. Hence value of A_M is assigned on how often the BS needs to know about the status of the network.

From the simulations in matlab it is observed that stability period and network lifetime of CHATSEP is higher than related protocols. CHATSEP has a higher throughput as compared to other protocols because of adaptive transmissions and higher lifetime but maintains network information structure intact. Critical and adaptive characteristics are implemented and are observed to be efficient and useful in time critical and safety aware applications where data is not required periodically but the information sensed is prioritized and dynamic status of the network is needed along with threshold sensitive monitoring.

5.3 Performance Evaluation- GEH

In this section we simulate our proposed GEH technique on two routing protocols TSEP [9] and our proposed protocol CHATSEP. GEH aims at increasing the performance of the networks with heterogeneous nodes with probability based CH selection. It introduces flexibility to the CH to take decision whether to distribute its responsibilities or not. In the GEH employed protocol the CH keeps track of the right candidate to distribute its responsibilities while the cluster formation phase and data transmission phase. The decision by the CH is taken just before the data is transmitted from the CH to higher level hierarchies and the decision is based on the residual energy of the CH and the candidate who is selected for the distribution of the task.

We simulate GEH technique in TSEP, a clustering protocol which is a threshold sensitive protocol with three levels of heterogeneity with normal, intermediate and advanced nodes. It is a reactive protocol in which transmission is triggered based on drastic changes in the environment and is monitored by the hard and soft thresholds. We also simulate GEH technique with our proposed protocol CHATSEP which is a threshold sensitive protocol with three levels of heterogeneity along with two additional features of prioritizing the information and keeping the BS aware of the status of the network by the additional of two broadcasting parameters Criticality aware threshold and adaptive meter. Thus added features increase the number of applications which can now rely on a threshold sensitive protocol. The introduced parameters are flexible to be changed in every round of the simulation to add flexibility to the user to control the trade-off between energy and awareness as per the requirements of the protocol. Thus we simulate the GEH technique with the aforementioned protocols to observe and analyze the performance of the introduced technique.

5.3.1 Performance Metrics

Performance metrics we used for analysis of the protocols are

- *Alive Nodes:* No. of alive nodes per round.
- *Throughput:* No. of packets sent to BS from CH.
- *Network Lifetime:* It is the time till the last node of the network is not dead.

5.3.2 Simulation Results

In this section we present simulation results of GEH technique in TSEP and CHATSEP taking the performance metrics into consideration in similar simulating environment of 100 nodes in 100*100 network area for 8000 rounds. These results are used for the comparison of performance of the protocols with or without GEH technique.

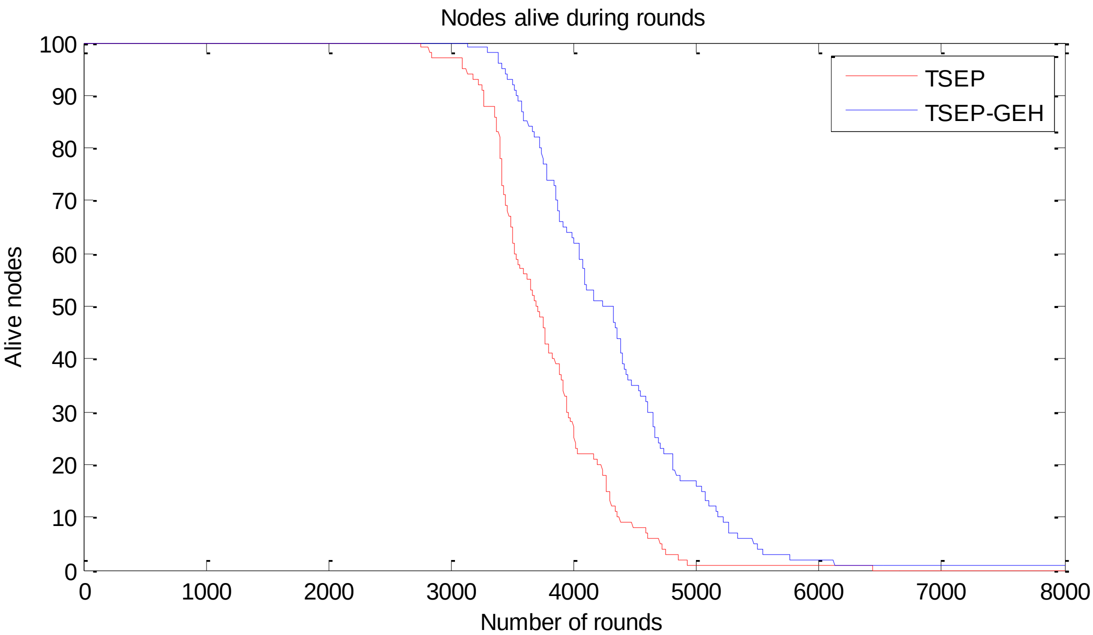

Figure 5.9: No. of alive nodes (TSEP, TSEP-GEH)

