THRESHOLD SENSITIVE ADVANCED DEEC ROUTING PROTOCOL FOR WIRELESS SENSOR NETWORKS (WSNS)

Thesis Submitted in Partial Fulfillment of Requirements for the Award of the Degree
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CERTIFICATE

This is to certify that Mr.**Amit Kumar Kaushik(2K12/ISY/03)** has carried out the major project titled **“Threshold Sensitive Advanced DEEC Routing Protocol For Wireless Sensor Networks(WSNs)”** as a partial requirement for the award of **Master of Technology** degree in **Information Systems** by **Delhi Technological University, Delhi.**

The Major project is a bonafide piece of work carried out and completed under my supervision and guidance during the academic session 2012-2014. The Matter contained in this thesis has not been submitted elsewhere for the award of any other degree.

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ABSTRACT

Wireless Sensor Network (WSN) is a kind of self-configuring network composed of a set of wireless sensor nodes (also called motes). The lifetime of WSN is limited because the sensor node works on battery life and it is hard to recharge the battery at regular basis because of the deployment of wireless sensor network in remote and hostile places. In order to prolong the network lifetime, a network routing protocol with high energy efficiency is necessary besides designing low-power sensor nodes. In Wireless sensor networks, several routing protocols have been developed to improve the various parameters such as stability period, throughput etc. Several Homogenous and heterogeneous Routing protocols were discovered in the domain of Wireless sensor networks. The homogenous network has all nodes of same energy and heterogeneous has nodes of different energies. But studies have shown that heterogeneous protocols are better to prolong the lifetime of the network. A clustering based homogenous protocol Low energy adaptive Clustering hierarchical (LEACH) gave a basic clustering approach to make efficient protocol for routing. After this many heterogeneous protocols were explored which successfully improved the throughput, lifetime etc of wireless sensor network. In this research the heterogeneous protocol, Distributed Energy efficient Clustering(DEEC),its enhanced Version EhancedDEEC(EDEEC) and their further improvements have been explored and have made them more efficient further by a new routing protocol “Threshold sensitive advanced distributed energy efficient clustering (DEEC) routing protocol for wireless sensor networks”. In this protocol, a new node named ‘superadvanced’ node in addition to normal, advanced and super nodes as in EDEEC is taken to increase the stability period and longevity of the network. As energy cost is more in term of transmission of data than processing data in the nodes, so to optimize the transmission, reactive routing protocol TEEN is applied in this research. This saves a lot of energy and makes transmission better in terms of throughput, longevity of the network etc. This research has been simulated in matlab and successfully outperformed the LEACH, DEEC and EDEEC in terms of alive nodes, dead nodes and throughput.

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Chapter 1

INTRODUCTION TO WIRELESS SENSOR NETWORK

1.1 Sensor Node

A sensor network is a type of network that is comprised of sensing, computing, and communicating elements that have ability to sense and respond to events in an application environment. The sensor node is basic unit of the sensor network. These sensor nodes are deployed in the networks which are observed by an administrator. The administrator controls the network through a main station point called as basestation. The observer can be a governmental, commercial, or any industrial entity. The network can be established in an area such as forest, a biological system such as hospitals etc and an information technology (IT) framework to monitor the various activities.

There are basically four components in a sensor network:

(1) A distribution of sensors nodes.

(2) A communication network (wireless-based).

(3) An information gathering station (or Basestation)

(4) Resources at the base station doing different operations such as collection of data, checking network status and analysis of received data.

The infrastructure of sensor networks is specific to the type of environment and based on nature of applications. Researchers see wireless sensor networks as an ‘‘emerging network systems consisting of low-power wireless sensors nodes (also called as motes) with a small amount of CPU and memory and large networks for high resolution sensing of the environment’’. The sensors networks used for air traffic control systems and weather monitoring stations, all of these systems use specialized computers and network communicating protocols which are very expensive and it is infeasible to deploy them in very large amount in an area. Less expensive wireless sensor networks are now being explored for different applications such as physical security, health care systems etc.

The advancements in wireless and wired communication networks and the development in IT field (such as high-power processors, large random-access memory chips) have opened the doors for the new generation of low-cost sensors. Sensor nodes size varies from nano-scale devices to micro-scale devices. The nano-scale devices have size from 1 to 100 nm and micro-scale devices have size from 10 to 1000 nm.

Sensor nodes equip with application-based sensing elements and signal processing mechanisms for extraction and manipulation of sensed environmental data. The figure 1.1 gives an overview of sensor node (in software perceptive rather than going into deep hardware view).

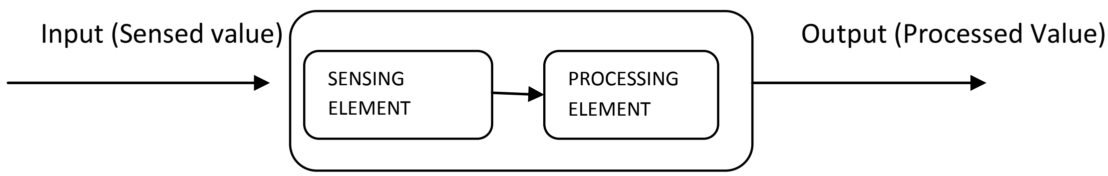

Figure 1.1.An Overview of Sensor Node (A Software View)

1.2 Wireless Sensor Networks

A Wireless Sensor Network consists of sensor nodes doing different operations such as data sensing, data processing, data computing and node-connectivity within the network. Sensors are fundamental units of wireless sensor networks which are connected to one another by self organizing means. Wireless Sensor networks transmit information to monitoring stations or Base stations that processed the received data further. Wireless Sensor Networks have to work under different constraints such as power constraints and limited battery life of the nodes, redundancy in acquisition of data in the network etc. At this time, Wireless sensor networking is becoming a rapidly increasing field, there is a widespread interest in this field not only from academic and government agencies side but also from developers, manufacturers etc. Current market reports say that more than half a billion sensor nodes are expected to be made and marketed for wireless sensor applications in the future. In the coming next years, sensor design advancements and reduction in cost of materials that have taken place in the recent past years would lead to reductions in the size, weight, power consumption, and cost of sensors nodes. These advancements would also lead to significant improvements in measuring accuracy of these networks used in different applications.

Implementation of wireless sensor networks has to address some technical challenges as specified below:

- First challenge is to develop low-power communication network with cost-efficient processing elements and effective self configuring mechanism and connectivity protocols in the sensor nodes.
- Another challenge is the need of an extended lifetime of the sensing node under the constraint of limited power supply.

Power efficiency in wireless sensor networks can be done in following ways:

1. Neighboring network (cluster) processing is deployed to reduce data quantity and thus reduce the transmission time in node communication.

2. Multi-hop networking reduces the necessity for long-range transmission since signal path loss varies with range or distance in exponential manner. Each node in the sensor network acts as a repeater and reduces link range coverage and ultimately the transmission power.

Wireless sensor networks and systems can be categorized into two types:

1. Type-1: These are mesh-based networks systems which can use one to one communication or multipoint communication system. Mostly these systems use dynamic routing for transmission of packets.

2. Type-2: These do multipoint-to-point or star based communication where the nodes use single –hop communication channel for the data transmission. These basically use static routing because of single-hop routing. So there is only one route from wireless sensor nodes to the basestation in the network.

Type-1 networks are deployed in highly dense distributed nodes applications such as environmental monitoring, national security systems etc. Type-2 networks are deployed in confined short-range spaces and less dense distribution of nodes such as a home, a factory, a building or the human body. Type-1 deal with large-scale multipoint-to-point systems with massive data flows whereas Type-2 focus on short-range point-to-point, source-to-sink applications with less data flows.

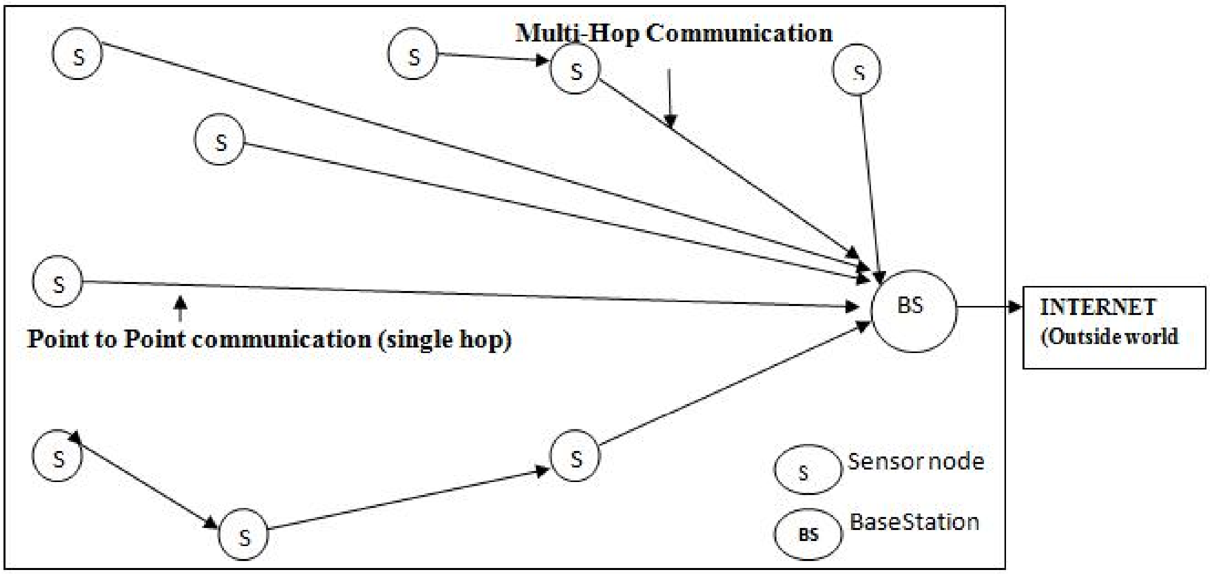

Figure 1.2.A general Architecture of a Wireless Sensor Network

1.3 Application of Wireless Sensor Networks

The power of wireless sensor networks lies in deploying large numbers of tiny sensor nodes that assemble and configure themselves automatically. These networks usage range from real-time tracking systems, to environmental conditions monitoring, monitoring of health of structures or equipments etc. The most used application of wireless sensor network technology is to monitor remote environments for sensing of data values. For example, a chemical plant can be easily monitored for leaks by deploying sensors nodes in the plant that dynamically form a wireless interconnection network and can immediately report the detection of any chemical leaks.

Deployment costs for the wireless sensor networks are less than wired networks. We have to simply place quarter-sized device using installers in the wireless sensor network rather than deploying thousands of feet of wires through protective pipes in wired networks, for example a sensor device named DOT as shown in Figure 1.3, can be deployed at each sensing point in sensor networks. The sensor network can be easily extended by adding more sensor devices without doing any redesigning or complex configuration. In addition to reducing the installation costs, wireless sensor networks can easily adapt themselves dynamically according to the changing environments as well. These adaptation mechanisms can respond to changes happened in network topologies and these can work in different modes of operation. For example, the same network deployed in leak monitoring in a chemical factory can be reconfigured into a application network for localization of the source of a leak and track the diffusion of poisonous gases. The network can then instruct workers to the safest path for emergency evacuation.

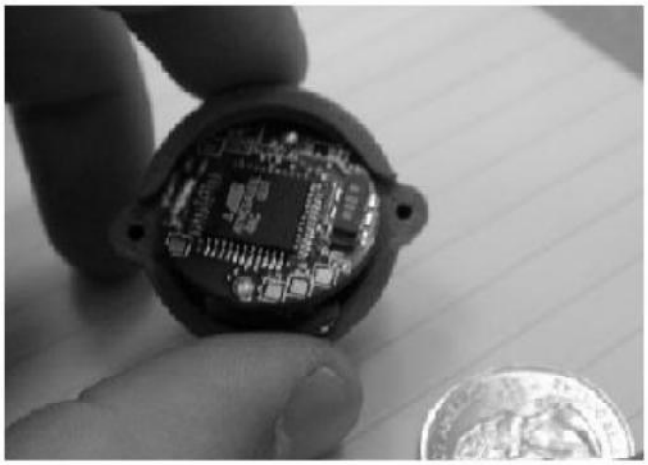

Figure 1.3.DOT – Wireless sensor network sensor device design having size of approximate size of quarter [1].