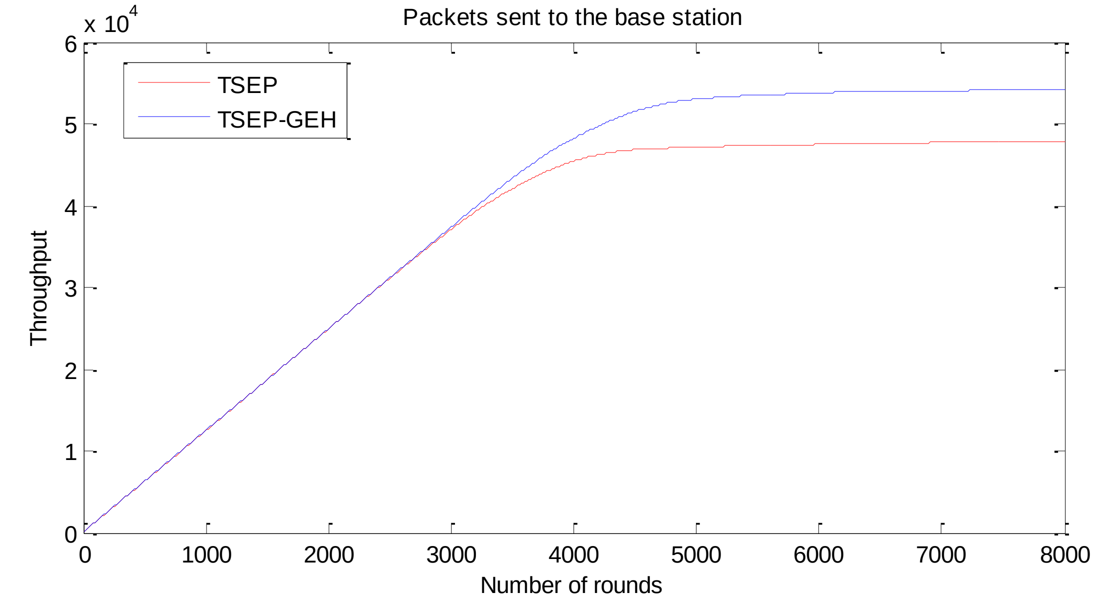

Figure 5.10: No. of packets sent to BS from CHs (TSEP, TSEP-GEH)

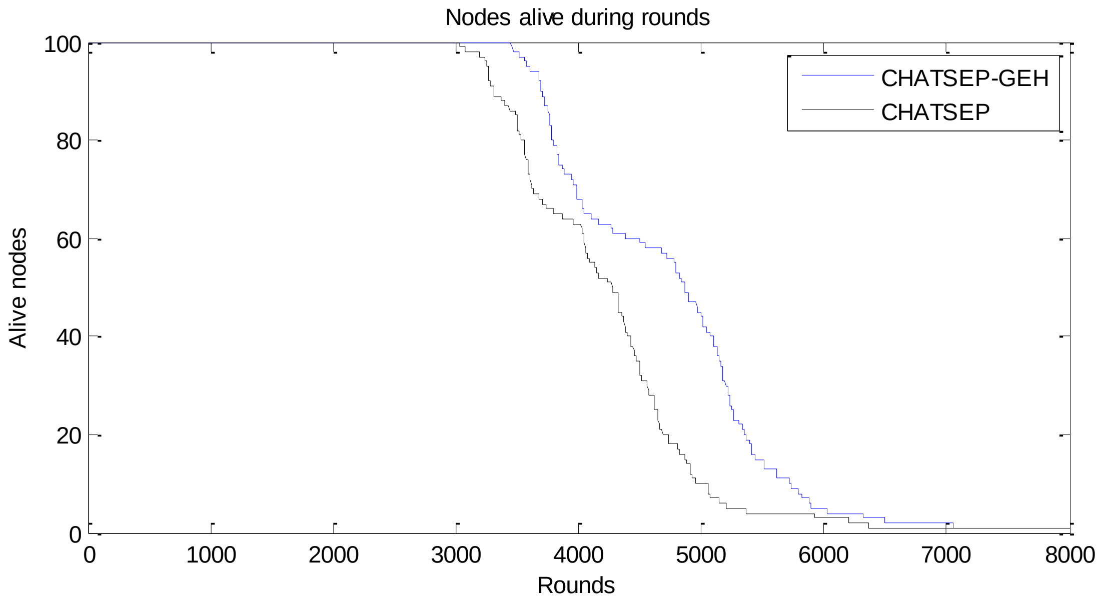

Figure 5.11: No. of alive nodes (CHATSEP, CHATSEP-GEH)