A list of applications of Wireless Sensor Network is as follows [2]:

1. Environmental applications
   - Monitoring of Climate Conditions
   - Forest fire detection system
   - Flood detection system
   - Volcanic eruption monitoring system
2. Health applications
   - Tracking and monitoring system for doctors and patients inside a hospital
   - Drug administration system
   - Elderly assistance system

3. Home applications

- Home appliances automation
- Automated meter reading system

4. Commercial applications

- Environmental control system for industrial and office buildings.
- Vehicle tracking and detection system
- Traffic flow surveillance system

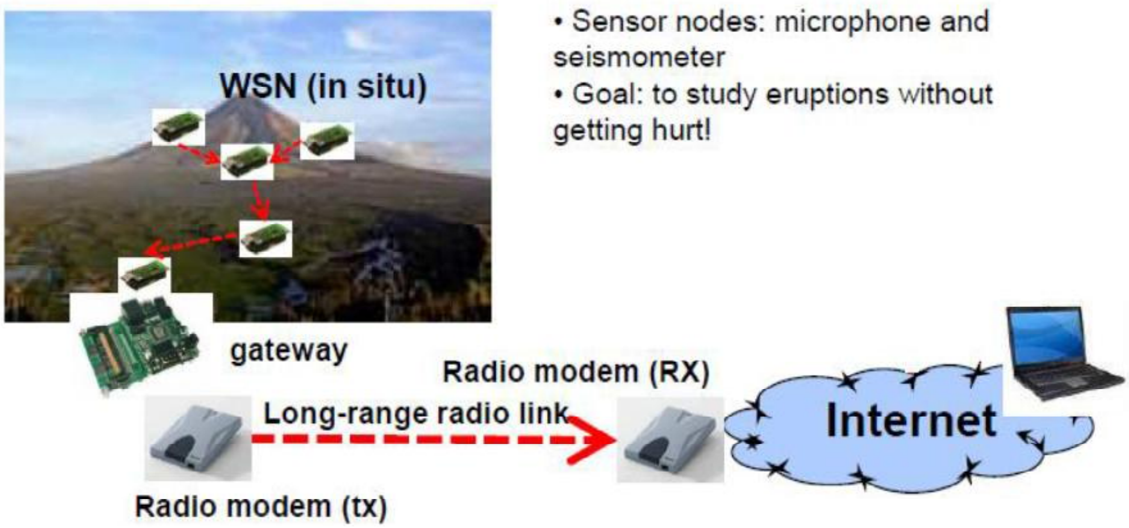

Figure 1.4.Application of Wireless sensor network in volcanic eruption monitoring.

1.4 Traditional Wireless Networks vs. Wireless Sensor Networks

When people think wireless devices they generally think about of items such as cell phones, personal digital assistants (PDAs) or laptops with 802.11 standard etc. These items are very expensive, target specific applications and highly dependent on infrastructure based network for their working. But wireless sensor networks use tiny, low-cost sensor nodes for wide variety of applications and works properly in an infrastructure-less (adhoc-type) network. Wireless sensor nodes usually do not communicate directly with the nearest basestation, but they communicate using peer-to-peer networking i.e. with help of their local sensors nodes. Instead, of depending on a pre-deployed infrastructure, each sensor node independently configure themselves to become component of the overall infrastructure. Peer-to-peer networking protocols provide a mesh-like interconnection to transport data between the thousands of sensor devices in a multi-hop way. The flexible mesh architectures dynamically support introduction of new nodes to get enlarged to cover a larger geographic region. Also, the system can automatically adjust to sensor nodes failures. In cell phone systems the service is adversely affected if many phones are active in a same area become of signal interference or due to network congestion, but wireless sensor network becomes stronger as nodes are added in the network. As long as there is enough space for new nodes, a single wireless sensor network of nodes can grow and cover a large area.

There is a significant research in the area of mobile ad hoc networks (MANETs) and its routing protocol. Wireless sensor networks are similar to MANETs in some ways as both involve multi-hop communications in the nodes. However, these are different if we consider their technical and application aspects. These differences are stated below:

1. In Wireless sensor network, sensor nodes use multipoint-to-point or broadcast communication, whereas MANETs uses point-to-point communications.

2. In most applications the sensor nodes are not mobile as mobility in the sensor nodes is very low, while nodes in MANETs are highly mobile in nature this implies that MANETs are more dynamic than wireless sensor networks.

3. As the data sensed by the sensor nodes are based on common phenomena, there is redundancy in the data collected and redundant data is communicated by the nodes in WSNs while this is not the case of MANETs.

4. A sensor node in Wireless Sensor Networks is energy constraint device while this is not a case of MANETs as human monitoring is higher in MANET than in wireless sensor networks. In mobile network, mobile devices handled by human users can be replaced or recharged on a regular basis.

6. The number of sensor nodes in wireless sensor networks is higher than that of mobile nodes of MANETs.

Due to above mentioned reasons; we can say that the routing protocols which have been used for mobile networks cannot be used effectively for wireless sensor networks. We need some other alternative routing protocols which can be implemented in the nodes and can satisfying the different constraints. These protocols are described in following chapters in which we have described the both MAC layer protocols and networking protocols.

Chapter 2

WIRELESS SENSOR NETWORKS' PROTOCOL STACK

Like TCP/IP stack network model, protocol stack for wireless sensor network has been developed. This layered model contains five layers as in the tcp/ip model i.e.

Upper layer (Application layer) (Corresponding to Application Layer of TCP/IP Model)

Transport layer (Corresponding to Transport Layer of TCP/IP Model)

Networking layer (Corresponding to Internet Layer of TCP/IP Model)

Link layer (Corresponding to Data link Layer of TCP/IP Model)

Physical medium (Corresponding to Physical Layer of TCP/IP Model)

The purposes of each layer are summarised in Table 2.1.

Upper layers(Application layer)	application database and storage ,application processing , data aggregation, query processing
Layer 4 (Transport)	Data dissemination and accumulation and storage
Layer 3 (Networking)	Data Processing ,Network Topology and routing management
Layer 2 (Link layer)	Channel sharing (MAC) mechanisms, Contention control
Layer 1 (Physical medium)	Communication medium , sensing and signal processing

Table 2.1. Layers of WSN stack model and its functions

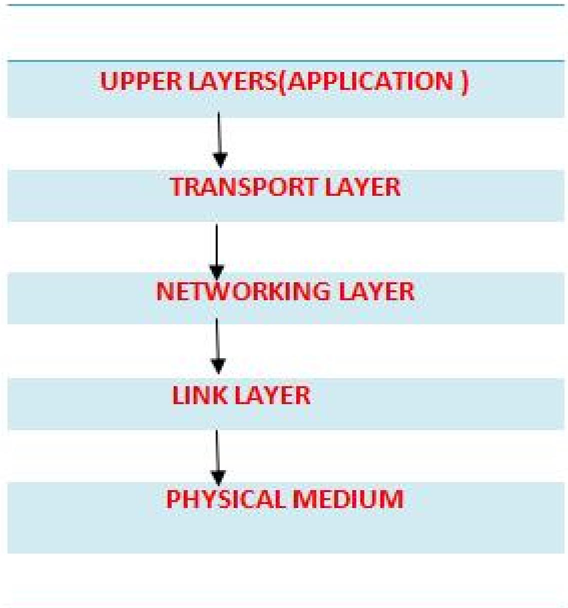

Figure 2.1. Wireless sensor network Protocol stack

2.1 Medium access control (MAC) Protocols for Wireless Sensor Networks

The design of scalable and stable MAC layer protocols is the most important thing to preserve the energy for wireless sensor networks. The designs of the protocol play a crucial role in how successfully and efficiently the message will be transmitted to the receiver sensor node.Several factors are responsible for wastage of energy in the nodes and in the network such as excessive overhead, idle listening, packet collisions and overhearing. These are discussed below:

- The exchange of a large number of the control and synchronization packets result into significant energy consumption in the sensor nodes.
- Long periods of idle listening in the sensor nodes also increase energy consumption and decrease network throughput in the network.
- The retransmission of colliding packets is also a source of significant wastage of the energy. A high number of such collisions lead to degradation in the performances of the MAC-layer protocols.
- Excessive overhearing includes receiving and decoding packets by the nodes which are intended for other sensor nodes in the network, which causes needlessly increases energy consumption and degrade throughput of the network. These packets are ultimately

dropped by the nodes after checking that the destination address is different from its own address.

These MAC layer protocols can be categorized into two types of protocols: schedule and contention-based MAC-layer protocols.

1. Schedule-based MAC layer protocols: These are deterministic MAC layer protocols of link layer in which schedule is made for the sensor nodes to access the medium. Channel access is given to only one sensor node according to its slot timing. This is achieved using preallocation of resources to each sensor nodes. For example:

1. Self-Organizing Medium Access Control for Sensor net (SMACS)
2. Low-Energy Adaptive Clustering Hierarchy (LEACH)

2. Contention-based MAC-layer protocols: It does not include preallocation of resources to individual sensors nodes according to any schedule. Instead of this, a single channel is shared by all nodes of the networks at the same time. For example:

1. Timeout-MAC (T-MAC)
2. Sparse topology and energy management (STEM)
3. Power aware multiaccess protocol with signaling (PAMAS)

These protocols have not been studied in detail in this research as these all concern with MAC layer routing and we have focused on networking based routing in this research.

2.2 Routing Mechanism in Wireless Sensor Networks

Despite the difference in sensor network applications and their deployment methods, the main aim of wireless sensor nodes is to sense the data and collect it from environment, process the data and then transmit the information to specific stations where the further processing of the data is done. We require an energy-efficient routing protocol to achieve this task efficiently. Routing protocol has to set up paths between sensor nodes and the data sink. The path selection is done in such a way so that the lifetime of the network gets maximized. The way of forwarding of data and queries between the base station and the nodes location where the target phenomena are observed is an important aspect of routing in wireless sensor networks.

The data dissemination and data gathering can be done using one-hop communication or multi-hop communication which is described as below:

- A simple approach is that each sensor node in the network exchange data directly with the Basestation. This is called single-hop based approach. A single-hop-based approach, however, is costly, as nodes that are farther away from the Basestation will deplete their energy rapidly, thereby restrictive the lifetime of the network. This is effective for short range applications and less dense distributed nodes.
- In multi-hop communication, data exchange between the sensors and the base stations is usually carried out using multihop (i.e. transmission involves more than one link) transmission over short distances. Such an approach eradicates the shortcoming of single-hop communication of energy depletion due to long-distance transmission. Thus it leads to significant energy savings in the nodes and reduces considerably communication interference between sensor nodes competing to access the channel in the highly dense wireless sensor network.

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Although a wireless sensor networks have many similarities with wired and other Wireless networks, they also have a number of distinctive characteristics which make them apart from existing networks. These distinctive characteristics lead to have new routing design requirements that are different from those we have in wired and other wireless adhoc networks and works properly in wireless sensor networks. Unique Characteristics of WSNs that lead to framing of different routing protocols are:

- Scalability and Time-Varying characteristics

The densities of node in the wireless sensor networks may vary from very sparse to very dense due to the large number of diverse applications,. Furthermore the sensor nodes numbering in the hundreds are deployed in an adhoc and unsupervised manner over wide coverage areas in many applications. In these networks, the behavior of sensor nodes is highly dynamic and adaptive as they have to adjust their behavior constantly in response to their current level of activity so that they can self-organize themselves and conserve energy. Sensor nodes may have to adjust their behavior in response to the unpredictable behavior of wireless connections due to high noise levels and radio-frequency interference, to prevent the performance degradation of the network.