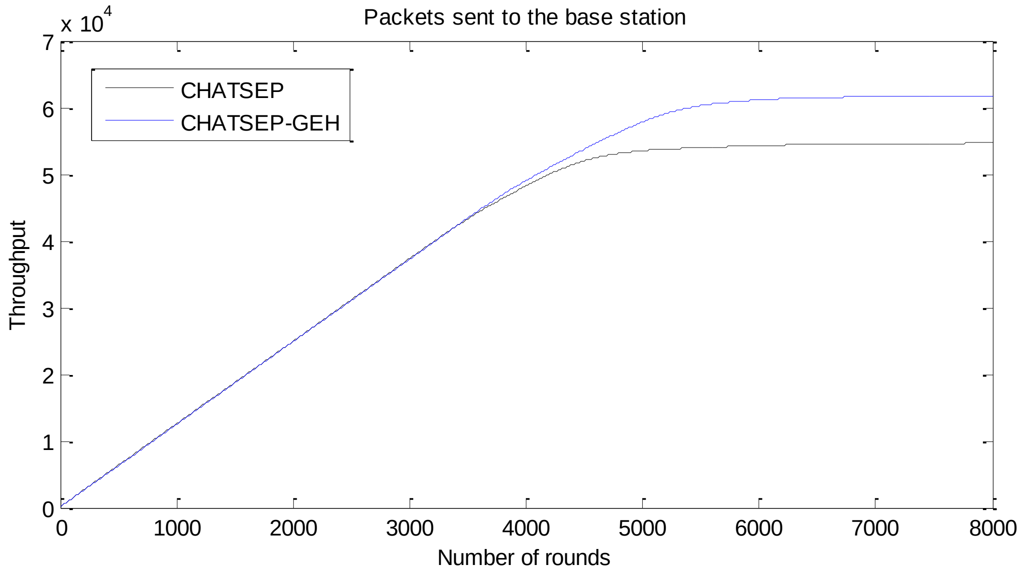

Figure 5.12: No. of packets sent to BS from CHs (CHATSEP, CHATSEP-GEH)

5.3.3 Analysis

From the simulation performed the observations can be quantified in the table 5.3.

Protocol	**Stability Period (rounds)**	**Lifetime (rounds)**	**Throughput (packets)**
TSEP	2780	4940	4.78×10^4
TSEP-GEH	3130	6120	5.42×10^4
CHATSEP	3060	6360	5.47×10^4
CHATSEP-GEH	3445	7050	6.15×10^4

Table 5.3: GEH Analysis

Thus we observe an increase of the stability period and lifetime of the WSNs when GEH technique is implemented on the routing protocols.

In figure 5.9 and figure 5.10 we compare the TSEP routing protocol with GEH technique and without GEH technique. We observed an increase in the stability period of

TSEP protocol with implemented GEH technique as compared to traditional TSEP. The stability period for a particular run of simulation was observed to be increased from 2780 to 3130 when GEH technique is implemented and hence increases the performance of the network. Implementation of GEH technique improved the network lifetime also with increase in the throughput of the network resulting from increase in the number of alive nodes and hence increasing.

In figure 5.11 and figure 5.12 we have compared the proposed CHATSEP routing protocol with GEH technique and without GEH technique. We observed an increase in the stability period of our CHATSEP protocol with implemented GEH technique as compared to original CHATSEP. The increase in the stability period for particular simulation shown was observed to be 3060 without GEH technique and 3445 with GEH technique.

Hence we have observed from the simulation results that proposed technique works efficiently in heterogeneous routing protocols with clustering and election probabilities based CH selection. Thus proposed GEH technique can be implemented to increase the performance, efficiency, improve the stability period and network lifetime in conventional routing protocols.

CHAPTER 6

CONCLUSION AND FUTURE WORK

We dedicated our research work to hierarchal WSNs and worked on finding solutions to existing problems in the threshold sensitive protocols of WSNs. We developed CHATSEP, a threshold sensitive routing protocol with two additional features of critical information prioritization and BS awareness about the network structure. To exercise the added features efficiently we introduced two new broadcasting parameters, critical threshold and adaptive meter. The introduced parameters can be changed after every CH selection and thus gives flexibility to user to control the trade-off between efficiency and versatility. Most of the applications require event driven transmission but also aim to prioritize the information and needs to be aware of the status of the network even if it is idle from long which is addressed in CHATSEP. Thus CHATSEP can entertain a wider range of applications. Future scope in this direction would be implementation of secure data transmission in CHATSEP. Simulation results have shown that CHATSEP has a higher stability period and higher lifetime than LEACH, SEP and TSEP which makes it preferable to use over the others.

We also proposed Greedy Efficient Hop technique which aims to balance the cluster energy and increase the efficiency of the network by finding the right candidate to perform the task distributed by CH if any. The selection of the right candidate is done based on the residual energy of the member nodes of the local clusters. Future work can be extending GEH technique for homogeneous networks also to increase their performance. Simulation results have shown that heterogeneous cluster protocols are observed to have performed better when GEH technique is implemented in them. Protocols with GEH technique also gave higher stability periods and network lifetime.

Thus the proposed protocol CHATSEP and proposed technique GEH are observed to be efficient in terms of energy, performance and the new added features can now entertain a wider range of applications. Hence the proposed work successfully addresses solution to the problem(s) we undertook as a part of this research work.

References

[1] R. Rajagopalan and P. K. Varshney, "Data Aggregation techniques in sensor networks: a survey," *IEEE communications surveys*, 4^{th} quarter, vol. 8, no. 4, 2006.

[2] J. Zhao, and A. T. Erdogan, " A novel self organizing hybrid network protocol for wireless sensor networks," In *Proceedings of the First NASA/ESA Conference on Adaptive Hardware and Systems (AHS'06),* 2006.

[3] R. Vidhyapriya, and P. Vanathi, "Energy efficient data compresssion in wireless sensor networks," In *The International Arab Journal of Information Technology,* Vol. 6, No. 3, July 2009

[4] A. Milenkovi´c, C. Otto, and E. Jovanov, "Wireless sensor networks for personal health monitoring: Issues and an implementation," *Computer Communications* (Special issue: Wireless Sensor Networks: Performance, Reliability, Security, and Beyond), vol. 29, pp. 2521–2533, 2006.

[5] N.S. Patil, and P.R. Patil, "Data aggregation in wireless sensor network ," *in IEEE international conference on computational intelligence and research*, 2010.

[6] S. Fedor and M. Collier, "On the problem of energy efficiency of multi-hop vs one-hop routing in wireless sensor networks," In *Proceedings of the 21^{st} International Conference on Advanced Information Networking and Applications Workshops (AINAW),* pages 1–5, 2007.

[7] A. Manjeswar and D.P. Agrawal, "TEEN: A protocol for enhanced efficiency in wireless sensor networks," In *Proceedings of 1st International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing*, San Francisco, CA, USA,pp. 189, 2001.

[8] T. He, S. Krishnamurthy, J. A. Stankovic, T. Abdelzaher, L. Luo, R. Stoleru, T. Yan, and L. Gu, "Energy-Efficient Surveillance System Using Wireless sensor networks" In *MobiSys'04,* Boston, June 6–9, 2004.

[9] A. Kashaf, N. Javaid, Z. A. Khan and I. A. Khan, "TSEP: Threshold-sensitive stable election protocol in wireless sensor network," In *10th IEEE International Conference on Frontiers of Information Technology*, 2012.

[10] Q. Qang, H. Hassanein, and K. Xu, "A practical perspective on wireless sensor networks," *Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems*, 2004.

[11] L. Subramanian and R. H. Katz, "An architecture for building selfconfigurable systems," In *Proceedings of the 1st ACM International Symposium on Mobile Ad Hoc Networking & Computing (MobiHoc)*, Piscataway, NJ, USA, pages 63–73, 2000.

[12] Th. Arampatzis, J. Lygeros, Senior Member, and S. Manesis, "A survey of applications of wireless sensors and wireless sensor networks," In *Proc. 13 th Mediterranean Conference on Control and Automation*, Limassol, pages 719–724, 2005.

[13] W. R. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "Energy efficient communication protocol for wireless microsensor networks," In *Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS-33)*, January 2000.

[14] G. Smaragdakis, I. Matta, A. Bestavros, "SEP: A Stable Election Protocol for clustered heterogeneous wireless sensor networks," *In Second International Workshop on Sensor and Actor Network Protocols and Applications (SANPA 2004)*, 2004.

[15] D. Li, K. D. Wong, Yu H. Hu, and A. M. Sayeed, "Detection, classification and tracking of targets in distributed sensor networks," In *IEEE Signal Processing Magazine*, pages 17–29, 2002.