- Resource Constraints

Sensor nodes are designed with minimum complexity to be deployed in a large-scale at a reduced cost. Energy is an important concern in wireless sensor networks, as network has to achieve a long lifetime while working on limited battery life. The energy managing problem, however, becomes challenging in many real time applications, where sensing is done at predetermined level and also communication performance constraints must be maintained. These two concerns have to be maintained simultaneously. Therefore, the challenge is to how to design scalable routing algorithms that can operate efficiently under this large range of performance constraints and design requirements.

- Applications Models

The network model describes the information flow between the sensor nodes and the Basestation in the network. These models are greatly dependent on the nature of the application and how data are requested and processed in the nodes. The complexity of the routing design problem as the variation in the data models increases. So the challenge to have an optimized routing protocol which can work under the application's specific data requirements and also supports a variety of data models and delivers a high scalability, responsiveness and power efficiency.

Different ways of routing techniques were proposed according to the architecture of the WSNs and constraints of these networks as described above. Also, various routing protocols have been developed which uses these routing techniques. Different ways of doing routing are:

2.2.1 Location-based Protocols

In location-based protocols, sensor nodes are recognized by the means of their address locations in the network. Location address information of sensor nodes is required in sensor networks by most of the routing protocols. This information is used to calculate the distance between two particular nodes so that energy consumption can be estimated. Some of protocols using this location-based technique are described below:

- Geographic and Energy-Aware Routing (GEAR)

  GEAR [19] is a routing protocol made for routing queries based messages from source node to target nodes in a sensor network. In this protocol, the sensors should be equipped with localization hardware such as a GPS unit or any other localization system to know the positions of other nodes and itself [20]. Also, the sensor nodes are aware of their residual energy as well as the address locations and residual energy of their neighbors. This protocol uses energy aware mechanisms that are based on geographical information to select sensor nodes to route a packet to its destination.
- Bounded Voronoi Greedy Forwarding (BVGF)

  In BVGF [21], Voronoi diagram [22] is used to frame the network model with the sites represents the positions of sensor nodes. BVGF is a type of greedy geographic routing in which a sensor node will forward a packet only to that neighbor node that is located at shortest distance. The sensor nodes which are eligible to become the next hops are the ones whose Voronoi regions are traversed by the segment line joining the source and the destination nodes in the network. In this, next hop is that the neighbor node that has the shortest Euclidean distance to the destination node among all eligible adjacent nodes. Each sensor has only one next hop to forward its data to the basestation.

2.2.2 Data Centric based Routing Protocols

In address-centric protocols, each source sensor that has the appropriate data responds to query by sending its data to the basestation. In address centric there is no role of intermediate sensor nodes. But, in data-centric protocols, when the source sensors send their data to the basestation, intermediate sensor nodes are involved and they perform some form of processing on the data coming from multiple source sensors and send the processed data toward the basestation. So intermediate sensors also have a crucial role in routing of the packets. This type of routing leads to energy savings because less transmission energy is required to send the data from the source nodes to the basestation. Some of the protocols based on this routing are:

- **Sensor Protocols for Information via Negotiation (SPIN)**

  The SPIN [23] routing protocol is a resource aware protocol. The sensors implementing the SPIN protocol need to compute the energy consumption required to compute, send, and receive the data. Thus according to this evaluation of the energy, sensor nodes can make well-versed decisions for efficient use of their own resources. The SPIN protocols are based on two process i.e. negotiation and resource adaptation. In this protocol, sensors need to negotiate with each other before any data propagation can occur in order to avoid the propagation of any non-meaningful information in network. Each sensor node has a resource manager which estimate and store information about the resource consumption. So each sensor node checks its resource manager before propagating of the data in the network. This resource manager helps to monitor the resources amount and adapt to any change according to that amount.

- **Directed Diffusion**

  Directed diffusion [7] is explained as:

  - It is a Data-centric routing protocol for sensor node query data dissemination and processing.
  - It provides energy efficiency, scalability, and robustness in the networks.
  - Directed diffusion routing approach includes data naming, interests and gradients, data propagation, and reinforcement mechanism.
  - In directed diffusion, a sensing message is in the form of attribute-value pairs. When directed diffusion process starts, the basestation has a low data rate for incoming events. After that, the sink can support one particular sensor node to send events with a higher data rate by resending the original interest message packet with a smaller interval. After that, if a adjacent sensor node receives this message packet and finds that the sender's interest has a higher data rate than before, and this data rate is higher than that of any existing gradient, it will strengthen one or more of its adjacent sensor nodes.

2.2.3 Hierarchical Routing Protocols

Clustering is a process of energy-efficient communication that is used by the sensors nodes to transport their sensed data to the basestation. In this technique, several sensor nodes group together to form clusters. Each cluster is headed by a respective clusterhead which is responsible for doing all the activities take place in the cluster. Cluster head has to route the packets from the own cluster to the other cluster heads or base station. In clustering, a hierarchy of sensor nodes are made and in this hierarchy data travel from a lower cluster layer to a higher layer. This reduces the transmissions distances from nodes to the base station to a large extent and thus energy required in transmissions also gets reduced. Some of these protocols are:

- **Low-energy adaptive clustering hierarchy (LEACH)**

  LEACH [6] is the first and most popular hierarchical clustering protocol for wireless sensor networks. Some of the points regarding the leach are:

  - In leach, direct (one-hop) communication is used by each cluster head (CH) to route the sensed data to the basestation.
  - It uses clusters to extend the life of the wireless sensor networks.
  - It uses aggregation techniques that combines or aggregates the original data into a smaller size of data that carry only meaningful or non-redundant information to basestation.
  - The operation of LEACH is divided into two phases as :

  (i) Setup phase to organize the sensor nodes into clusters. It includes cluster head advertisement and creation of transmission schedule.

  (ii) Steady-state phase includes data aggregation, compression, and transmission to the basestation.

- **Power-Efficient Gathering in Sensor Information Systems (PEGASIS)**

  PEGASIS [26] is an enhanced version of the LEACH protocol. In this protocol, it forms chains of sensor nodes so that each node transmits and receives from a adjacent node in the chain and only one node is selected from that chain to transmit the data to the base station. The data is gathered and it moves from one node to another node, aggregated and ultimately sent to the basestation. The chain construction is done in a greedy way. It selects its node for forwarding of packets by checking the energy status of their neighboring nodes. Although in this protocol, the clustering overhead is eliminated, it still requires dynamic topology management as the sensor nodes need to know about the energy status of their neighbors nodes in order to know where to route its data. Such topology creates a high overhead for highly utilized networks.

- **Hybrid, Energy-Efficient Distributed Clustering (HEED)**

  HEED [23] is also an extension of LEACH which uses residual energy and degree or density of the node as a criterion for cluster head selection. This approach is used to achieve power balancing in the network. HEED increases network lifetime by distributing energy consumption and producing well-distributed cluster heads and optimized clusters. In HEED, the protocol periodically selects cluster heads according to two clustering parameters.

1. The first and primary parameter is the residual energy of the sensor node which is used in calculating probability of becoming a cluster head.
2. The secondary parameter is the intra-cluster communication cost which is the function of cluster density or number of neighbors in the cluster.

Chapter 3
LITERATURE SURVEY

3.1 Clustering-A Routing Approach

In this Research, we have used clustering based approach for doing the routing in the network. Clustering is a routing mechanism in which nodes forms cluster according to some similarities among the nodes and then cluster heads are made after satisfying some condition. In this project, distance is a measure parameter for forming the clusters Thus adjacent nodes try to be same cluster. Custer head uses CDMA codes for preventing the inter-cluster interference in the networks. This CDMA codes are broadcasted with the packets for proper transmission of the messages. How clustering saves a lot of energy in the network and maximize the lifetime of the network, it can be seen in this way:

In the network without clustering the nodes uses one to one communication path to transmit data to the base station. The nodes near to base station dissipates less energy but distant nodes have to expense a lot of energy to do communication so depletion of energy occurs at high rate in distant nodes and these becomes dead in early stages of the network. These large distances transmission by a lot of nodes lead to a limited life of a WSN. Now Clustering makes cluster and cluster members make one-hop transmission of a data to cluster head within a short distance. Then cluster heads transmits this data to Base station. Thus long distance communicating nodes has been decreased due to clustering to a large extent. Thus, a very short percentage of nodes will die in early phases of the network which is better than network without clustering.

Some aspects of clustering based routing are:

- Cluster heads uses schedule based communication to its cluster members. For this it uses Time division multiple access (TDMA) scheme and allots times slots to its members and on that time members have to send their data.
- For preventing the inter-cluster interference(occurs due to existence of clusters within vicinity of each other),the cluster heads used Code division multiple access(CDMA)

scheme to make each cluster head unique. Thus data is embedded with the CDMA code of each cluster head to do proper transmission.

- The optimal probability depends upon the spatial density of the nodes in the network. So the optimal probability exists when nodes are uniformly distributed in the network. When nodes are well distributed over network, the energy consumption will be minimum and optimal clusters are made. This clustering is also called optimal clustering [4].

In clustering cluster heads are made according to some condition. So a node becomes cluster head if it fulfills a specified condition. Such as in LEACH [5], a threshold is evaluated according to an equation (1) and then a random number is chosen. If the calculated thrshold is greater than chosen random number and that node has not been a cluster head since last 1/p rounds then it become a cluster head (here p is the probability of becoming the cluster heads in the network).

$$T(n) = \begin{cases} \frac{p}{1-p\times\left(r\times mod\ \frac{1}{p}\right)} & n\epsilon G \\ 0 & Otherwise \end{cases} \tag{1}$$

After cluster heads are made, nodes attach themselves with a particular cluster head using a distance parameter. So nodes calculate distance with cluster heads and cluster head with minimum distance include that node within its cluster. This approach is applied by us in this project for simulation purpose. In actual scenarios, the cluster head broadcasts its id to the nodes. This id is a kind of signal. So node selects that signal with highest strength and stores that id in its database.

Various Routing protocols were proposed which used clustering as routing mechanism in the wireless sensor network. In our research, we also focused on clustering based routing protocols and make them more efficient in terms of different network parameters such as throughput, scalability, responsiveness etc. Now we are giving the detailed view of routing protocols which we have studied and improved them further.

3.2 Low-Energy Adaptive Clustering Hierarchy (LEACH)

Low-energy adaptive clustering hierarchy (LEACH)[2,5,6] is a hierarchical based routing protocol which uses clustering to collect and transmit the data from nodes to basestation. The main focus of the LEACH protocol is on three points as mentioned below:

- To extend the lifetime of the network.
- To reduce the energy consumption by the sensor node in the network.
- To reduce the flow of redundant information in the network using data aggregation mechanisms.

LEACH works in hierarchical way in which it organizes the network into a set of clusters. Each cluster is governed by a elected cluster head. The cluster head is responsible to carry out multiple tasks. It includes collection of data from the member nodes of the cluster and transfer the the collected data to the basestation after applying the data compression and aggregation mechanism. The transmission of the aggregated data is done through a single hop. The cluster heads receive the data from the member nodes in the periodical basis. The periodical basis is achieved using the Time division multiple access (TDMA).In this TDMA, slots are created for each member node by the cluster head and then cluster head advertises these slots times to their member nodes. So nodes will only send the data to their respective cluster heads according to their slots timing. Also to eliminate the chances of the inter-cluster interferences in the network each cluster head uses code division multiple access(CDMA).The CDMA codes are advertised by the cluster heads to their cluster member nodes.

The operation of LEACH is divided into two phases as :

(i) Setup phase to organize the sensor nodes into clusters. It includes cluster head advertisement and creation of transmission schedule.

(ii) Steady-state phase includes data aggregation, compression, and transmission to the basestation.

These two phases are shown in figure 3.2.

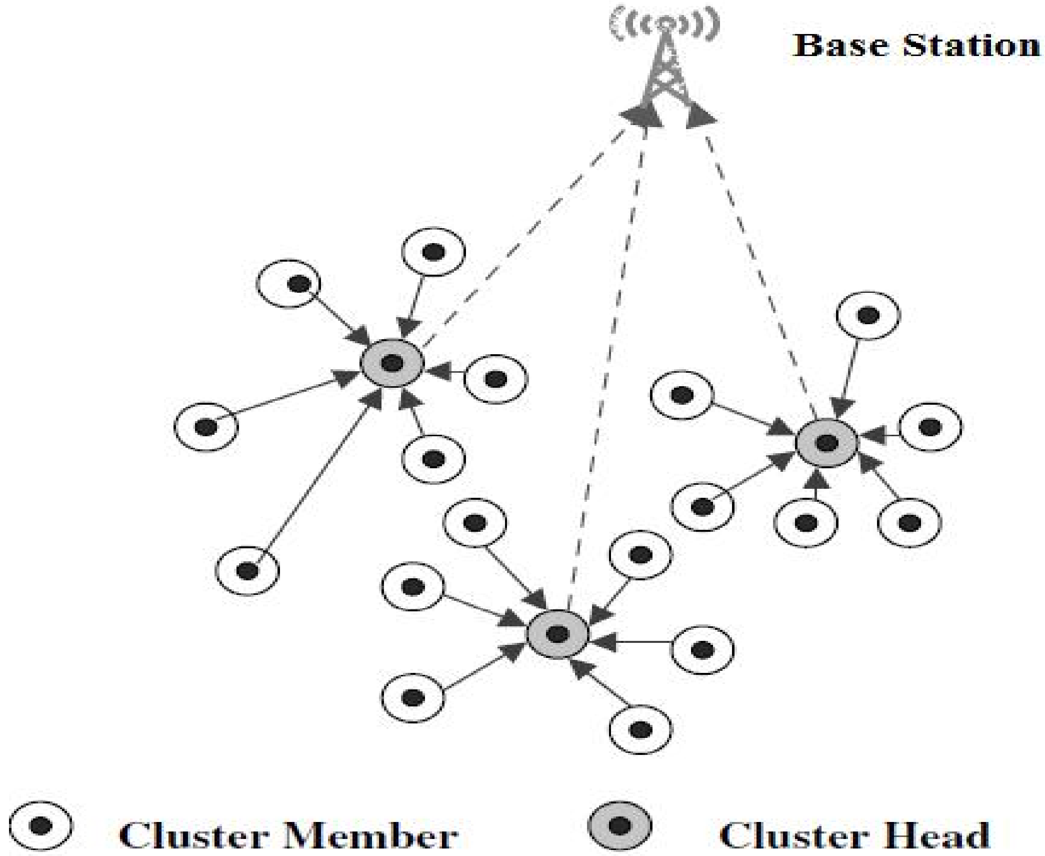

Figure 3.1.Shows the Clustering mechanism in Leach protocol

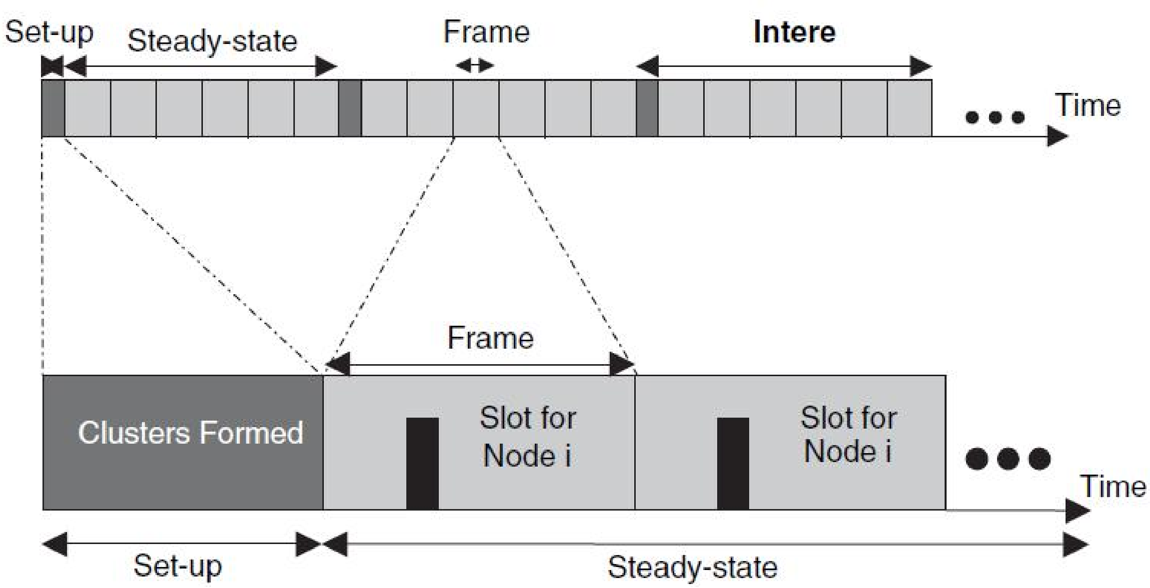

Figure 3.2.Shows the operation of two phases of the leach [2]

The set-up phase duration is shorter than the steady phase. In the set-up phase the cluster heads are selected and cluster heads advertisement is done. This takes much less time than the steady time. As the steady phase includes the transmission of the data which consumes more time and energy resources. Also steady phase is more dominant over set-up phase. Cluster head selection in the leach is explained as:

Cluster Head Selection: In leach a threshold is calculated using equation 2.This threshold is calculated using a probabilistic method. In this probability of cluster heads and round number is used to calculate the threshold. This threshold ensures that the node will eligible to become a cluster head only after inverse of chosen the probability of cluster heads i.e. (1/p). A random number g is also taken. The value of g lies in [0, 1] set. If the value of the threshold is greater than the random number g then the corresponding node for which the threshold is calculated become cluster head otherwise it would not be.

$$T(n) = \begin{cases} \frac{p}{1-p\times(r\times mod\frac{1}{p})} & n\in G \\ 0 & otherwise \end{cases} \qquad (2)$$

The variable G represents the set of nodes that have not been become cluster heads in the last 1/p rounds, and r denotes the current round. The p represents the cluster head election probability. It is clear from the threshold calculation, that if a node has become as a cluster head in the last 1/p rounds, it will not be elected in this round.

After the completion of the cluster head selection in the network, the cluster heads make TDMA slots for their member nodes. These slots are broadcasted by the cluster heads to their respective clusters members. This broadcasting also contains CDMA code which gives unique id to each cluster head. Thus cluster head advertise the slots timing with their ids. This process eliminates the inter-cluster interference in the network. The code is selected carefully so as to reduce inter-cluster interference and proper intra-cluster communication. After this set-up phase steady phase starts. This phase include the collection of the data from the members nodes by the cluster heads. These cluster heads then compress the data and this compressed data is sent to the basestation. Simulations have shown that LEACH perform well and saves a lot of energy in the network.

But LEACH has also some shortcomings which were explored by the researchers. These are as below:

- The probability of selecting cluster heads does not consider the residual or remaining energy of the nodes. The threshold calculation is based on the probabilistic method which does not take the remaining energy of nodes into account. These results into a situation where a low energy node can also become a cluster head. Thus low energy cluster head will get died quickly as whole transmission is done by that cluster head. This ultimately led to shorter lifespan for the network.
- The probabilistic method of leach has a problem of unbalanced clusters in the network. Thus unequal distribution of the energy takes place in the network.

These above issues are considered in other routing protocols and rectify them. Also these protocols outperformed the leach in terms of energy and proper cluster head selection. These enhanced protocols taken residual energy into consideration in selecting the cluster head in the network [9]. These protocols were based on homogenous nature of network i.e. all nodes have same amount of energy in the network but our research is based on heterogeneous nature of network where all nodes are not considered equivalent in term of energy. So we are not describing these enhanced leach protocol further.

3.3 Stable Election Protocol (SEP)

Leach protocol works basically on homogenous property of the network. This property says that all the nodes in the network have same kind of the energy. So we can say that all nodes have an equal significance in the network. All the nodes in the network behave in almost same way in terms of energy. But after the leach, researchers thought about the introduction of the heterogeneity in the network. Heterogeneity gives some nodes more preference than other nodes and all nodes will not have an equal significance in the network. Some nodes will be preferred more than other nodes. This heterogeneous issue was explored in the SEP[9]. SEP has given some motivation factors of introducing the heterogeneity in the nodes. Some of the factors are:

- In a network when all the nodes have an equal energy. Thus a time will come in the operation of the network when some nodes will get died due their selection as the cluster heads in the previous rounds. These nodes now cannot work properly and so cannot route the packets to the other sensor nodes or basestation. These nodes have to be replaced in the network with the new sensor nodes. These replacement lead to a scenario in the network where we have new nodes with full initial energy and others sensor nodes having less energy than these new nodes as they have been working from the previous rounds. When the operation of the network starts again this network will behave like a heterogeneous network as all the nodes will not have equal energies. These new nodes having more energy will die later than the previous one and if these new nodes are elected as cluster heads then their energy will not get deplete earlier as their energy is full. So they will also save other nodes having less energy in the network and extend the overall lifetime of the network. So this factor should be considered to introduce the heterogeneity in the system.

- Cost of replacing the batteries is less than the cost of the replacing the node itself. Thus if we use high-energy batteries in some nodes in the network from the initial working of the network, then we can increase the longevity of the network without much cost.
- Note that due to cost constraints it is not always possible to satisfy the constraints for optimal distribution between different types of nodes as proposed in [5].
- The dissipation of the energies in different nodes is also different as it varies with the different factors such as radio communication characteristics, failure of short term link or shape of the terrain in which sensors are deployed.

Thus these all factors can be considered for introducing the heterogeneity in our network. Now we are describing this SEP protocol. In this protocol a percentage of the nodes are taken special nodes or nodes with higher energies than other nodes. These higher energy nodes are taken in fraction of m. These nodes are also termed as advanced nodes. Thus if we have n number of total nodes then n.m are advanced nodes and rest of nodes i.e. n.(1-m) are normal nodes. These lower energy nodes are termed as normal nodes.

Normal nodes: n.(1-m)

Advanced nodes: n.m

The initial energy of the normal nodes is denoted as E_0 and for advanced nodes the energy will be more than the normal nodes by fraction of α. Thus initial energy of the advanced nodes is taken as $E_0(1+\alpha)$. So total energy of the system is calculated as

$$n \cdot (1-m)E_0 + n.\, m.\, E_0 \cdot (1+\alpha) = n.E_0\, .(1+\alpha \cdot m)$$

it means total energy of the system is greater than homogeneous system by $(1 + \alpha \cdot m)$ factor. These advancement nodes are taken for extending the life of the network. This total energy is an important factor in deciding the probabilities for normal and advanced nodes. The epoch is term coined in the SEP this term is defined as the numbers of the rounds after which the a node become eligible for cluster head again. In the network operation, we always want that high energy node will become cluster head as cluster head has to dissipate a high amount of the energy in the transmission of the packets. In leach we have p which is the probability of choosing the cluster heads and epoch time is 1/p in the leach. Here in SEP the p is denoted p_{opt} with the same meaning. The overall operation of cluster head election depends upon the probability chosen. Now In SEP the first requirement is to make advanced nodes cluster head more rapidly than normal nodes. This reduces the burden on the normal nodes and thus makes their life extended. In SEP the probabilities for normal and advanced nodes are taken in the proportion of their energies. Thus advanced nodes have to become cluster head earlier than normal nodes so their probability of electing cluster heads should be higher than the probability of the cluster head election for normal nodes. This will lead to short epoch time for advance nodes and higher for normal nodes. So the new epoch time for the normal nodes becomes $\frac{(1+\alpha.m)}{p_{opt}}$ and $\frac{(1+\alpha.m)}{p_{opt}\ (1+\alpha)}$ for advanced nodes. These are made according the total energy and their respective energies. Thus,

- normal node becomes cluster head once every $\frac{(1+\alpha.m)}{p_{opt}}$ rounds per epoch.
- advanced node becomes cluster head exactly $\frac{(1+\alpha.m)}{p_{opt}\ (1+\alpha)}$ rounds per epoch.