[16] C. Meesookho, S. Narayanan, and C.S. Raghavendra, "Collaborative classification applications in sensor networks," In *Sensor Array and Multichannel Signal Processing Workshop Proceedings*, pages 370–374, 2002.

[17] A. Mainwaring, D. Culler, J. Polastre, R. Szewczyk, and J. Anderson, "Wireless sensor networks for habitat monitoring," In *Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications*, pages 88–97, New York, USA, 2002.

[18] A. Ephremides, "Energy concerns in wireless networks," *IEEE Wireless Communications Magazine*, pp. 48–59, August 2002.

[19] J. Burrell, T. Brooke, and R. Beckwith, "Vineyard computing: Sensor networks in agricultural production," *IEEE Pervasive Computing*, pp. 38–45, January 2004.

[20] K. Romer, and F. Mattern, "The Design Space of Wireless Sensor Networks," *IEEE Wireless Communications,* pp. 54-61, December 2004.

[21] A.S. Tenanbaum, Computer networks, *3rd edition, patiance-Hall interantional,* 1996.

[22] F. Ye, G. Zhong and L. Zhang, "PEAS: A robust energy conserving protocol for long lived sensor networks", In *23rd international conference on distributed computing systems(ICDCS'03),* pp. 1-10, May 2003.

[23] W. Heinzelman, J. kulik, and H. Balakrishnan, "Adaptive protocol for information dissipation in wireless sensor networks," In *5th ACM/IEEE Mobicom Conference,* Seattle, pp. 174-185, August 1999.

[24] C. Intanagonwiwat, R. Govidan, and D. Estrin, "Directed diffusion: a scalable and robust communication paradigm in sensor networks," In *6th Annual International Conference on Mobile Computing and Networking,* Boston, pp. 56-57, 2000.

[25] H. O. Tan and I. Korpeoglu, "Power efficient data gathering and aggregation in wireless sensor networks," *SIGMOD record,* vol. 32, no. 4, pp. 67-71, December 2003

[26] D. Mandala, X. Du, F. Dai, and C. You, "Load balance and energy efficient data gathering in wireless sensor networks," *Wireless Communications and Mobile Computing,* vol. 8, pp. 645-649, January 2008.

[27] Y. He, Y. Zhang, X. Ji, and X. Shen, "A new energy efficient approach by separating data collection and data report in wireless sensor networks," In *IWCMC'06,* Vancouver, British Columbia, Canada, pp. 1165-1170, July 2006.

[28] Y. Xu, J. Heidemann, and D. Estrin, " Geography-informed energy conservation for ad hoc routing," In *7th Annual ACM/IEEE International Conference on Mobile Computing and Networking,* Rome, pp. 70-84, July 2001,.

[29] H. Zang and H. Shen, "Ergr: Energy-efficient geographic routing in wireless sensor networks," In *IEEE International Conference on Parallel Processing (ICPP),* Xi'an, September 2007.

[30] S. K. Singh, M P Singh , and D K Sing, "A Survey of Energy-Efficient Hierarchical Cluster-Based Routing in Wireless Sensor Networks" *Int. Journal of Advanced Networking and Applications,* Vol. 02, No. 02, Pages: 570-580, 2010.

[31] M. Aslam, N. Javaid, A. Rahim, U. Nazir, A. Bibi, and Z. A. Khan, "Survey of Extended LEACH-Based Clustering Routing Protocols for Wireless Sensor Networks" *Networking and Internet Architecture (cs.NI) 5th AHPCN in conjunction with 14th HPCC-2012,* Liverpool, UK, 2012.

[32] S. D. Muruganathan, D.C. F. Ma, R. I. Bhasin, and A. O. Fapojuwo, "A Centralized Energy-Efficient Routing Protocol for Wireless Sensor Networks," *IEEE Radio Communications*, March 2005.

[33] M. B. Yassein, A. Al-zou'bi, Y. Khamayseh, and W. Mardini, "Improvement on LEACH Protocol of Wireless Sensor Network (VLEACH)," *International Journal of Digital Content Technology and its Applications,* Vol. 3, No. 2, June 2009.

[34] A. Manjeshwar, and D. P. Agrawal, "APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks" In *Proceedings of the International Parallel and Distributed Processing Symposium (IPDPS.02),* 2002.

[35] H. Xia, H. L. Bertoni, and L. R. Maciel, "Radio propagation characteristics for line-of-sight microcellular and personal communication," *Antenna and Propagation*, vol. 42, no. 10, pp. 1439-1447, October 1993.