In the network, the average number of cluster heads per round per epoch is equal to $n \times p_{opt}$. This average number of the cluster heads should be equal to sum of number of the cluster heads made for advance nodes and for normal nodes in a round. Thus

Number of normal nodes cluster heads = $n \times (1 - m) \times p_{nrm}$.

Number of advance nodes cluster heads = $n \cdot m \times p_{adv}$

and

$$n \cdot (1 - m) \times p_{nrm} + n \cdot m \times p_{adv} = n \times p_{opt}$$

The weighed probabilities for normal and advanced nodes are calculated as :

$$p_{nrm} = p_{opt} \times \frac{1}{(1 + \alpha \cdot m)}$$

$$p_{adv} = \frac{p_{opt}(1+\alpha)}{(1+\alpha m)}$$

Now, the threshold is calculated with new probabilities for normal and advanced nodes as

$$T(s_{nrm}) = \begin{cases} \frac{p_{nrm}}{1-p_{nrm}\left(r \bmod \frac{1}{p_{nrm}}\right)} & if\ s_{nrm} \in G' \\ 0 & otherwise \end{cases} \quad (3)$$

The $T(s_{nrm})$ is calculated using the weighted probability of the normal node as given above. In this, r is the current round, G' is the set of normal nodes that have not become cluster heads within the last rounds of the epoch i.e.$1/p_{nrm}$ and $T(s_{nrm})$ is the threshold applied to a population of $n \cdot (1 - m)$ (normal) nodes. This guarantees that each normal node will become a cluster head exactly once every $(1/p_{opt})*(1+\alpha \cdot m)$ rounds per epoch, and that the average number of cluster heads that are normal nodes per round per epoch is equal to $n \cdot (1 - m) \times p_{nrm}$.

$$T(s_{adv}) = \begin{cases} \frac{p_{adv}}{1-p_{adv}\left(r \bmod \frac{1}{p_{adv}}\right)} & if\ s_{adv} \in G' \\ 0 & otherwise \end{cases} \quad (4)$$

G'' is the set of advanced nodes that have not become cluster heads within the last $1/p_{adv}$ rounds of the epoch, and $T(s_{adv})$ is the threshold evaluated on n.m advanced nodes. Sub-epoch time is epoch time for the advanced nodes the network.

Some important points in SEP are:

- In SEP a "heterogeneous epoch" is used which is epoch time for heterogeneous system due to different epoch time for normal and advanced nodes.Thus advanced nodes has $(1 + \alpha)$ sub-epochs and thus each advanced node becomes a cluster head $1+\alpha$ times more than normal nodes within a heterogeneous epoch.
- The average number of cluster heads that are advanced nodes per sub-epoch in a round is equal to $n \cdot m \times p_{adv}$.

- For optimal and stable region in the network, the average total number of cluster heads per round per heterogeneous epoch is equal to:

  $n \cdot (1 - m) \times p_{nrm} + n \cdot m \times p_{adv} = n \times p_{opt}$

  which is the desired number of cluster heads per round per epoch.

So SEP has given average number of cluster heads as $n \times p_{opt}$ which provides an optimal no of cluster heads in our system. Thus SEP has proven the positive side of introducing heterogeneity and optimal cluster heads are also framed in the network system as well.SEP has increased the epoch period for normal nodes by introducing the sub-epoch of the advanced nodes. The advanced node become cluster head rapidly than normal nodes, energy dissipation will be more in advance nodes than normal nodes and this is not a big problem as energy of advance nodes are higher than normal nodes. As higher the probability of becoming cluster heads lesser will be epoch time for a node and in SEP the probabilities are calculated considering the fraction energies of normal and advance nodes in total energy. Thus SEP increased the stability period (the round when first node dies [9]) and maximized the lifetime of the network. SEP has made strong background for future researchers by using the concept of heterogeneity in the wireless sensor network.

3.4 Distributed Energy Efficient Clustering (DEEC) Protocol

The main shortcoming of the LEACH [5] is not considering the effect of residual energy (energy left after doing the transmission) in the election of the cluster head. Thus a low energy node is equally eligible to become a cluster head. SEP [9] introduced the heterogeneity in the network to stabilize the network and optimize other parameters but it also did not study the impact of energy in the selection of cluster head ,this result into election of low energy advanced or normal node to become cluster head in the network. As these both work on probabilistic basis so does not ensure optimum cluster head selection. DEEC [10] studied the effect of residual energy in the threshold calculation and cluster head election. This does not before these researchers did not consider this factor but they considered this in homogenous network. DEEC embed this factor in the heterogeneous environment thus ensuring that always high energy advanced or normal node will have more chances to become cluster head than low energy advanced or normal node. This improved the routing protocol in all terms such as stability period, throughput etc further.

Now we are describing the DEEC protocol.

Here n_i is used to represent the epoch which is the number of rounds to become a cluster head for the node s_i .In SEP level two heterogeneity was introduced in the network. This increased the epoch time for the normal time. Thus advanced nodes increased the lifetime of the network. But SEP has the same shortcoming as with the LEACH. Both of them used the probabilistic method of electing the cluster heads in the network. None of them do not consider the advantage of using the residual energy or remaining energy in the election of the cluster heads. In DEEC the concept of residual and average energy is considered and the method of election of the cluster heads is changed. Here the average energy is taken to study the effect of the energies of all the nodes of the network. In the network, all the nodes cannot have the same residual energy so it is important to study the effect of residual energy in the cluster heads selection.

In DEEC $\bar{E}(r)$ is used to denote the average energy of nodes in a round which is calculated as

$$\bar{E}(r) = \frac{1}{n}\sum_{1}^{n} E_i(r) \quad \{\text{for i=1 to n}\}$$

Where n is total number of the nodes in the network. In this $\bar{E}(r)$ is considered as the reference energy, it shows

$$p_i = p_{opt}\left[1 - \frac{\bar{E}(r) - E_i(r)}{\bar{E}(r)}\right] = p_{opt}\frac{E_i(r)}{\bar{E}(r)}.$$

Thus the average number of cluster heads the average per round per epoch is calculated as:

$$\sum_{1}^{n} p_i = \sum_{1}^{n} p_{opt}\frac{E_i(r)}{\bar{E}(r)} = p_{opt}\sum_{1}^{n}\frac{E_i(r)}{\bar{E}(r)} = np_{opt}$$

and is equal to np_{opt} which guarantees for a optimal clustering in the network.

It is the optimal cluster-head number we want to achieve. In this, cluster head threshold , that each node s_i use to determine whether to become a cluster head or not in a round is given as

$$T(s_i) = \begin{cases} \frac{p_i}{1-p_i\left(r \bmod \frac{1}{p_i}\right)} & n \in G \\ 0 & otherwise \end{cases} \tag{5}$$

where G as specified earlier is the set of nodes that has not become cluster heads till round r. If node $s_i \in G$ then it has become cluster head in last $1/p_i$ rounds. Now a random number is chosen that lies in [0, 1] set. If the threshold calculated is greater than the random number then node become the cluster head in this round r.

In the DEEC, the epoch n_i is chosen based on the residual energy $E_i(r)$ in a round r of node s_i as follow

$$n_i = \frac{1}{p_i} = \frac{\bar{E}(r)}{p_{opt} E_i(r)} = n_{opt} \frac{\bar{E}(r)}{E_i(r)}$$

and $n_{opt} = 1/p_{opt}$ denote the reference epoch to be a cluster-head. So in this, the nodes with high residual energy take more turns to be the cluster-heads than lower ones.

In homogenous network all the nodes have equal energy and their probability of choosing the cluster heads is same and therefore the epoch round will be same for each node. But in case of heterogeneous networks, there is different kind of nodes having their different probabilities of cluster heads selection. So the epochs time for each node is not same in this system. In this two-level heterogeneous networks, p_{opt} is replaced with the weighted probabilities for normal and advanced nodes as given in Eq. 6.

$$p_{nrm} = p_{opt} \times \frac{1}{(1+\alpha \cdot m)} \quad \text{and} \quad p_{adv} = \frac{p_{opt}(1+\alpha)}{(1+\alpha m)} \tag{6}$$

Therefore the p_i is evaluated based on the type of the node. The p_i in generic way is given in equation 7 according to above probabilities for normal and advanced nodes as

$$p_i = \begin{cases} \frac{p_{opt} E_i(r)}{(1+\alpha m)\bar{E}(r)} & \text{if node is normal} \\ \frac{p_{opt}(1+\alpha) E_i(r)}{(1+\alpha m)\overline{E(r)}} & \text{if node is advanced} \end{cases} \tag{7}$$

So substituting the value of p_i in equation 7 from equation 6 we get probability for electing the cluster head in the network. Instead of using total energy of the nodes, the average energy is considered in evaluation of the threshold. The average energy $\bar{E}(r)$ is used as reference energy for each node. It is the energy that each node should own in current round to keep the network alive to the greatest extent. In an ideal situation, the energy of the network and nodes are uniformly distributed, and all the nodes should die at the same time. Thus DEEC estimate the average energy $\bar{E}(r)$ of rth round as follow

$$\bar{E}(r) = \frac{1}{n} E_{total} \left(1 - \frac{r}{R}\right) \quad (8)$$

where R denote the total rounds of the network lifetime. It means that every node dissipate the same amount of energy in each round, which is also the target of each energy-efficient protocol. So, main idea of DEEC to control the energy expenditure of nodes by means of adaptive approach. To compute $\bar{E}(r)$ by Eq. (8), the network lifetime R is needed. Assuming that all the nodes die at the same time, R is the total of rounds from the network begins to the entire nodes die. R can be estimated as follow

$$R = \frac{E_{total}}{E_{round}}$$

Where E_{round} denote the energy consumed by the network in each round. To summarise the operation of DEEC we can say that, initially, all the nodes need to know the total energy and lifetime of the network to calculate the average energy of the network. The total energy is calculated in the beginning of the network operation by the basestation. R is stored in a variable in the basestation. This R depends upon the duration of network operation which is usually taken in approximate value. The network administrator stores this value R in the basestation. Basestation broadcast these parameters i.e. total energy E_{total} and R in the network. Nodes after receiving this value calculate average energy. The residual energy of each node is calculated in each node. Thus in this way threshold is evaluated and the cluster heads are selected in the network.

3.5 Enhanced distributed energy efficient clustering (EDEEC) routing protocol

After DEEC, several enhanced version of this protocol like DDEEC, EDEEC etc came into existence. These versions applied the concept of residual and average energy on the three level of nodes i.e. normal, intermediate and advanced. Thus heterogeneity level is increased to 3.These heterogeneity level was increased in EnhancedSEP [25].In this ESEP, one more node is added to the network i.e. intermediate node between the normal and advanced as in SEP. Here, the energy of intermediate node is between the normal and advanced nodes. In [18], it has been evaluated that EDEEC has outperformed the DDEEC in term of increasing lifetime of the nodes and throughput of the network. That’s why EDEEC has acted as motivating factor to improve it further in the domain of wireless sensor network. DEEC applied the residual energy and average energy in the election of clusterheads in the heterogeneous network. EDEEC applied the same process but on more distributed network i.e. three levels of the nodes. These nodes are termed as normal, advanced and super nodes. In EDEEC, the nodes are distributed according to fraction m and mo as

$$
\begin{aligned}
&normal: && n.(1-m) \\
&advanced: && n.m.(1-mo) \\
&super: && n.m.mo
\end{aligned}
$$

where n is total no of nodes in the network and energy of the nodes are:

$$
\begin{aligned}
&\text{normal:} && E_0 \\
&\text{advanced:} && (1+a)E_0 \\
&\text{super:} && (1+b)E_0
\end{aligned}
$$

The total initial energy of the three-level heterogeneous networks is given by:

$$
\begin{aligned}
E_{total} &= E_0.n.(1-m) + (1+a)E_0 n.m.(1-mo) + (1+b)E.n.m.mo \\
&= n.E_0(1+m(a+mo.b))
\end{aligned}
$$

So total energy is greater than homogenous network with single node by fraction of $(1+m(a+mo.b))$.

Now the probability for election for different nodes according to their energies is calculated as:

$$
p_i = \begin{cases}
\dfrac{p_{opt} \times E_i(r)}{(1+m(a+mo.b)) \times \bar{E}(r)} & \text{if node is normal node} \\[2ex]
\dfrac{p_{opt} \times E_i(r) \times (1+a)}{(1+m(a+mo.b)) \times \bar{E}(r)} & \text{if node is advanced node} \\[2ex]
\dfrac{p_{opt} \times E_i(r) \times (1+b)}{(1+m(a+mo.b)) \times \bar{E}(r)} & \text{if node is super node}
\end{cases}
$$

p_{opt} is average probability of electing the cluster heads (same as that of p in LEACH) for all types of nodes in a round in a network and $E_i(r)$ and $\bar{E}(r)$ is energy of nodes in a round and average energy of the network resp.Thus threshold $T(i)$ is calculated as

$$T(i)=\begin{cases} \frac{p_{norm}}{1-p_{norm}\left(r\times mod\left(\frac{1}{p_{norm}}\right)\right)} & if\ i\ is\ normal\ and\ i\in F \\ \frac{p_{adv}}{1-p_{adv}\left(r\times mod\left(\frac{1}{p_{adv}}\right)\right)} & if\ i\ is\ advanced\ and\ I\in F' \\ \frac{p_{sup}}{1-p_{sup}\left(r\times mod\left(\frac{1}{p_{sup}}\right)\right)} & if\ i\ is\ super\ and\ I\in F'' \\ 0 & \text{otherwise} \end{cases}$$

where F is the set of those normal nodes that have not become cluster heads since the last $1/p_{norm}$ rounds of the epoch , F' is the set of those advanced nodes that have not become cluster heads within the last 1/ p_{adv} rounds of the epoch , F'' is the set of those super nodes that have not become cluster heads within the last $1/p_{sup}$ rounds of the epoch. E-DEEC used the same mechanism for estimating the energy in the network as proposed in DEEC. Since the probabilities calculated depend on the average energy of the network at round r. This average energy is estimated as

$$\bar{E}(r)=\frac{1}{n}E_{total}\left(1-\frac{r}{R}\right)$$

where R denotes the total rounds of the network lifetime. Value of R can be evaluated manually or it can be calculated using total energy and round energy as given in DEEC protocol.

$$R=\frac{E_{total}}{E_{round}}$$

E_{round} is the round energy that is dissipated by the nodes in a particular round in the network.

3.6 Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN)

This TEEN[13] protocol focus on attribute based sensor network where nodes communicate using a query-response mechanism. In this node send a query to other node, the receiver node give response to sender by sending the value of attribute whose value has been asked by the query sender node. This response is given without any need to specify the location of response-sender node as nodes are more interested in response to query. This approach is also fall under data-centric approach where nodes are more focused in data rather than location. Various protocols such as Directed diffusion etc uses attribute based routing. In this paper author has classified the sensor network according to periodical and non-periodical transmissions of the data. These are proactive and reactive sensor networks. These are given below:

Proactive sensor networks:

The nodes in this type of network periodically switch on their sensors elements and transmitters and sense the environment and transmit the data. Thus, they communicate at regular intervals with each other. So, they are well designed for applications requiring periodic data monitoring. When clusters are made, the cluster-head advertises the following parameters to their members:

- Report Time: This is the time period at which the transmission is done by the node on a periodical basis.
- Attributes value: These are physical sensed parameters whose value is asked by the sender nod.

The cluster head after getting elected as cluster head make a TDMA schedule. This schedule contains timing slots for their member nodes. Then cluster heads broadcast this schedule to the members. The members sense the value from the environment and then can only transmit the data in their report time which is timing slot for them. At every report time, the cluster members sense the value parameters specified in the attributes and send the data to the cluster-head. The cluster-head aggregates this data and sends it to the base station. Because of the periodicity with which the data is sensed, it may be the case that the time critical or real time data is available only at report times thus may cross the deadlines of receiving the data Thus, this proactive scheme may not be highly suitable for real -time data sensing applications. The report time is equivalent to the frame time in LEACH.

Reactive Sensor networks:

Reactive sensor network are more reactive to the sudden or drastic change in the values being sensed by the nodes. These networks basically are used to be deployed for real time applications As real time applications need the transmission of the data in specified time thus it does not wait for any periodical time or slot to send its data. In these networks or protocols used in these networks there is no concept of report time as we have in proactive sensor networks. The report time is used to send the data by the node. In these networks, data is not sent in periodical basis.

The transmission of the data depends upon the significance of the data for the sensing node and receiving node. This significance lies in whether we have sent the same data or not in previous transmission. For doing this process we have two thresholds i.e. hard and soft threshold. The previous and latest send value is stored in a variable called as Sensed value (SV).The current sensed value is termed as current value (CV).Hard and soft thresholds are defined as :

- Hard Threshold (h): This value is minimum and significant data value. All transmission will be done only if the sensed value is greater than this threshold. If the value is greater than this threshold then we apply soft threshold on the data.
- Soft Threshold (s): If the current sensed value is greater than hard threshold then the difference between the current value and sensed value should be greater than soft threshold. This threshold signifies that may be current value is greater than hard threshold ,it should differ than previous received value by a significant amount.

In these networks the node gets into sleep mode when there is no transmission is being done. Whenever the sensed value is greater than the hard threshold then the node gets into active mode and switch on its transmitter and send the data by checking the soft threshold. Thus we have these criteria for transmission of the data:

1. The current value should be greater than the hard threshold (h) and

2. The difference in current value of the sensed attribute (CV) and sensed value (SV) should be greater than the soft threshold(s).

Whenever a node transmits data, SV becomes equal to this transmitted data. Thus we can say that the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed data is significant. The soft threshold further reduces the number of transmissions by eliminating all the transmissions which is not significant as compare to previous transmissions even these values are greater than hard threshold

Chapter 4
PROPOSED APPROACH

Till now we have studied different routing protocols for wireless sensor network such as LEACH[5],DEEC[10],SEP[9] etc. Some are applied in homogenous environment and some are in heterogeneous environment. Now we are describing our approach of improving the various parameters such as throughput, stability period, lifetime etc further. Our approach is minimize transmission time in the network. The basic theory is that clustering is done because the nodes which are clustered have a sensed data which vary in very insignificant amount. So cluster head in a cluster when take the data from their members is similar in nature. Cluster heads have to send similar type of data again and again to base station which is time consuming and wastage of energy by the cluster heads. This concept was explored in detail in TEEN [13] which imposed two thresholds hard and soft threshold which optimized the communication and thus extend the lifetime of the network. In sensor network literature TSEP [8] used the TEEN on SEP which has lower stability period than DEEC. So we have used the optimization Protocol TEEN on enhanced version of DEEC i.e. EDEEC and has developed a routing protocol "Threshold Sensitive Advanced Distributed Energy Efficient Clustering Routing Protocol (TADEEC)". But we according to our scheme we first increased the stability period by introducing a new node "superadvanced" in our network. Introducing a node increased the heterogeneity to level four but thing is that it is not using nodes having energy more than super nodes as in EDEEC.

So nodes are in our scheme are

$Normal\ nodes: E0$ $\qquad$ $Advanced: E0(1+a)$

$Super: E0(1+b)$ $\qquad$ $Superadvanced: E0(1+c)$

$Where\ a = c/2; b = 3c/4; c = 1;$

Here p is probability of choosing the clusterheads in the network so a node becomes eligible for cluster head again after $1/p_0$ rounds. So no of cluster heads should be $n*p_0$ if n is total no of nodes. In our scheme nodes are distributed according to constant m and m0 and nodes are:

$normal = (1 - m) * n;$

$advanced = (1 - m0) * m * n;$

$super = (m0 * m * n)/2;$

$supadvanced = (m0 * m * n)/2;$

So Total energy of the network in a round is

$$E_0 * (1 - m) * n + E_0(1 + a) * (1 - m0) * m * n + E_0(1 + b) * (m0 * m * n)/2 + E_0(1 + c) * (m0 * m * n)/2 = n * E_0(1 + a * m - m * m0 * (a - ((b + c)/2));$$

So entire energy of our system is greater than normal homogenous system energy by (1+a*m-m*m0*(a-((b+c)/2)) factor .As we have described in SEP these increased energy should participate in increasing the epoch time of network i.e. probabilities for different nodes will be calculated in proportion of their energies. We want that in our system the epoch time should be in the increasing order of superadvanced->super->advanced->normal nodes. So that less epoch time, more energy nodes will become cluster heads earlier than less energy nodes(i.e. large epoch time).The weighted probabilities for different kind of nodes are as:

For normal node:

$$p_{nrm} = \frac{p_{opt}}{(1 + a * m - m * m0 * (a - ((b + c)/2))}$$

For advanced node:

$$p_{adv} = \frac{p_{opt} \times (1 + a)}{(1 + a * m - m * m0 * (a - ((b + c)/2))}$$

For super node:

$$p_{sup} = \frac{p_{opt} \times (1 + b)}{(1 + a * m - m * m0 * (a - ((b + c)/2))}$$

For superadvanced node:

$$p_{sadv} = \frac{p_{opt} \times (1 + c)}{(1 + a * m - m * m0 * (a - ((b + c)/2))}$$

As we can see that probabilities are weighed according to factors a ,b and c.

Also, it was shown in the SEP that for better clustering, there should be n* p_{opt} cluster heads in a round for the different heterogeneous nodes in a network.

p_{norm} * (1-m)*n + p_{adv}*(1-m0)*m*n+ p_{sup}*(m0*m*n)/2+ p_{sadv}*(m0*m*n)/2 =n*p_{opt}

It clearly shows the correctness of this proposed protocol as total no of cluster heads in a round is equal to n*p_{opt} which is our desired requirement of routing protocol.

The new probabilities with the concept of DEEC's residual (E_i) and average energy(E_a) are as:

$$p_i = \begin{cases} \dfrac{p_{opt} \times E_i(r)}{(1+a*m-m*m0*(a-((b+c)/2))\times E_a} & \text{if node is normal node} \\ \dfrac{p_{opt} \times E_i(r)\times(1+a)}{(1+a*m-m*m0*(a-((b+c)/2))\times E_a} & \text{if node is advanced node} \\ \dfrac{p_{opt} \times E_i(r)\times(1+b)}{(1+a*m-m*m0*(a-((b+c)/2))\times E_a} & \text{if node is super node} \\ \dfrac{p_{opt} \times E_i(r)\times(1+c)}{(1+a*m-m*m0*(a-((b+c)/2))\times E_a} & \text{if node is superadvanced node} \end{cases}$$

Ultimately our new threshold for deciding the cluster heads election is as:

$$
T(i)= \begin{cases} \frac{p_{norm}}{1-p_{norm}\left(r\times mod\ \left(\frac{1}{p_{norm}}\right)\right)} & if\ i\ is\ normal\ and\ i \in F \\ \frac{p_{adv}}{1-p_{adv}\left(r\times mod\ \left(\frac{1}{p_{adv}}\right)\right)} & if\ i\ is\ advanced\ and\ I \in F' \\ \frac{p_{sup}}{1-p_{sup}\left(r\times mod\ \left(\frac{1}{p_{sup}}\right)\right)} & if\ i\ is\ super\ and\ I \in F'' \\ \frac{p_{sadv}}{1-p_{sadv}\left(r\times mod\ \left(\frac{1}{p_{sadv}}\right)\right)} & if\ i\ is\ superadvanced\ and\ I \in F''' \\ 0 & \text{otherwise} \end{cases} \quad (9)
$$

Now, cluster heads are made according to eq.9. We randomly take a number g in a set [0,1].
If the threshold T(i) for ith node is greater than g and it belongs to set(F or F' or F''or F''')then it become cluster head otherwise it will be a simple node. Here F, F', F'' and F''' are set of normal, advanced, super and superadvanced nodes respectively which has not become cluster heads yet. Cluster heads are elected then cluster heads make a TDMA slots for their cluster members nodes. This schedule is distributed by the cluster heads in its cluster. This TDMA slots are used by the cluster member nodes to know their turns to send their data to the cluster heads. Also cluster heads maintain a unique id using CMDA code to prevent the inter-cluster interference among the adjacent clusters.
Now we are describing the role of TEEN routing protocol in our network. The TEEN is implemented in the sensor nodes. These cluster heads nodes store two threshold hard and soft thresholds. Hard threshold (h) is calculated over highest and lowest value sensed by the nodes. For example in temperature sensing applications the hard threshold is calculated as the average of maximum temperature sensed and minimum temperature sensed. In our scenario we have simulated our network as temperature sensing wireless sensor network and hard Threshold is

taken as 100 (in degree Celsius). Also, we are using the term data for the temperature sensed by the nodes. After Cluster heads are elected in the network, they calculate the value of hard and soft thresholds and send these values to its cluster members. The nodes store these values and each time they sense the data values, they compare this data with the stored thresholds. They send the data to the cluster heads only if data values meet with these conditions:

1. The currently sensed data (CV) should be more than the hard threshold i.e.(CV>h)
2. The difference between currently sensed value (CV) and sensed value SV should be more than soft threshold i.e. diff (CV-SV)>s.

CV is the data sensed by the nodes in current round.SV is the previous sensed value that satisfied the thresholds and sent by the nodes to their cluster heads. This SV is stored in a variable in the memory of the sensor node. This SV is also known as effective sensed value. After satisfying the above mentioned conditions the nodes send their data to their respective cluster heads, then after cluster heads again apply these above conditions and decide whether to send the data to basestation or not. If current sensed data value (CV) is sent by the node then this current sensed value becomes SV or effective sensed value for future transmissions. The TEEN we mentioned the report time or frame time, in which sensor nodes turn on their transmitters to send the data. In LEACH ,DEEC or EDEEC or other proactive protocols, this time is used by the sensor nodes to send the data to their cluster heads. This time is scheduled according to the TDMA schedule broadcasted by their respective cluster heads. This time is fixed and cannot be changed by the nodes themselves. So if there is a time critical or real time application, the data sending can cross the deadlines as data values will only be sent in their respective report or frame times. TEEN has eliminated this report time and sending time will depend upon the criticality of the sensed data i.e. significance of data value. Thus nodes using TEEN will send the data whenever they see any drastic change in the sensed value which has a great significance for receiver. This significance of the data value can be checked by imposing the hard and soft thresholds. As if the same type of the data is being sent by the cluster members, then it would only be wastage of energy for receiver to receive them each time. Thus TEEN assures that nodes will only turn on their transmitter whenever sensed data is different in some way to the previous transmissions. This is done by TEEN using above mentioned two thresholds i.e. hard and soft thresholds and can only transmit the sensed data value if they satisfy above threshold conditions.

We can summarise our approach with these points as below:

- We have used a reactive routing protocol i.e. TEEN which acts as an optimization protocol for making our routing in network effective and energy-saving. This has made transmission better in the nodes and prolongs the lifetime of nodes by preventing unnecessary transmissions.
- Before applying the above routing protocol, we have increased the stability period of our network by introducing a new node i.e. superadvanced node in addition to normal, advanced node and super nodes in our network.
- This introduction of superadvanced node has inserted another sub-epoch time for increasing the sub-epoch time of super nodes and ultimately epoch times for normal and advanced nodes.
- In our research, we have not increased the energies of superadvanced nodes beyond the energies of super nodes of EDEEC routing protocol. Thus initial energy of nodes in our scenario are:

normal:	normal [as of EDEEC]
advanced:	advanced [as of EDEEC]
super:	energy between advanced and super nodes of EDEEC
superadvanced:	super[as of EDEEC]

  Thus we have not taken superadvanced nodes having more energy than super so same nodes as in the EDEEC can be used in our scenario.
- In our scenario we have taken an environment of forest where sensor nodes are deployed to sense the temperature from vicinity. In this environment, nodes check the significance of the data after sensing the temperature data by applying the hard and soft thresholds. The nodes only turn on their transmitter if the current sensed value satisfy the criteria of thresholds conditions otherwise it drop the data and transmitter remain in sleep mode. Then nodes would send the data to their respective cluster heads and cluster heads again decide whether they have to send the data to the Basestation or not according to hard and soft thresholds.
- In our scheme there is no concept of report time or frame time in the nodes. Nodes can transmit the data on the basis of their own judgment.

Steps of Sensing and transmitting the data in sensor node:

Sensing Time

Sensing Element is active mode	Transmitter is in sleep mode

If sensed data value meet the threshold conditions

Sensing Element is sleep mode	Transmitter is switched on and ready to send data

Else

Sensing Element is sleep mode	Transmitter is remain in sleep mode

4.1 Flow Chart

The sequences of events happening in the network are depicted in flowchart. This flowchart is shown in figure 4.1.It is showing the starting of the network and then cluster heads are elected using eq.9.After communication is done in the clusters, the hard and soft thresholds conditions are checked and then data is transferred according to satisfying the conditions.

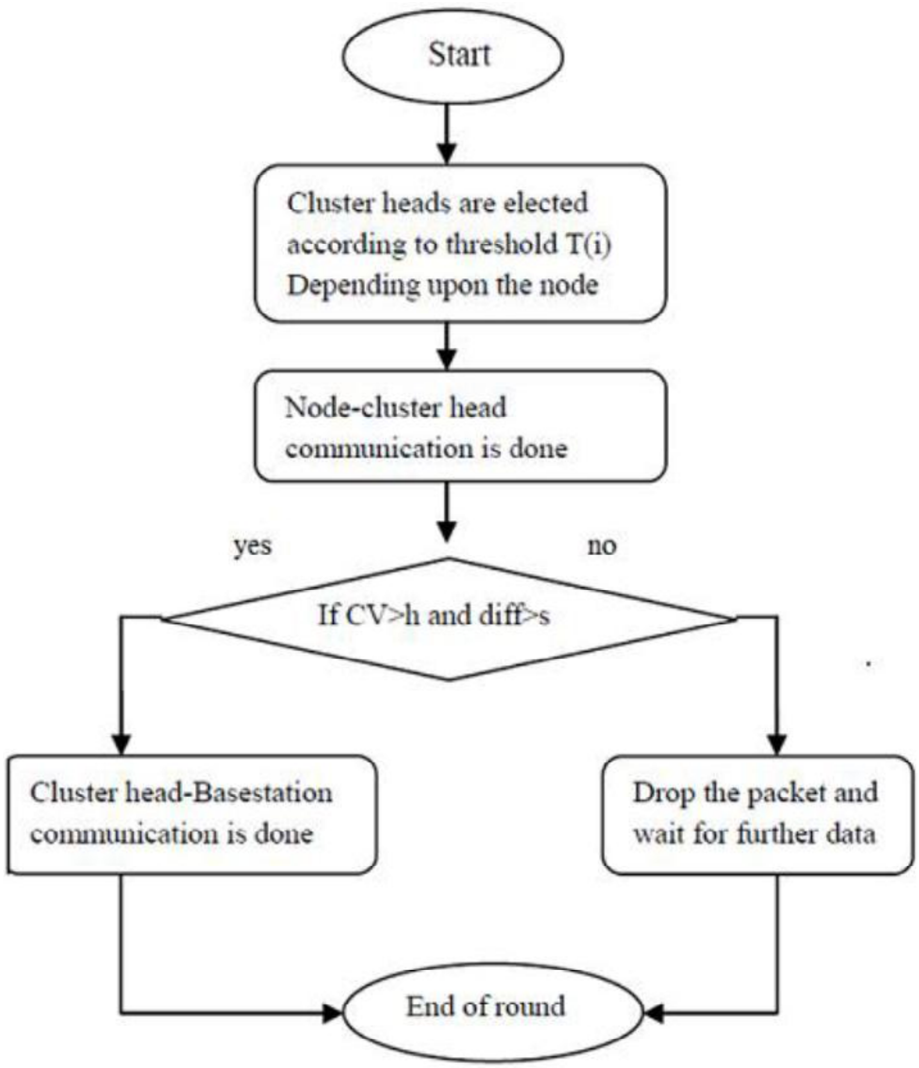

Figure 4.1.Flow chart showing the process of communication in the network.

4.2 Radio Models Used in Wireless Communication

In this network we have two types of radio models are used. These communication models are used to calculate the energy required under different environments in wireless systems. Due to positive and negative interferences, the energy of the signal get increased or decreased. Thus these radio models help us to supply as much of energy to the signal so that proper energy of the signal is maintained and signal is transmitted successfully to the receiver. In this project two types of models are used for communication in the network. These are explained below:

4.2.1 Free space model

This model is used in those wireless environment having very low or null negative interferences caused by the objects in the line of sight path. Also it takes that energy of signal decreases ($1/x^2$) in the path. So transmission energy is taken as

$$E_{trans} = B * E_{elec} + B * E_{fs} * d^2 \qquad if\ d \leq d_0$$

- d_0 is called reference distance. Reference distance is that distance up to which the interference caused by the obstacles is positive and does not degrade the signal energy in larger way.
- B is the message size transmitted.
- E_{elec} is an energy required to generate the signal in the sensor node. Usually when node is not in sensing mode then it comes into sleep mode.
- E_{fs} is free space amplification energy required to maintain a signal to noise ratio in the free space wireless environment.
- d is distance between the transmitting and the receiving node in the network.

Energy required to receive he signal as it required switching on the transmitter from sleep state is given as.

$E_{rcv} = B * E_{elec}$

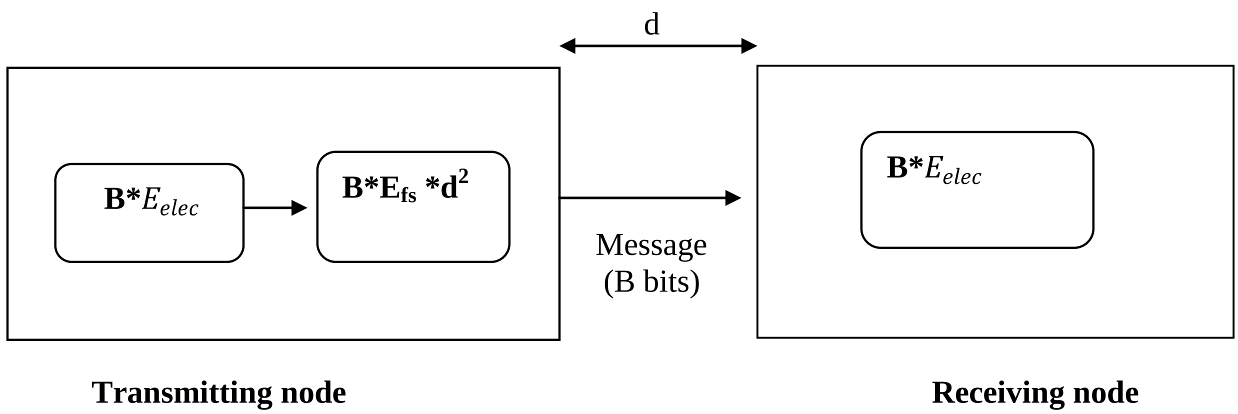

Figure 4.2.Shows the Transmitting and receiving nodes in the network in free space model.

4.2.2 Two ray Path Model (or Multi path Model)

In this model we take that distance is larger than do or obstacles create degrading of signal. In this model the energy loss is proportional to d^4 .So more amplification energy is maintained for properly transmitting the signal from one node to another.

Energy required to transmit the signal is:

$E_{trans} = B * E_{elec} + B * E_{mp} * d^4 \quad if\ d > d_0$

- Here the d is larger than d_0 where d_0 is reference distance.
- E_{elec} is energy required to generate the signal
- E_{mp} is multi path amplification energy to maintain proper Signal to noise ratio.
- B is message(packets) size

Receiving energy for B bits message is:

$E_{rcv} = B * E_{elec}$

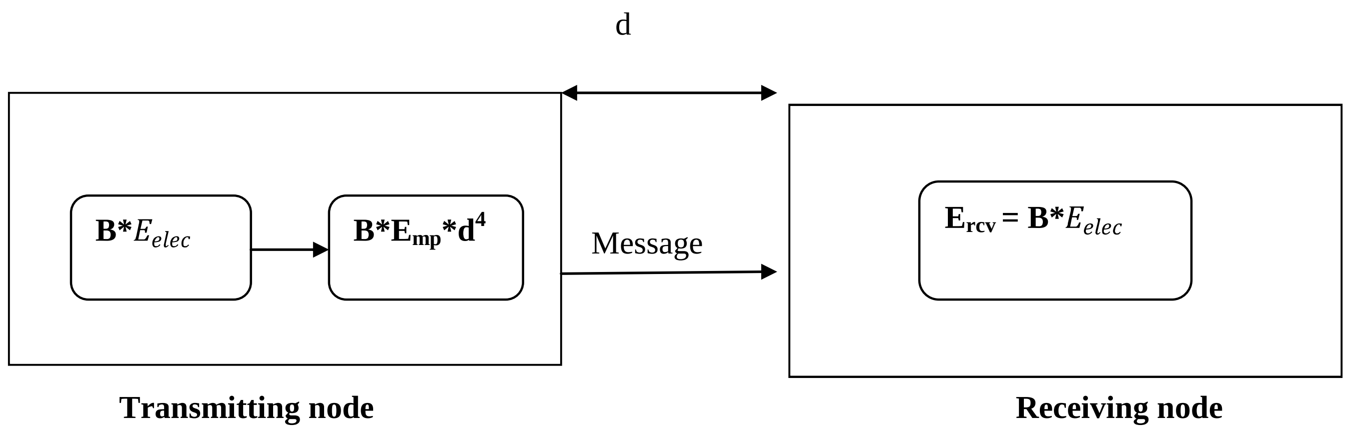

Figure 4.3.Shows the Transmitting and receiving nodes in the network in two ray path model.

Chapter 5

SIMULATION AND RESULTS

This research is simulated in matlab software. Different graphs have been plotted to compare the performances of our proposed protocol with others routing protocol in the literature for different parameters. We have compared the performances of four protocols LEACH,DEEC,EDEEC and our approach i.e. Threshold sensitive advanced distributed energy efficient clustering(TADEEC) routing protocol. The positions are calculated on the basis of manual deployment of the nodes so all nodes mutually know positions of each other in the network. The network is taken as an area of 100*100 square meters. The 100 nodes are deployed on the network. The various parameters of the network are listed in table 5.1.

Some of the important points regarding our Research are:

- Energy of the advanced nodes and super nodes are taken as a and c times of normal energy as in EDEEC but we in our research have not introduced new node i.e.superadvanced with more energy than super node of the EDEEC.

  We have taken energy of nodes as

  normal : normal[as of EDEEC]

  advanced : advanced[as of EDEEC]

  super : energy between advanced and super nodes of EDEEC

  superadvanced : super[as of EDEEC]

- We have worked on two performance parameters:

  Allive nodes (or Dead nodes (reverse of alive nodes)) and throughput (packets send to the Base station by cluster heads per round)

- Cluster heads are not sending data on periodical basis (reporting time[1]) but on the basis of hard and soft threshold applied.

In our simulation we have worked on three parameters to make better than previous schemes. These are:

- Stability period: the round in which first node get dead. It is very high in TADEEC

- Lifetime: it is duration during network works in successful way and it is max. no of rounds up to at least one node is alive.
- Throughput: this is no of packets send per round from cluster heads to basestation.

Table 5.1.List of simulation parameters

Parameters	**Value**
Area	100*100 square meters
Basestation	(50,50)(in m)
Initial Energy	0.5J
Transmission Energy	50nJ/bit
Receiver Energy	50nJ/bit
No Of Nodes	100
Free space Amp Energy	10pJ/bit/m^2
Multipath Amplification Energy	0.0013pJ/bit/m^4
Message Size(B)	4000 bits
Round	10000
5Aggregation Energy	5nJ/bit/packet
Hard Threshold	100 degree Celsius
Soft threshold	2 degree Celsius
p_{opt}	0.1
M	0.5
m0	0.2

Figures 5.1 and 5.2 shows the allive nodes and dead nodes existence respectively in network with increasing rounds in different protocols such as LEACH,DEEC,EDEEC and TADEEC and figure 5.3 shows the packets send from cluster heads to the basestation. TADEEC is performing better than previous protocols in all these graphs.

It has maintained longevity of the nodes in the network to large no of rounds (even greater than maximum number of rounds we have in our simulations). Table 5.2 has listed the stability period (as stated previously it is the round in which first node dies) for LEACH, DEEC, EDEEC and TADEEC which is clearly stating the stability period is very high for TADEEC. For TADEEC, it takes even more than double time of DEEC for first node to be dead. Also our third parameter i.e. lifetime is also increased by the implementation of TADEEC in the nodes. Table 5.3 is showing drastic improvement in lifetime of the network in various simulations of TADEEC which is greater than the LEACH, DEEC and EDEEC. EDEEC definitely worked on to increase lifetime of the network and is better than DEEC but it has been observed in few simulations that stability period for DEEC is more than EDEEC. But TADEEC has outperformed DEEC and EDEEC in all parameters such as stability period, lifetime and throughput. Figure 5.3 shows the data transmitted to basestation from cluster heads. The throughput of network for different protocols is stated in table 5.4. TADEEC has highest data throughput with 27 packets are sent per round in network.

So from the figures and tables we can see that our proposed approach has made routing in the wireless sensor network easier, effective and efficient. This routing protocol has maintained the alive nodes to larger time and has increased the lifetime of the network to a large extent. Thus sensor network can work to larger days without human monitoring for replacing the faulty nodes and has an efficient transmission of data to the main station or monitoring station.

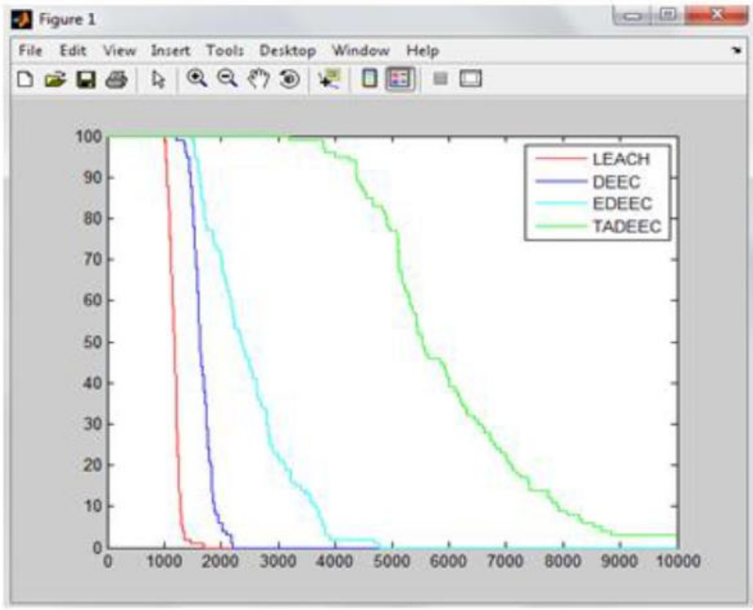

Figure 5.1.Shows the no of allive nodes vs. rounds in the network.

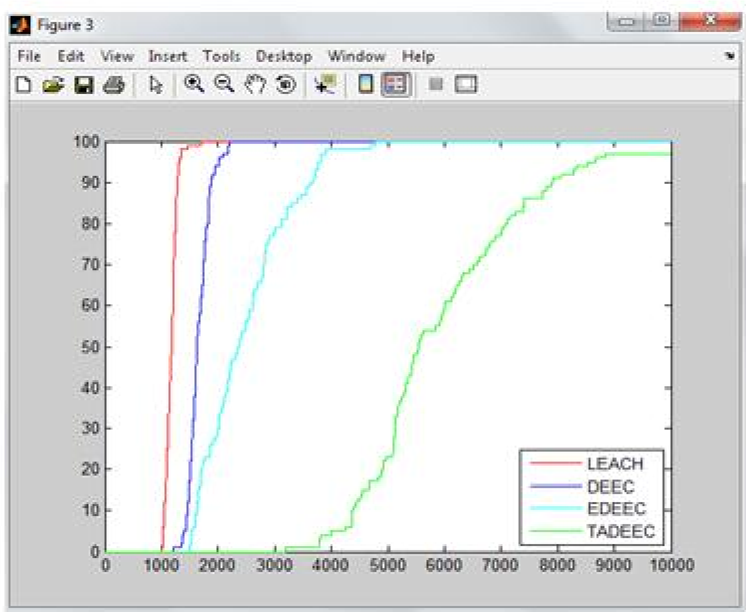

Figure 5.2.Shows the no of dead nodes vs. rounds.

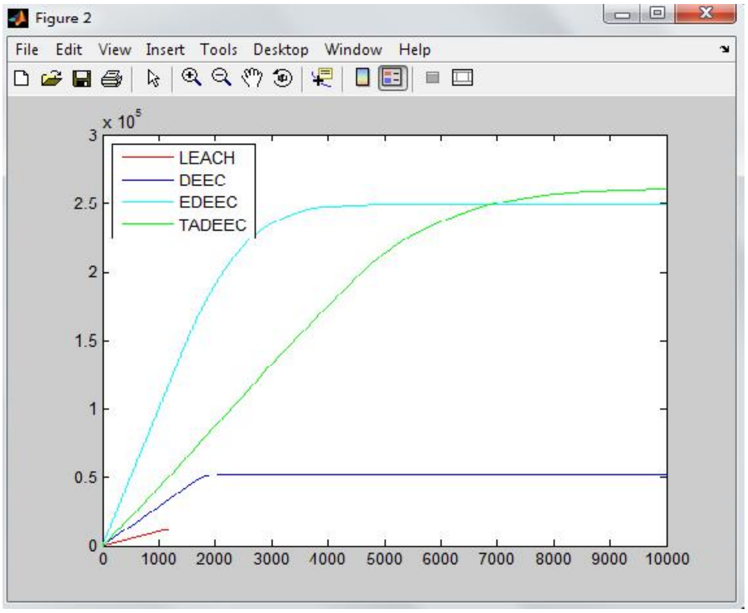

Fig 5.3.Shows the Packets from cluster heads to Base station

Table 5.2.Showing the round number in which first node get dead (stability period)

Protocol	**LEACH**	**DEEC**	**EDEEC**	**TADEEC**
Simulation 1	987	1266	1276	3300
Simulation 2	983	1272	1457	3586
Simulation 3	937	1244	1304	3538
Simulation4	990	1296	1448	3600

Table 5.3.Showing the round number in which last node get dead (lifetime of network)

Protocol	**LEACH**	**DEEC**	**EDEEC**	**TADEEC**
Simulation 1	1400	2290	4574	>10000
Simulation 2	1884	2206	4838	9560
Simulation 3	2096	2114	4761	>10000
Simulation4	2266	2626	4595	9954

Table 5.4.Showing the network throughput for various protocols

Protocol	**Throughput(packets/round)**
LEACH	2
DEEC	5
EDEEC	25
TADEEC	27

CONCLUSION

EDEEC properly used the heterogeneity of nodes for improving the lifetime of the network. We in this research followed same approach of increasing the heterogeneity of nodes but with the application of an optimization routing protocol. The way of introducing the new node has increased the stability period by decreasing their period of becoming the cluster heads. Also we can see that the optimization algorithm TEEN improved the communication among the heterogeneous nodes using the selective and effective transmission among the nodes and base stations and thus extends the lifetime of the nodes to maximize the communication. Thus this research is successful in achieving high stability period, lifetime and throughput of the network. This research provided a better transmission approach in the network while taking care of limited-energy sensor nodes. The research simulation outperformed the LEACH, DEEC and EDEEC and gave a better mechanism for routing in the wireless sensor network.

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